Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 78 (2015) 1335 – 1340

Energy Procedia

6th International Building Physics Conference, IBPC 2015

Study on conservation of decorated chamber walls in Kamao tumulus

Madoka Keshi[a]*, Daisuke Ogura[a], Shuichi Hokoi[a]

[a)] *Graduate School of Engineering, Kyoto University, Kyotodaigaku-Katsura, Nishikyo-ku, Kyoto, 615-8530 Japan*

Abstract

The Kamao tumulus which is one of the decorated tumuli in Kumamoto city, Japan does not ordinarily open to the public because of a fear of the deterioration of decorated chamber walls. It seems to be thought that the cause of the deterioration is the dew condensation in the tumulus that is fallen, or flowed down on the decorated wall. The purpose of our study is to propose appropriate measures to prevent dew condensation in performing preservation and an exhibition. In this paper, we investigate the followings: (1) The primary factors of dew condensation (by analizing moist air movement in the stone chamber) (2) The validity of the analysis model of temperature and humidity behavior in the tumulus taken into consideration of the temperature and moisture distribution of the mound and the inside of the tumulus. (3) Whether or not the measure which we shield the entrance door so as not to be exposed to solar radiation is effective to prevent dew condensation. The main results are as follows: (1) The evaporation at the soil surface in the tumulus near the door of the entrance is the main factor of the dew condensation. (2) The calculated results using the analysis model we developed agree with the behavior of measured temperature, humidity and condensation. (3) The counter measure which we shield the entrance door is effective to prevent the dew condensation

Keywords: cultural assets; dew condensation; deterioration; tumulus; decorated chamber walls

1. Introduction

There are about 700 extant tumuli which have feathers that the stone surface has been decorated by carvings or/and paint work. These have been preserved in local, and some of them ordinarily open to the public. The Kamao tumulus in Kumamoto city, Japan, is estimated to be built in the late 6th century. Since the ceiling stone and stacked stone collapsed, major repair work was carried out in 1967. There is a facility that has an entrance door made of iron facing south and one can observe decorated chamber walls in the burial chamber which directly connects to the entrance through the dromos. However it does not ordinarily open to the public because of a fear of the deterioration of decorated chamber walls. It seems to be thought that the cause of the deterioration is the dew condensation in the tumulus that is fallen, or flowed down on the decorated wall. We measured hydrothermal environment in the Kamao tumulus for two years and examined annual temperature and humidity behavior and observed the annual distribution of dew condensation occurrence. The results of the survey are as follows: (1) The entrance door facing a south directly receives solar radiation. (2) The temperature difference occurs inside or inside and outside, so the air flow tends to occur. (3) The relative humidity at burial chamber is almost 100% all year round. (4) In the burial chamber which has decorated chamber walls, dew condensation occurs over the entire surface in summer and at part of ceiling of north in winter.
It seems to be that air exchange between internal air in the burial chamber and external air by stack effect remarkably influence on the annual behavior of dew condensation distribution in the burial chamber. As a result of discussion, we supposed two causes

* Corresponding author. Tel.: +81-(0)75-383-2920; fax: +81-(0)75-383-2920.
E-mail address: mmmmuuuuad@gmail.com

doi:10.1016/j.egypro.2015.11.150

for what the dew condensation in the burial chamber mainly occur. (1) Evaporation from the soil surface in the tumulus near the door of the entrance. (2) Moisture exchange between external and internal air by the ventilation through the gap of the door. In Chapter 3, using measured temperature and humidity, we investigate the primary factor of dew condensation by analysing moist air movement in the stone chamber. Next in chapter 4, we develop a two dimensional temperature and humidity analysis model in the tumulus and verify its validity. And then we investigate whether or not the counter measure which we shield the entrance door so as not to be exposed to solar radiation is effective to prevent the dew condensation.

Fig. 1. (a) Appearance of Kamao tumulus; (b) Appearance of burial chamber; (c)Appearance of the ceiling of burial chamber .

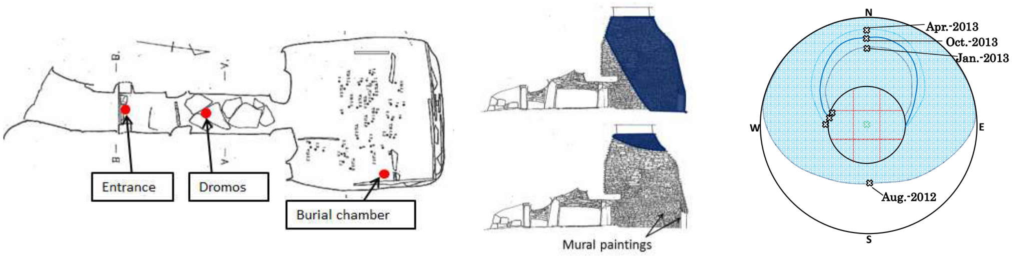

Fig. 2. Outline of measurement positions and measurement results in Kamao tumulus
(a) Measurement positions; (b) dew condensation distribution. top: Aug.2012 bottom: Jan.2013; (c) dew condensation distribution at ceiling

2. Investigation of the main factors of dew condensation

2.1 Analysis model

In the analysis model, we divide the chamber in 3 rooms (in Fig.3), and calculate the amount of ventilation by stack effect M_1 (outside-entrance), M2 (entrance-dromos), M3 (dromos-burial chamber) which takes into account of the temperature difference between each room. We identify both the gap width which is the parameter of the amount of moisture movement from outside and the surface area of chamber which is the parameter of the amount of evaporation at surface as measured results are reasonably explained. In this calculation, we use the moisture balance equation treated as the instantaneous steady state.

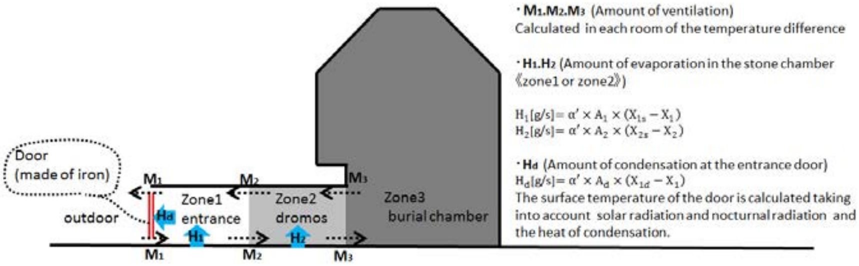

Fig. 3 Schematic diagram of the Analytical model

2.2 Results and discussion

Fig.4 shows the annual variation of the absolute humidity of measured values and analysis values (gap width at 2mm~1cm) when not considering the evaporation or condensation in the stone chamber. All the calculated value does not agree with measured value very well. It seems that the model is not taken into account evaporation and condensation occurs in the stone chamber. Fig.5 shows annual variation of the amount of evaporation at the surface in the entrance and the dromos (H_1+H_2) and the amount of dew condensation at the entrance door. The amount of evaporation at surface in the stone chamber remarkably increases in summer, and the dew condensation at the entrance door frequently occurs in winter. Therefore, the calculated value taken into account the evaporation and the condensation agree with the measured value when the opening width is 2mm very well in Fig. 6. Then, Fig.7 shows the amount of moisture movement calculated by using the identified opening gap. In summer, the water vapor moves from the dromos to the burial chamber by stack effect and the dew condensation occurs in burial chamber. On the other hand, in winter the water vapor moves from the burial chamber to the dromos and the surface easily dry in the burial chamber. These results correspond to the measured results as shown inFig.2 (c). Thus moisture movement in the stone chamber can be generally reproduced in the ventilation calculation. Fig.8 shows that the comparison between the amount of evaporation from the soil surface in the entrance and the dromos and the amount of moisture exchange between external and internal air by the ventilation through the gap of the entrance door. It can be said that the evaporation at the soil surface in the tumulus near the door of the entrance is the main factor of the dew condensation in summer. Also it is thought that the influence of moisture movement through the gap of the door on the condensation is small. In addition the dew condensation at the entrance door in winter is the main factor of the drying in winter. Now we come up an idea that shading the entrance door is the counter measure the solar radiation in order to suppress the evaporation. We will examine it in a following chapter.

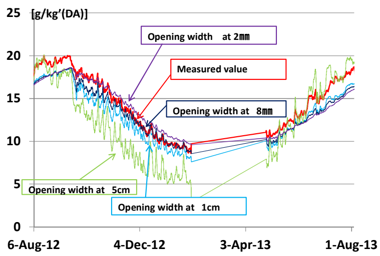

Fig. 4 Influence of air gap of the entrance door on the absolute humidity

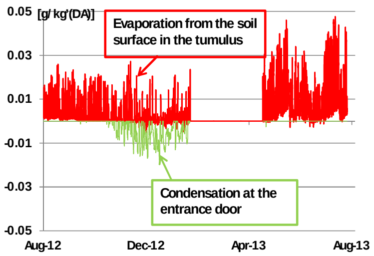

Fig 5 the amount of evaporation and dew condensation in the entrance and the dromos

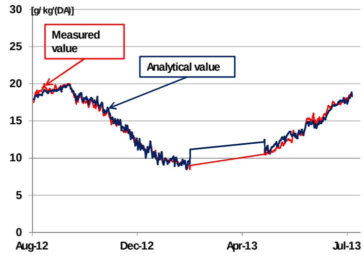

Fig.6 Comparison between calculated value and measured value in the absolute humidity

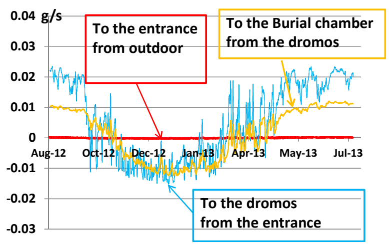

Fig. 7 The amount of moisture movement in the tumulus

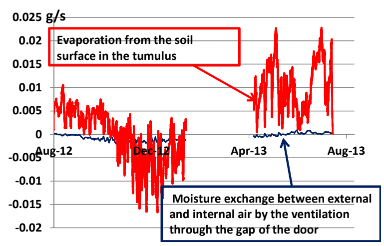

Fig. 8 The comparison between the ventilation of the outdoor and the evaporation in the chamber on the amount of the moisture movement

3. Heat and moisture transfer behavior considering 2-dimensional mound of the tumulus

In chapter 3, it can be said that the evaporation at the soil surface in the tumulus near the door of the entrance is the main factor of the dew condensation in summer. On the other hand, it is not clear where dew condensation occur in burial chamber because we cannot make clear the temperature and the moisture content distribution of the mound. Thus in this chapter, we develop the two-dimensional analysis model taken into account the mound and its surrounding ground. Firstly, we confirm the validity of this model in order to investigate the counter measure suppressing the condensation. Next we investigate the calculated results when the entrance door has a shading to suppress the solar radiation.

3.1 Method for analysis

Materials forms the tumulus are stone, concrete, soil which are porous materials. In this chapter, we use simultaneous heat and moisture transfer equations developed by Matsumoto [2].

The driving force of heat and moisture transfer is temperature and water chemical potential.
Moisture chemical potential μ [J/kg] is as follows:

$$\mu = R_v T \ln(h) \tag{1}$$

Heat and moisture balance equations are as follows:

$$c\rho\, \partial T/\partial t = -\nabla\cdot(-\lambda\nabla T) - r\nabla\cdot\left(-\lambda'_{\mu g}(\nabla\mu - nF_w) - \lambda'_{Tg}\nabla T\right) \tag{2}$$

$$\rho_w(\partial\varphi/\partial\mu)\,\partial\mu/\partial t = -\nabla\cdot\left(-\lambda'_{\mu g}(\nabla\mu - nF_w) - \lambda'_{Tg}\nabla T - \lambda'_{\mu l}(\nabla\mu - nF_w) - \lambda'_{Tl}\nabla T\right) \tag{3}$$

Heat and moisture balance equations of the air in the stone chamber is as follows:

$$\mathrm{crV}\,\partial T_i/\partial t = \sum_{j=1}^{n} S_j\alpha_i(T_s - T_i) + crnV(T_0 - T_i) + Q \tag{4}$$

$$\mathrm{c'r'V}\,\partial P_i/\partial t = \sum_{j=1}^{n} S_j\alpha'_i(P_s - P_i) + c'r'nV(P_0 - P_i) + J \tag{5}$$

Then the amount of ventilation between each room uses the calculated value obtained in chapter2.
The heat and moisture generation which are Q and J, are assumed to be 0[W], 0[kg/s], respectively because people rarely enter the tumulus.
Where R_v is the gas constant of water vapor (R_v=R/M_v) T is the temperature [K], h is the relative humidity[%], cρ is the volumetric specific heat capacity of the material [J/kg・K], λ is the thermal conductivity [W/mK], α_i is the indoor heat transfer coefficient [W/m^{2}K], α'_i is the indoor moisture transfer coefficient [kg/m^{2}K], cr is the volumetric specific heat capacity of air [J/m^{3}K], c′r′ is the volumetric specific moisture capacity of air [kg/m^{3}K], S_j is j_{th} area of inner surface of the stone chamber [m^2], n is the air change rate [s^{-1}], ρ_w is the density of liquid water[kg/m^3] φ is the moisture content [m^3/m^3] , F_w is the external force of gravity[m/s^2], V is the air volume in the chamber [m^3], T_0, T_i, T_s are the outdoor, indoor and surface temperature, respectively [K] , P_0, P_i, P_s are the outdoor, indoor and surface water vapor pressure, respectively [Pa], Q is the heat generation in the room.[W], J is the moisture generation in the room [kg/s], $\lambda'_{\mu g}$ is the moisture conductivity at gas phase on moisture chemical potential gradient [kg/m・s(J/kg)] , λ'_{Tg} is the moisture conductivity at gas phase on temperature gradient [kg/m・s(J/kg)], $\lambda'_{\mu l}$ is the moisture conductivity at liquid phase on moisture chemical potential gradient [kg/m・s(J/kg)], λ'_{Tl} is the moisture conductivity at liquid phase on temperature gradient [kg/m・s(J/kg)]

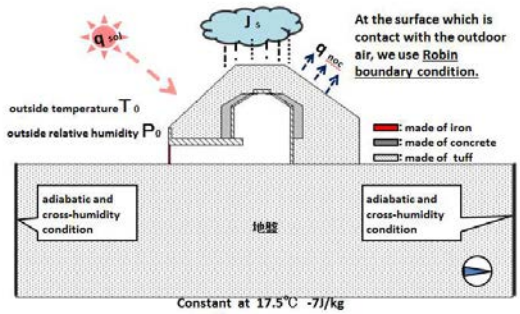

Fig.9 Schematic diagram of analysis model

In this analysis, the two-dimensional model containing the stone chamber shown in Fig.9 is analyzed. This model is North-South cross section of the tumulus. The stone chamber consists of tuff, concrete and soil layer. Hydrothermal properties of the material reference to the literature values [3]. We use forward finite difference method for calculation.

3.2 Results and discussion

3.2.1 Behavior of temperature and humidity in the stone chamber

Fig.10 shows the temperature of analytical value and measured value of the entrance and burial chamber, and Fig.6 (b) shows the absolute humidity. Although the analysis value become slightly less than the measured value through late February from late September, behavior of temperature and humidity is generally consistent.

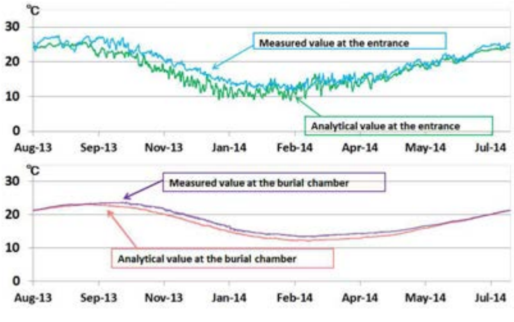

Fig.10 Comparison between calculated and measured value of temperature in the chamber

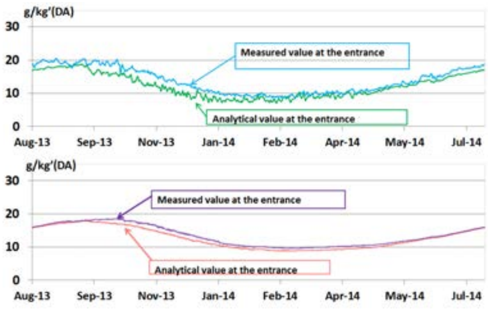

Fig.11 Comparison between calculated and measured value of absolute humidity in the chamber

3.2.2 Behavior of dew condensation in the stone chamber

Fig.12 shows the calculated value of the amount of dew condensation at the surface in the burial chamber and at the entrance door. We assume that dew condensation occurs when the moisture chemical potential is more than -5J/kg (RH99.9%) and there is moisture flow towards the wall from the air. Dew condensation in the burial chamber occurs from early April through the end of October, and the amount of condensation especially increases from June through August. On the other hand, dew condensation at the entrance door occurs from October through December. The amount of the dew condensation at the entrance door promotes the water vapor to flow out from the burial chamber toward the entrance, the surface does not occur dew condensation that means the surface is not wet in winter and the surface is wet in summer. This result is consistent with the result obtained by the visual investigation at the field survey in Fig.2 (c). Next, Fig.7 (b) shows the position in which is occurred dew condensation in summer and winter.

In January 5th, dew condensation does not occur in the burial chamber but occurs at the entrance door. Against in June 5th, dew condensation does not occur at the entrance door but occurs at the side wall of north of the burial chamber. Fig.14 shows the temperature distribution of the mound in June 5th. The top of the south slope is highest, and the north bottom is lowest in temperature. It is because solar radiation incomings at the south are large and soil temperature at the northern slope where the solar radiation is not coming is lower than outside temperature in summer. Fig.15 shows the moisture content distribution of the mound in June 5th.

This is also because the evaporation is large at the southern slope caused by solar radiation. So it can be said that dew condensation occurs at the north side wall of the burial chamber in summer because of these temperature and moisture content distribution above mentioned. Compared with the results of the field survey, the calculated results can reproduce that the parts where the surface is dry in winter and wet in summer, and that the dew condensation occurs at the side wall of north of burial chamber in summer. On the other hand, the calculated results cannot reproduce the feature that dew condensation occurs at the ceiling in the burial chamber all the year round. As possibility, it can be said that water is easily accumulated on the ceiling because of materials of the mound or that there is vertically distribution in absolute humidity. We have been investigating the issue.

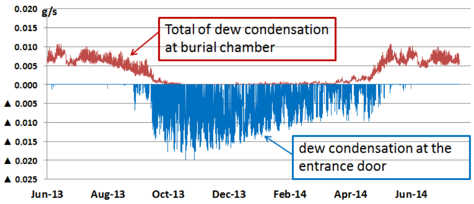

Fig.12 Annual variation of the amount of dew condensation

Fig.13 the position occurring the dew condensation in winter (left) and summer (right)

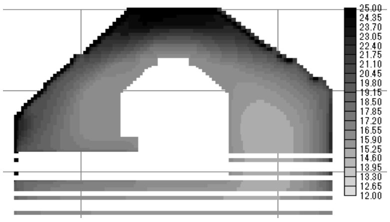

Fig.14 Temperature distribution of the tumulus in summer

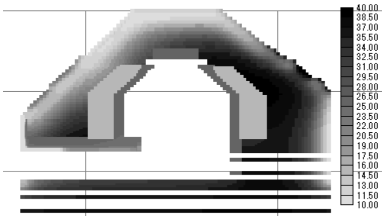

Fig.15 Moisture content distribution of the tumulus in summer

3.2.3 Investigation on a conservation measure by shielding solar radiation at the entrance door

In the chapter 2, we clarify that the evaporation from the soil surface in the tumulus near the door of the entrance is the main factor of the dew condensation in the burial chamber in summer. Absorbed solar radiation at the door is easy to be transmitted through into the chamber because the door is made of iron. As a result, a temperature rise in the tumulus by solar radiation causes promotion of the evaporation on the ground near the door. So we investigate the case that is shielding solar radiation at the entrance door by using the two-dimensional analysis model. As a condition of the shielding door, the amount of solar radiation coming into the door assumes 0[W/m^2]. The both results of amount of the dew condensation at the surface of the burial chamber before shielding and after shielding are shown in Fig.16.

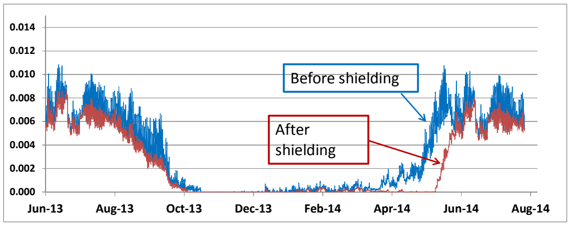

Fig.16 the amounts of dew condensation at surface of burial chamber before shielding and after shielding

Whereas the dew condensation occurs through late October from late April without the shielding, the dew condensation occurs through early October from late May with the shielding, the season when the dew condensation occurs with the shielding is shorter than result before the shielding. In addition the amount of the dew condensation at the surface of the burial chamber decrease about 20% in July compared with the result without the shielding.

In order to reduce the amount of dew condensation at the surface of the burial chamber more, we propose an insulating the door as the additional measure.

4. Conclusions and perspectives

In this study, we investigate of the main factor of the dew condensation and counter measure to suppress the dew condensation of Kamao tumulus. We calculated considering the ventilation by stack effect and the evaporation at the surface and two-dimensional simultaneous heat and moisture transfer equations. The following results are obtained. (1) In summer, the water vapor moves from the dromos to the burial chamber by stack effect and the dew condensation occurs in burial chamber. On the other hand, in winter the water vapor moves from the burial chamber to the dromos and the surface easily dry in the burial chamber. The evaporation at the soil surface in the tumulus near the door of the entrance is the main factor of the dew condensation in summer. In addition the dew condensation at the entrance door in winter is the main factor of the drying in winter. (2) The calculated results using the analysis model we developed agree with the behavior of measured temperature, humidity and condensation. On the other hand, the calculated results cannot reproduce the feature that dew condensation occurs at the ceiling in the burial chamber all the year round. As possibility, it can be said that water is easily accumulated on the ceiling because of materials of the mound or that there is vertically distribution in absolute humidity. (3) The season when the dew condensation occurs with the shielding is shorter than result before the shielding. In addition the amount of the dew condensation at the surface of the burial chamber decreases about 20% in July compared with the result without the shielding. In order to reduce the amount of dew condensation at the surface of the burial chamber more, we propose an insulating the door as the additional measure.

Acknowledgements

We would like to thank K.Sakaguchi (Kumamoto Prefectural Ancient Burial Mound Museum) and T.Ikeda (Kumamoto Prefectural Board Of Education) and E. Miyoshi (Kumamoto City) for making this work possible.

And this research was supported by KAKENHI (23560694).

References

[1] Ikeda T., Constructing a monitoring system with temperature and humidity and visual performance of the coloring as a target, Kumamoto Prefectural Ancient Burial Mound Museum Inc (In Japanese)

[2] Matsumoto, M., Energy Conservation in Heating Cooling Ventilating Building; Heat Transfer Technique (ed. Hoogendon C.T., Afgan, N.H.,) (Proc. of 1977 Int. Seminar of Heat and Mass Transfer, Dubrovnik) Vol.1 p.45 Hemisphere, 1978

[3] Yonghui LI, Daisuke OGURA, Shuichi HOKOI, and Takeshi ISHIZAKI: Numerical analysis of heat behavior of stone chamber after excavation, THE 16TH SEMINAR OF JSPS-MOE CORE UNIVERSITY PROGRAM ON URBAN ENVIRONMENT,Vol.2008,pp.385-392,Oct,2008

[4] Hokoi S.,Ikeda T. and Nitta K., Building environmental engineering – Heat transfer, moisture transfer and ventilation-, Asakura Inc (In Japanese)[5] Japan Society of Thermo Physical Properties: Thermophysical Properties Handbook,YOKENDO Inc (In Japanese)