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Simulation of The Heat Transfer Process Inside The Thatch Walls with The Aim of Saving Energy in The Buildings

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ABSTRACT

The insulation is one of the emphasized methods in recent years to reduce energy consumption in buildings. As an insulator, thatch has the advantages such as the accessibility of the site, the least energy consumption in its construction (low cost), recyclability and compatible with the nature and the environment. The aim of this study is determining of the heat transfer coefficient and thatch mechanical properties So that due to its advantages it used as insulation and thereby reducing energy consumption in buildings considered and used. In this study, the heat transfer process in a cylindrical turn of thatch was studied. In the conducted experiments the temperature changes inside a cylinder turn were determined for different values of the ratio of the Straw to the used soil and then the obtained results were simulated using the version 2.4 of the COMSOL software. The compressive strength and mechanical properties of thatch were tested. By increasing the consumed Straw weight of 50 to 90 kg per 1 cubic meter of soil, the heat conductivity coefficient from about 1.1 decreased to about 0.3 (W/m K), the contraction percentage decreased and the porous, the compressive strength and the thatch deformability increased in the failure. Thermal insulation and the mechanical properties of the thatch were improved by the mixing of appropriate ratio of straw to soil in the construction of thatch. It can be used in the plaster of the walls and the internal and external ceilings of the building.

Keywords: Comsol Software, Heat Transfer, Thatch, Simulation.

INTRODUCTION

The energy consumption in buildings is about 40% of the total world's energy consumption and about 50% of carbon dioxide in the air caused by the governance structure. Therefore, the building industry is the main consumer of energy. Energy is used for production, transportation of construction materials, construction of the buildings and for the heat and cold of the building. Each year, several billion dollars are spent in Iran for energy consumption in buildings and about % 35 of this energy could save by optimal consumption [1]. The fuel consumption per person is 5 times greater than the global average and 13 times greater than the fuel capita of China in Iran [2]. The thermal insulation is done in order to reduce the heat transfer and energy dissipation in the building [3]. By insulation the building and therefore decreasing the fuel consumption (decreasing the energy consumption) could prevent the spreading of the greenhouse gas, directly [4, 5]. Mud bricks and Thatch is a good insulating for the roof and the walls of buildings in the dry and desert areas and If it is to be implemented accurate, then it has the advantages such as decreasing the energy consumption, environmental compatibility, environmental protection, decreasing the cost of insulation, available on the premises, recyclability, ability of the preparation by the variety of soils, sound insulation, fire-resistant. Also, the energy consumption in the manufacturing of thatch is low because of the simple manufacturing process and using the native technology [6, 7, 8, 9]. In the Al rim's research and et al. with the title of the impact of the wood percentage in the mechanical and thermal properties of the soil, cement and wood composite, it is mentioned that by increasing the percentage of wood particles, the percentage of porous increases and the density and heat conductivity of the composite decreases [10]. Mud mortar will crack after drying but the Straw prevents the cracking that caused by drying of thatch and also decreases the contraction rate of the thatch caused by the drying effect. Straw has a tensile strength and the speed of the water evaporation is low, the Straw as a stabilizer is a factor of adhesion between mud layers [11, 12]. Thatch is used for insulation of livestock and poultry places also it is used in the hot and dry areas of Iran to insulate the roof of residential areas now. Now, the industrial companies are trying to improve the properties of thatch until increase the applications of this production. The conducted researches were related to the soil composite with the synthetic fibers such as polystyrene and the natural fibers such as the Straw, husk, the sugar beet pulp, on the adobe and brick, and to calculate the thermal conductivity coefficient of the composite has been applied the analysis approach of the repetition method in the thermal probe measurement values in other researches [13]. But no research has been done on the thatch. In this paper, the impact of the ratio of the Straw to the soil for providing the thatch on the thermal conductivity coefficient, the compressive strength and the weight and volume of thatch have been investigated. Then the experimental results have been simulated using the COMSOL software to calculate the thermal conductivity coefficient.

MATERIALS AND METHODS

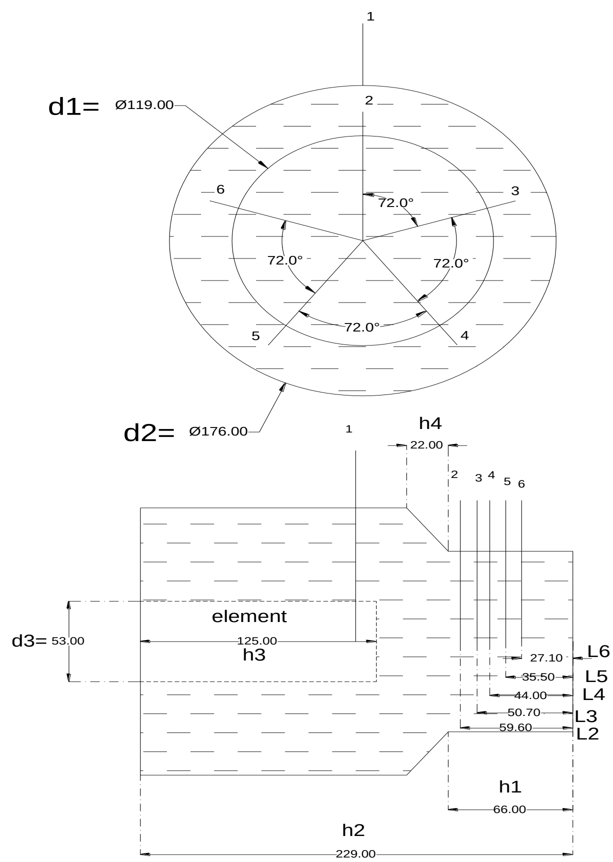
Experimental

To study on the thermal properties of the thatch and the impact of the ratio of the Straw to the soil on the heat transfer rate of thatch, three thatch turn cylindrical with different ratios of the Straw to the soil, 50Kg of the Straw per one cubic meter of soil, thatch of type ❶, 70Kg of the Straw per one cubic meter of the soil, thatch of type ❷ and 90Kg of the Straw per cubic meter of soil, thatch of type ❸ like Fig. 1 were built that their different sizes have been presented in the table 1.

The heat transfer experiment was done for each thatch turn cylindrical separately, and its results were recorded. Used soil for producing thatch was prepared from the clay of Damghan mine. This soil has been used at the core of Damghan earth dams (Shahid Shah Cheraghi dam). The characteristics of grain, soil plasticity and its classification have been given in the table (2) that the classification of this soil is in the clay group with the low plasticity property (ASTM D2487) according to the Unified Soil Classification System instructions, [14]. It was used from soft wheat Straw, that its characteristics are sheeted with the length of 5 to 20mm and a width of about 1mm.

An electric sensor and a temperature controller were applied for fixing the temperature to about 500$^{\circ C}$ in this section of thatch turn. The other end of the cylinder has been contacted on a polystyrene container containing a mixture of water and ice with a thin film of aluminum between container and cylinder, therefore temperature was fixed in 0$^{\circ\,C}$ in the end of cylinder.

Fig. 1. (a) front view, the thermometers were located with a relative angle of 72 ° than each other (b) the side view of the thatch cylindrical turn that the distance of thermometers at the end of the cylinder has been determined.



By measuring the amount of melted ice at the specified time interval, the heat transfer rate from the environment and the end of the cylinder was measured. Another polystyrene container was used with identical characteristics and similar ice-water mix that with measuring of the melted ice amount has been determining the heat transfer rate of the environment at the same time interval specified.

The amount of heat transfer of the end of the cylindrical was determined by subtracting the amount of the melted ice in one container of another. As Fig. 1 shows, at the various distances of the initial of the cylinder, the electric thermometers placed that they displayed the temperature of various points of it. The heating element was switched on for 24 hours until the moisture of thatch was evaporated and the electrical thermometers displayed a constant temperature in the fixed condition [15].

Table1. The characteristics of the thatch cylindrical turn in millimeter for a variety of samples.

Type of thatch	d1	d2	d3	h1	h2	h3	h4	L6	L5	L4	L3	L2
❶	109.3	172.2	61.8	67	239	118	10	29.8	38.6	50.3	58.4	67
❷	106.7	170	63	84.8	265	140	36.2	25.6	38.8	53.3	66.7	79.6
❸	119	176	53	66	229	125	22	27.1	35.5	44.0	50.7	59.6

Table 2. The characteristics of the used soil in thatch.

Unified Soil Classification System	Gs	Passing#200	sand	SL	LL	PL	PI
CL	2.65	86%	12%	15	38	18	20

According to the similar researches to calculate the weight and volume relations and also the compressive strength of thatch, 10 cube samples with the sizes of 15 centimeters (similar to the concrete cubes to calculate the compressive strength of concrete) were provided from each types of thatch until for each experiment would been tested five samples of thatch [16]. The soil was sieved by the sieve of 10mm, and then after mixing the soil and straw, the water was added to the mixture until the thatch became formable enough. Thatch was stirred manually until thatch uniformity achieved. After 24 hours, the thatch was stirred manually again and molded. The cubic samples were used to calculate the volumetric- weight relations, the contraction amount and the compressive strength of the thatch. Sampling was done for calculating the moisture percentage after the experiment of the compressive strength. For the available straw amount in the samples, cylindrical sample with the diameter of 1cm of the cube sample of any type of the thatch was provided then the samples were placed in an oven at 105° C for 24 hours to dry so perfectly. The samples were dried and weighed and were kept at 550° C for six hours. The mass of straw was measured with the reweighed of the samples. For calculating the volumetric-weight relations of the straw, it was acting similar to the used method for calculating of the specific gravity of soil. In addition the weight and volume of thatch were calculated based on the weight and volume relations of the soil [17]. For calculating the compressive strength of the 28-day thatch was applied to the compressive strength device of soil mechanics laboratory of technical and professional center of Damghan. The amount of pressure was 200kPa per second of the experiment time. For calculating the compressive strength of the 56-day thatch was applied to the compressive strength device of the building material laboratory of the Shahrood Technology University. The coming down speed of the device grips was regulated 7mm per minute according to the Bouhicha and et al. research on the reinforced composite with barley straw in the compressive strength experiment [11].

Modeling

For calculating the thermal conductivity coefficient of thatch, the conducted test in the experimental section of this paper has been simulated using the Comsol software (version 2.4). In this simulation, after the geometric drawing of each one of the three expressed thatch cylindrical turns, the process of heat transfer of the system was modeled. In the modeling of the heat transfer process, it was assumed that the heat transfer has been done in three dimensions and in cylindrical coordinates and the heat has been conducted from the cylindrical turn internal cavity (the place of heating element) to its vertex (the place of cold water bath) by the conduction mechanism, and also the cylindrical turn has been exchanged the heat by the convective mechanism with the air of 20C°. In this paper, the results have been provided for a steady state (stationary), because as it was mentioned in the previous section, for reading the experimental data, sufficient time has been given to the system to fixation of temperatures by the thermometer. Considering the above assumptions and for different amounts of thermal conductivity coefficient (K), the temperature distribution inside the cylindrical turns has been calculated and with comparing between the experimental data and calculation results, the best value for K has been considered.

RESULTS

The heat transfer process

Temperature distribution inside thatch cylindrical turns that 50 kilograms of the Straw were mixed with one cubic meter of clay soil, thatch of the type ❶, has been shown in Fig. 2. Fig. 2a shows the temperature distribution in the form of three-dimensional and the Fig. 2b shows the isothermal surfaces in the form of two-dimensional. As can be seen in these figures, the maximum temperature of the system assigned to the cavity location of the heating element. By away from the cavity, the system temperature decreased and the lowest temperature was attributed to the vertex of the cylindrical turn that it directly was in contact with the cold water bath. Fig. 2b shows that the highest of the temperature change was along the axis of the cylinder that in this direction, the heat flew from the hot source to the cold water bath by thermal conductivity mechanism. But in the radial direction, the heat was be transferring to the air by convective mechanism and thus the created temperature difference in this direction was less than the axial direction. By changing the ratio of the Straw to the consumed soil, the thermal conductivity coefficient changed and thus the temperature distribution inside the cylindrical turn also changed. Also due to human error, the sizes of the shapes and the location of the thermometers were different and therefore the temperature distribution was different in the cases where it has been changed the ratio of Straw to the consumed clay.

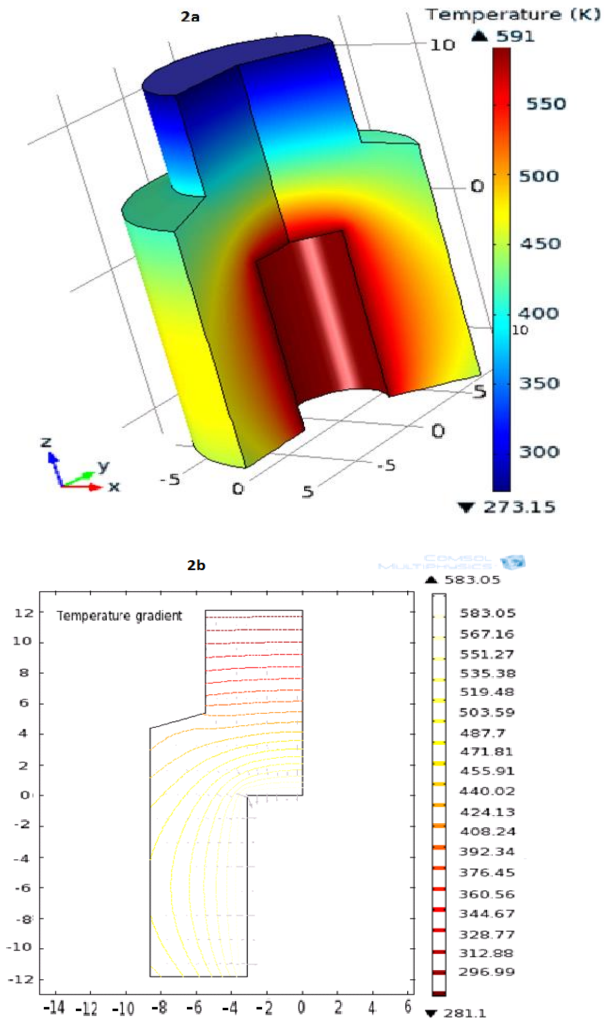


Fig. 2. (a) the three-dimensional temperature distribution within thatch element with the Straw amount of 50 kg per cubic meter of clay, thatch type ➊, and (b) the isothermal surfaces in the case of two-dimensional for the Straw amount of 50 kg per cubic meter of clay, thatch type ➊.

The Fig. 3 (a and b) shows the temperature distribution in the three dimensions state and within thatch cylindrical turns with the quantities of 70 and 90kg of Straw per 1 cubic meter of the soil (the thatch of type ➋ and the thatch of type ➌). It can be seen in this Fig.. When the ratio of Straw to the consumed soil increased, temperature distribution was as previous state except that the heat emission intensity by increasing the ratio of Straw to soil decreased. In the next section, it will be shown that this decreasing in heat emissions intensity was due to a significant decrease in thermal conductivity coefficient.

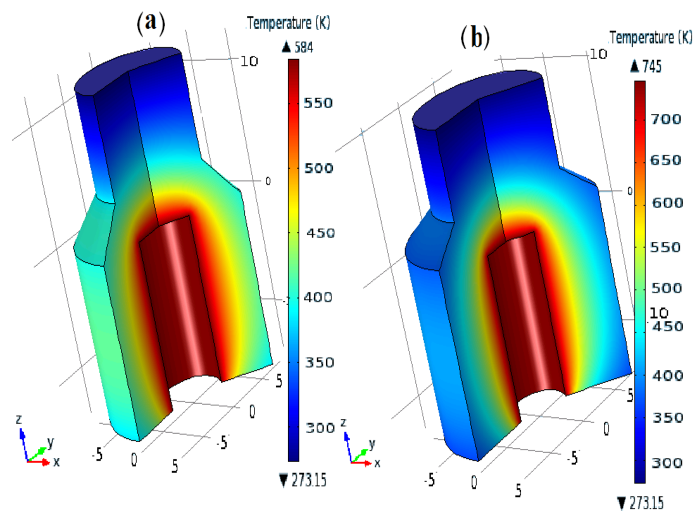


Fig. 3. (a) and (b). The three-dimensional temperature distribution inside thatch elements with the values of 70 kilograms of straw per one cubic meter of clay, the thatch type ❷ and with the values of 90 kilograms of straw per one cubic meter of clay, thatch type ❸.

Fig. 4 shows the temperature distribution inside the thatch cylindrical turn with the ratio of 50kg Straw per cubic meter of clay,(the thatch of the type ❶). This Fig. shows the temperature distribution for different values of thermal conductivity coefficient (K) from 0.3 to 1.3. Also the measured experimental values in the experiments of thatch cylindrical turn have been shown in this Fig.. The comparison of experimental data with calculation results showed that the thermal conductivity coefficient of thatch in the ratio of 50 kilograms per cubic meter of clay, (thatch type ❶) was approximately equal to 1.1 W/mk.

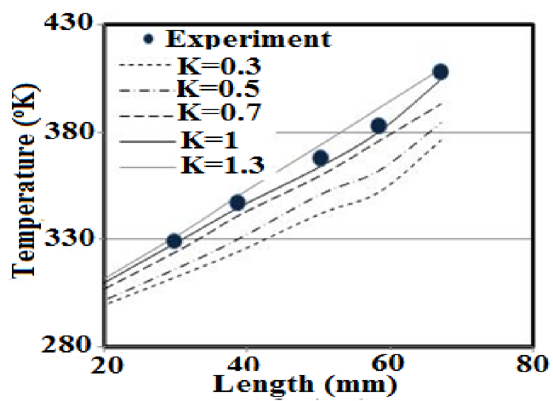


Fig. 4: Temperature distribution inside the cylindrical turn clay with Straw the ratio of 50 kg per cubic meter of clay, (thatch type ❶, for different values of thermal conductivity coefficient). Line and line drawing folds represents calculation results (K=0.3 to 1.3) and solid points represent experimental data.

Fig. 5a and 5b.show the calculated temperature distribution for the ratios of 70 and 90kg Straw per one cubic meter of clay, (the thatch of type ❷ and thatch of type of ❸) in different values of thermal conductivity coefficient with the experimental results of the temperature distribution. Comparing the experimental data and calculation results for these Fig.s, the thermal conductivity coefficient can consider 0.5 W/mK and 0.3 W/mK.

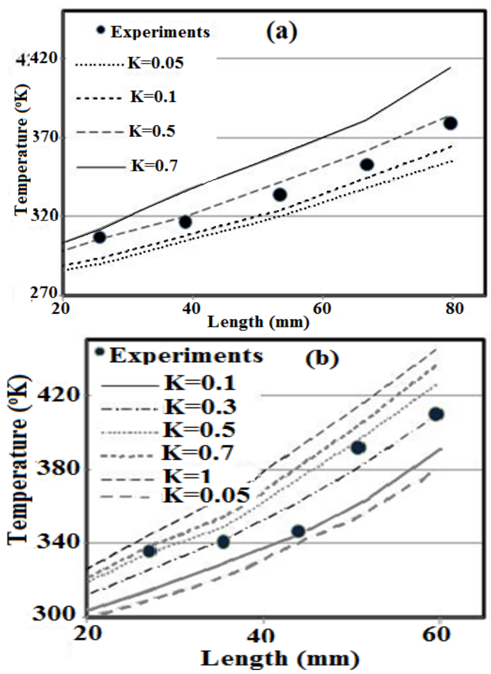


Fig. 5. (a) and (b). the temperature distribution in thatch cylindrical turn at different values of the thermal conductivity coefficient with the experimental results with 70 kg of Straw per 1 cubic meter of clay, (thatch of type ❷) and with 90 kg of Straw per 1 cubic meters of clay, (thatch of type ❸).

Fig. 6 shows the changes of thermal conductivity coefficient of thatch by changing the amount of consumed Straw. Based on the presented results in this Fig., by increasing the weight of consumed Straw of 50 to 90kg (per one cubic meter of clay) the thermal conductivity coefficient decreases from 1.1 to about 0.30.

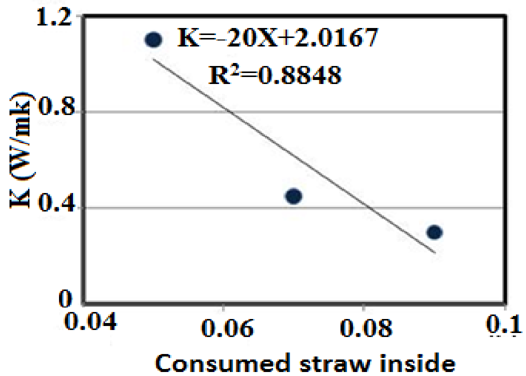


Fig.6. Thermal conductivity coefficient changes of thatch according its Straw.

Mechanical properties thatch

The results of weight and volume and compressive strength relations of thatch have come in the Tables (3, 4) and Fig. 7 strain is dimensionless.

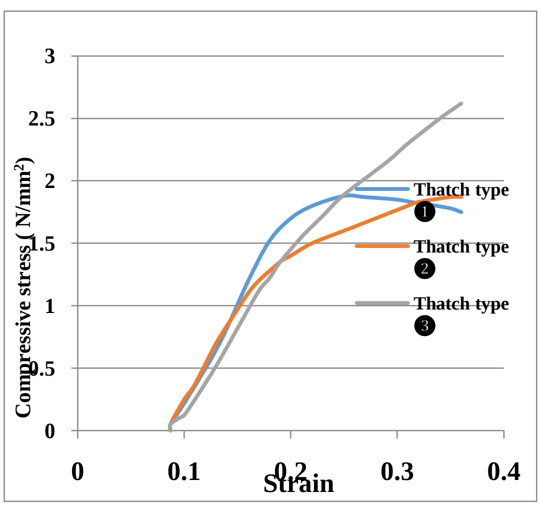


Fig7. the stress-strain graphs of thatch 56 days, the sample❶ 50 kg Straw per one cubic meter soil, the sample ❷ 70 kg Straw per 1 cubic meter of soil and the sample ❸ 90 kg Straw per 1 cubic meter of soil.

Table 3. the compressive strength and density relations results of the 28-day thatch.

Type of thatch	❶	❷	❸
Maximum compressive strength (N/mm^2)	2.4	1.98	3.1
Moisture percentage	2.24	1.59	1.80
Density (Kg/m^3)	1327	1206	1160
Dry density Kg/m^3	1297	1187	1139

Table 4. The compressive strength and volumetric and weighting relations results of the 56-day thatch.

Type thatch	❶	❷	❸
Volumetric shrinkage percentage	14.5	11.6	9
Moisture percentage	1.69	1.45	1.49
Density (Kg/m^3)	1308	1205	1146
Dry density (Kg/m^3)	1286	1118	1130
Volume air percentage	32.2	33.8	30.7
Volume Straw percentage	23.3	25.9	32.3
Volume soil percentage	44.5	40.3	37

DISCUSSION

According to the studies, thatch thermal conductivity coefficient changes depending on the amount of the consumed Straw inside thatch. Comparison of values of the thermal conductivity coefficient in Fig.s 4 and 5 showed that with increase in the consumed Straw from 50 to 90kg Straw per one cubic meter of soil, the thermal conductivity coefficient from 1.2 W/mK decreased to 0.3W/mK.

In Fig. 6 the linear relationship between the amount of available Straw for one cubic meter of soil and thermal conductivity coefficient has been given. This implies that the heat coefficient decreases with increasing the percentage of Straw. This conclusion match with Al rim's research that was done in 1999, about the composite cement, soil and wood particles that in this study has been shown with increasing the wood particles percentage, the thermal conductivity coefficient of the composite decreased [10]. In this research also found that with increasing the porous level, the thermal conductivity coefficient decreases that it match with Lertwattanaruk and Choksiriwanna's research in 2011 that is about how changes of the thermal conductivity coefficient by increasing the porous in the soil composite and Bagasse and soil composite and rice husk [18]. Thatch 28-day compressive strength was measured by a device that the loading speed was 200 Pa per second and just during the experiment the maximum of tolerable force by the thatch sample was measurable that by measuring the level of the sample the maximum of the compressive strength of thatch was measured. With increasing the amount of the Straw in the sample, the maximum of the sample strength of the sample in the larger strains occurred and solidarity of the sample components was significant in failure. Therefore the 56-day compressive strength was measured by devices with more capabilities that its stress – strain graph is given in the results. The graphs have been resulted from a minimum of three and maximum of five experiments on the compressive strength on each type of thatch. With increasing the Straw in the samples, Thatch will be more flexible and it will absorb more elastic energy until its failure, therefore thatch of type ❸ has more resistant than the other two types for earthquake. Binici and *et al.* and Sharma and *et al.* were achieved similar results in conducted research relating on the increasing the amount of straw in thatch composite in 2004 [16, 19]. According to data from the table 4 with an increasing in the Straw amount in the samples decreases the sample volumetric shrinkage and with increasing the moisture level of samples increases the shrinkage amount. In the conducted research by Yetgin and *et al.* in 2006, about the impact of the fiber on the mechanical properties of the brick, concluded that increasing the amount of fiber decreases the amount of the shrinkage and increase the moisture causes increasing in the amount of shrinkage [20]. According to the data in Tables 3 and 4, it can be concluded that with increasing of the straw in thatch decreases the density. With increasing the amount of straw in the making of thatch the required water for increasing formability and performance of thatch increases and the straw as a channel of air transmission can be effective in the drying up of the available water. Therefore, comparing the moisture percentage of samples in the Tables 3 and 4, after 28 days, the amount of moisture has been decreased and the speed of reducing of moisture percentage in the sample ❸ is more than sample ❷. But decreasing rate of moisture percentage in the sample ❶ is more than two the other samples, this decreasing rate can be explained by the amount of moisture percentage than the other two samples. With the increasing of the amount of available straw in a variety of thatch, the straw volume percentage increases according the table 4, the amount of available soil in a variety of thatch has decreased. The percentage of the available air in the thatch of the type ❶ and ❷ with increasing the straw amount has increased but it has decreased in thatch of type ❸. In the case; the porosity would be defined as the empty volume between the grains of the soil, that this volume has been occupied by air or straw, it can say that the porosity increases with increasing the straw in the sample. Al rim and et al. also concluded this result [10].

CONCLUSION

Increasing the consumed straw per one cubic meter of clay in thatch can't only decrease the thermal conductivity coefficient, density and volumetric shrinkage of thatch but also it can increase flexibility, compressive strength, coherent and the porosity of thatch. Therefore, thatch can use as thermal insulation in building.

ETHICAL ISSUES

The study was approved by the ethics committee of Semnan University of Medical Sciences.

CONFLICT OF INTEREST

Authors of the manuscript did not have conflict of interest.

AUTHORS' CONTIBUTION

The overall implementations of this study were the results of efforts by corresponding author. All authors have made contribution into the review and finalization of this manuscript. All authors read and approved the final manuscript.

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