TM Coupling Analysis of Weathering Effects on Dinosaur Fossil

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***Abstract* — Dinosaur fossils have great scientific value in studying earth evolution, biological evolution, stratigraphic correlation, geological time identify and paleo-environment reconstruction. But weathering is a serious problem for the excavated dinosaur fossils, as many fossils were destroyed by weathering within a time span of few years or shorter. In this paper, to explore in depth the weathering cause and mechanism of dinosaur fossil geological relics, TM coupling method is used for analyzing weather regularity of dinosaur fossil in Zhucheng area, Shandong province. The interaction law between fossil and surrounding rock under temperature change is analyzed in depth considering their deformation incongruity. Its effect on weathering is also discussed. Finally, preliminary cause and regularity of weathering is revealed to provide scientific reference for fossil protection.**

Keywords - Dinosaur fossil, Weathering, Surrounding rock, Temperature stress, TM coupling

I. INTRODUCTION

Temperature change is one of the main factors cause fossil and surrounding rock weathering [1]. Due to heat-expansion and cold-contraction, volume change is produced on fossil and surrounding rock, which is called thermal strain. Then thermal stress is produced because of different thermal expansion coefficient between fossil and surrounding rock[2-3]. At the same time, thermal stress is also generated by non-uniform distribution of temperature. Cracks appears when fossil or surrounding rocks cannot bear the additional stress. That cycle repeats causing cracks expanding and lead to the fossil weathered. For the fossils in the open air, during the day, surface suffers strong sunlight and expands more than interior, while during the night, surface cool and contracts quicker than interior. This lead to more serious weathering. For fossils indoor, expansion caused by temperature change is relatively small, but uneven expansion also leads to cracks and surface exfoliating [4-7]. At the same time, chemical corrosion will be accelerated by temperature, and the strength of its internal structure will be affected. Water's effect will also be accelerated by temperature and put important influence on dinosaur fossil weathering [8-10]. In view of the above situation, TM coupling method is used in this article to analyze weathering mechanism of Zhucheng dinosaur fossil [11-14].

II. CALCULATION PRINCIPLE AND PARAMETERS

A. Constitutive Model

In this paper, the thermal coupling constitutive equation of fossils and rock are shown as formula (1) - (4):

The mechanical constitutive equation of the fossils and rock:

$$-\nabla \cdot \sigma = F_v \quad , \quad \sigma = s \tag{1}$$

$$s - s_0 = C:(\varepsilon - \varepsilon_0 - \varepsilon_{inel}) \quad , \quad \varepsilon_{inel} = \alpha(T - T_{ref}) \tag{2}$$

$$\varepsilon = \frac{1}{2}\left[(\nabla u)^T + \nabla u\right] \tag{3}$$

Where: ε is strain, ∇u is displacement gradient, C is the fourth-order elastic tensor, s_0 is the initial stress, ε_0 is the initial strain, α is thermal expansion coefficient, s is stress, T is temperature, T_{ref} is the strain reference temperature, ε_{inel} is thermal strain .

Heat conduction constitutive equation of the fossils and rock:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \cdot \nabla T = \nabla \cdot (k \nabla T) + Q \tag{4}$$

Where: ρ is material density, C_p is heat capacity at constant pressure , k is thermal conductivity , Q is heat source, T is temperature.

B. Parameter Determination

According to the experimental results, and access to relevant data, model parameters are shown in table 1:

TABLE 1. THERMAL MECHANICAL COUPLING PARAMETERS

Category Parameters	Density (kg/m^3)	Elastic Modulus (GPa)	Poisson's ratio	Specific heat capacity [J/(kg・k)]	Coefficient of thermal expansion (1/k)	Thermal conductivity [W/(m・k)]
Rock	2469	10	0.25	80	3×10-5	1.241467+0.005733333×T
Dinosaur Fossils	1765	4	0.35	90	1.5×10-5	11.28342-0.02833641×T +2.570169×10^{-5}×T^2

In this paper, it is assumed in the initial state, the temperature of the fossils and rock is 12 □,which is Zhucheng annual average temperature, the temperature varies depending on the actual temperature changes in a day of Zhucheng, shown in Figure 1.

Fig.1 Temperature variation process curve in Zhucheng.

III. THE MODEL GENERALIZATION AND COMPUTING SCENARIOS

A. Generalized Computing Model

In this study, dinosaur fossils have been generalized into the cylinder, for analysis its weathering scene after excavation, part of the dinosaur bones is outside the surrounding rock, the rest is placed inside the wall rock. Calculation model shown in Figure 2.

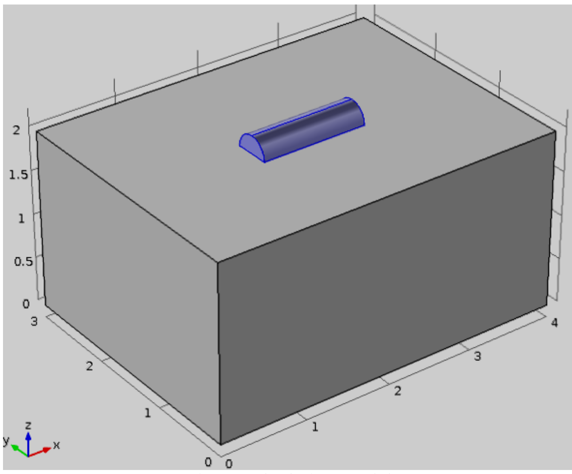
Fig.2. Calculation model

Model is taken to be symmetric around the boundary. Fixed bottom boundary, bind its x, y, z direction displacement,and free the upper boundary. Thermal convection between the upper surface of the model and the outside world. The initial temperature of the rock and fossils are 12 ℃.

B. Computing Scenarios

In this paper, TM coupling laws is used to analyze, fossil and surrounding rock interaction and two stages of heating and cooling. The heating stage temperature change curve shown in Figure 3, the cooling phase of the temperature curve shown in Figure 4.

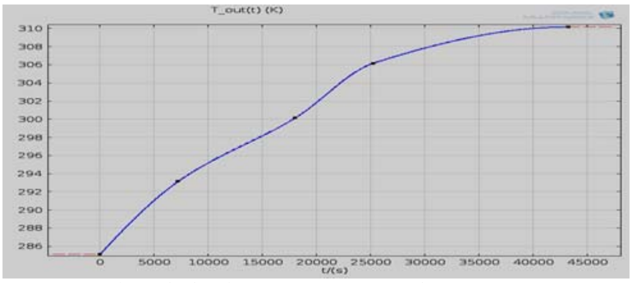

Fig.3 The heating stage temperature change curve.

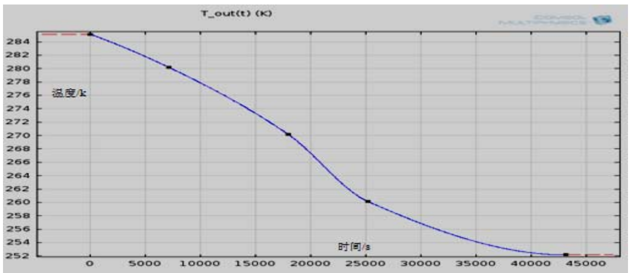

Fig.4 The cooling stage temperature change curve.

IV. THE CALCULATION RESULTS AND ANALYSIS

A. The heating Stage TM Calculation and Analysis

Application temperature curve shown in Figure 3, carried TM coupling calculation, the results shown in Figure 5.

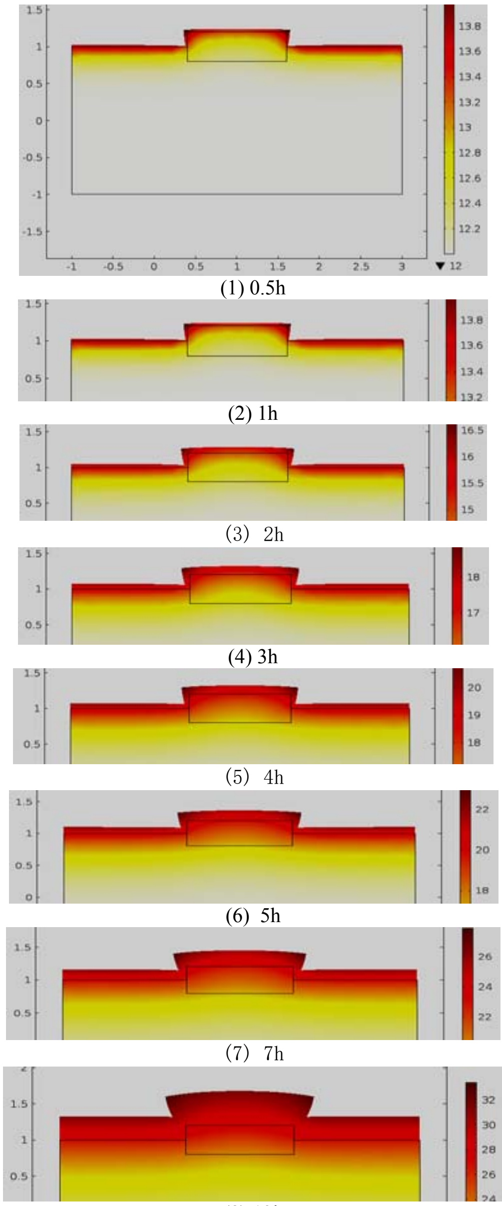
(1) 0.5h
(2) 1h
(3) 2h
(4) 3h
(5) 4h
(6) 5h
(7) 7h
(8) 12h

Fig. 5 Fossil internal temperature changes during the heating stage

Figure 5 shows the fossil and surrounding rock's internal temperature changes, as a result of the outside temperature changes. It can be seen from Figure 5, when the outside temperature continues to rise, fossil and surrounding rock's surface temperature keeps rising, while the internal temperature is almost constant. Due to thermal expansion and contraction effect, both fossil and surrounding rock appeared expansion.

Temperature stress by calculation is shown in Figure 6.

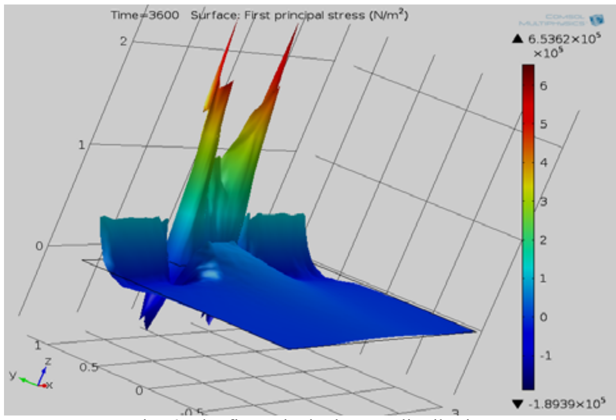

Fig. 6 The first principal stress distribution

Figure 6 suggests that with one-hour influence of outside temperature change, due to the effect of temperature stress, the tensile stress acts on the surface of the fossil and rock, but the compressive stress acts on the contact zone of the fossil and surrounding rock. As a result of the action of thermal expansion and contraction, when the outside temperature rises, the temperature of fossils and rock's surface rises rapidly, and the internal temperature is not affected, the stress occurs on the surface of fossils and surrounding rock on the effect of temperature gradient. However, the thermodynamic parameters of fossils and surrounding rock are different, so the sizes of tensile stress are different. Because of mutual restraint, compressive stress zone occurs on the contact zone between fossil and surrounding rock.

In addition, this paper analyzes its displacement, the left edge of the overall displacement of fossil exposed area with outside temperature changes shown in Figure 7.

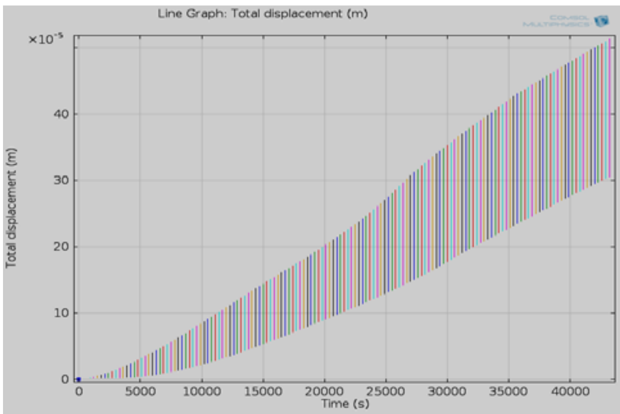

Fig.7 The left boundary displacement change of dinosaur fossils

Analysis shows that, with the outside temperature continuing to rise, the displacement increases. In the fossil physical and mechanical properties in certain circumstances, the greater the displacement, the more crack-prone the fossil is, the more easily weathered happens.

Fossil surface stress, internal stress and temperature distribution shown in Figure 8 (when the time is 3h).

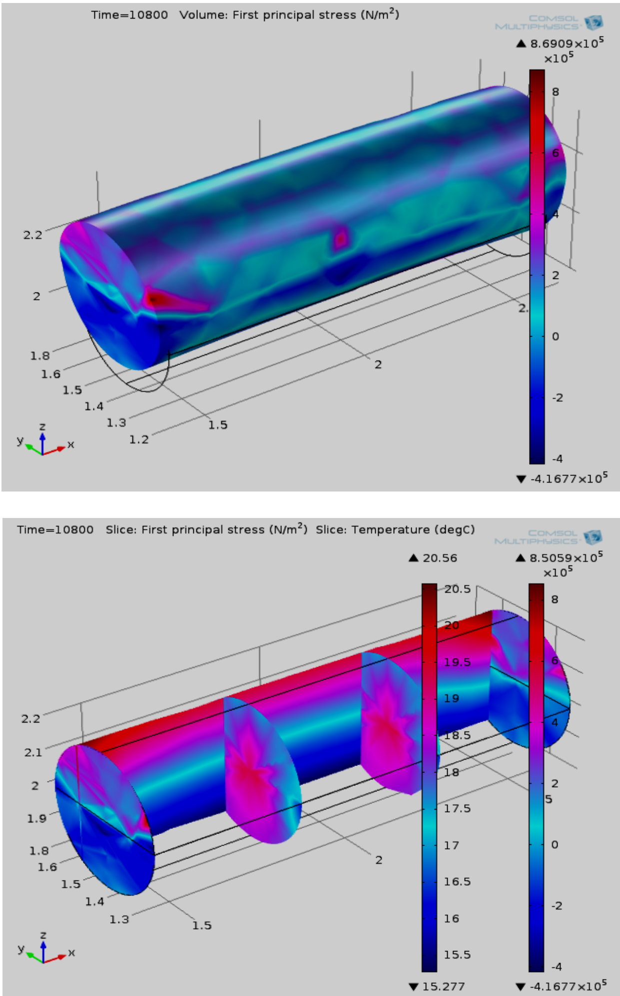

Fig.8 Fossil surface stress distribution and internal stress and temperature slices

Figure 8 shows that, when the outside temperature changes as shown in Fig 3, in 3h , fossil internal temperature rapidly, the maximum temperature at this time was 20.56 ℃, fossil' s end portion passes faster than the intermediate temperature, where the internal temperature of the fossil extremely unevenly distributed.

As it can be seen from the YZ section (FIG. 8), the fossil' s intermediate portion, the maximum tensile stress concentration area extends down inside the fossil intermediate portion, divergently shaped distribution, and the maximum tensile stress occurs at both sides of the exposed portion of the fossil, the maximum tensile stress 1.2MPa.

Figure 8 shows that fossil' s exposed surfaces are subject to tensile stress, which is unevenly distributed. The maximum tensile stress is about 0.86MPa. The fossils buried inside the rock is effected by compressive stress, the maximum compressive stress the fossil suffered is 0.42MPa.

Based on above analysis, during the temperature rise stage, fossils are influenced by ambient temperature change and the surface tension stress is larger, so the more exposed in the air, the greater the bones is affected by the temperature.

B. The Cooling Stage TM Calculation and Analysis

In the temperature decreasing process, if the temperature drops below freezing, the water in the surrounding rock or fossil will freeze. Due to the lack of coordination of the two materials, fossil and surrounding rock deform will make them interact force, and so forth will inevitably accelerate weathering fossils, fossil cause damage. TM calculated temperature drop curve is shown in Figure 4.

Variation of Pore water in fossils and rock with the outside temperature changing is shown in Figure 9.

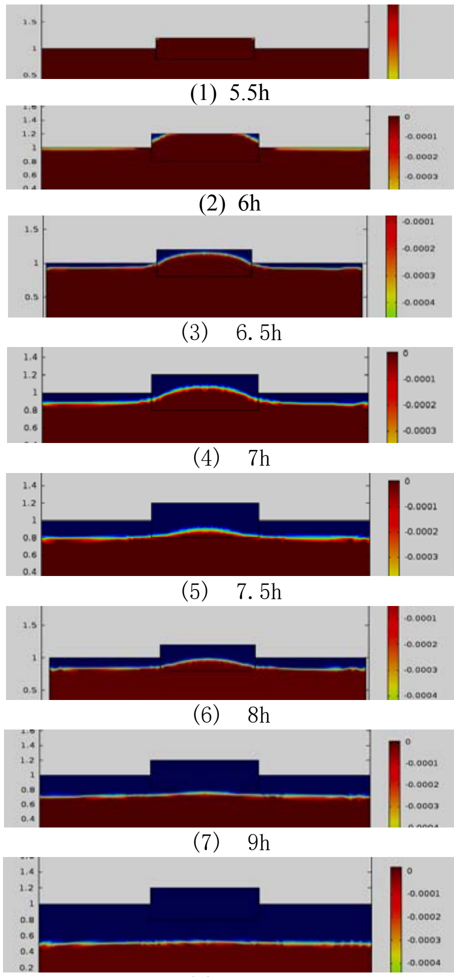

Fig.9 Internal pore water freezing process

The calculation revealed that water in cracks of naked fossils and surrounding rocks have finished phase change into solid ice. Frozen first happened on the edge exposed to the air, then internal temperature reduced gradually and pore water freeze further. With sustained low temperature, pore water continues to freeze and internal stress of fossils and its surrounding rocks keeps changing. Frost heaving force is generated. Uncoordinated deformation lead to the fossil weathering continuously.

According to calculations, fossils and rock stress distribution shown in Figure 10, the deformation shown in Figure 11.

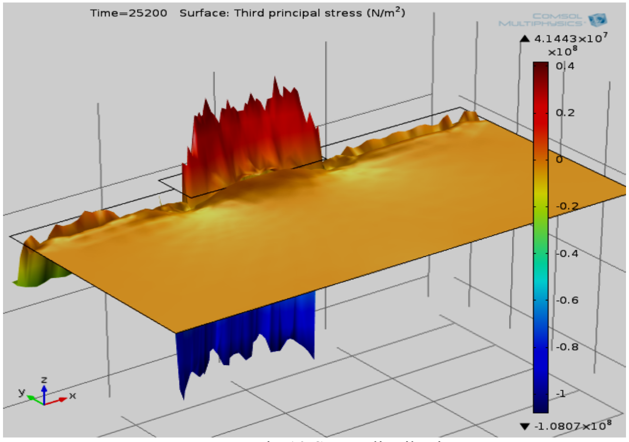

Fig.10 Stress distribution.

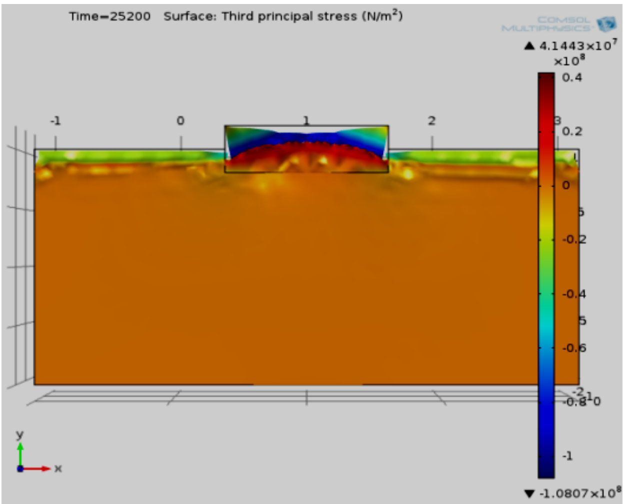

Fig.11 Deformation distribution

TM calculation suggest that on the surface of fossils and surrounding rocks, tensile force is generated after pore water reached freezing point temperature, but as it is not restrained by surface, the stress increased from outside in. At freezing point, interior stress is produced, at the same time, the volume of fossil and surrounding rock shrinks because of thermal expansion and contraction stress effect, and pore water’ s volume expand after it is frozen. So the internal stress with temperature reduction is bigger than that with temperature increment.

V. CONCLUSIONS

The research shows that due to the different response parameters of temperature changes between fossils and surrounding rock, the deformation of the both is discordant, so that the interaction leads to fossil’s damaging. TM calculations did during temperature rise and drop stage suggest that the response process for temperature stress inside fossil and surrounding rock is different. Surface temperature stress changes first and conducts inward gradually. Contrastive analysis reveals that fossil damage during temperature r drop is less serious than during temperature rise, especially when temperature dropping below freezing point. The essential reason is frost heave effect of water and this should be pay more attention in future fossil protection.

Besides, other factors such as heat coupling analysis are also very important for in-depth study of weathering mechanism. Through the study in this article, the author expects to start a discussion, attract more scholars to do in-depth research in aspects of TM coupling analysis and hydro-mechanical coupling analysis, so that gradually set up mechanics analysis system for fossil weathering study and lay scientific and technical foundation for prevention of fossil weathered.

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REFERENCES

[1] ZHANG Yanxia.The impact of change climate on the mass mortality of Zhucheng dinosaur [A]. The Abstract Book on the Eleventh National Congress cum 27th Annual Symposium by the Palaeontological Society of China [C]. Palaeontological Society of China:,2013:1.

[2] Jiazuo Zhou,Dongqing Li. Numerical analysis of coupled water, heat and stress in saturated freezing soil[J]. Cold Regions Science and Technology, 2011

[3] Ning Li,Bo Chen,Feixong Chen,Xiaozu Xu. The coupled heat-moisture-mechanic model of the frozen soil [J]. Cold Regions Science and Technology . 2000 (3).

[4] ZHU Wancheng , WEI Chenhui , TIAN Jun , et al. Coupled thermalhydraulic-mechanical model during rock damage and its preliminary application [J]. Rock and Soil Mechanics,30(12) : 3 851 -3 857,2009.

[5] ZHANG Yujun. Coupled thermo-hydro-mechanical model and finite element analyses of dual-porosity fractured medium for ubiquitous-joint rock mass[J]. Chinese Journal of Rock Mechanics and Engineering,28 (5) : 947-955,2009.

[6] TONG F G, JING L R, ZIMMERMAN R W. A fully coupled thermo-hydro-mechanical model for simulating multiphase flow, deformation and heat transfer in buffer material and rock masses [J].International Journal of Rock Mechanics and Mining Sciences,47(2) : 205-217,2010.

[7] ZHUANG Zhuo. Extended finite element method[M]. Beijing: Tsinghua University Press,48-61,2012.

[8] TANG Chun・an, MA Tianhui, LI Lianchong, et al. Rock failure issues in geological disposal of high-level radioactive wastes under multi-field coupling function[J]. Chinese Journal of Rock Mechanics and Engineering,26 (Supp.2):3 932-3 938,2007.

[9] LI Lianchong, YANG Tianhong, TANG Chun・an, et al. Study on coupled thermalmechanical-damage model in rock failure process[J]. Rock and Soil Mechanics,27(10):1 727-1 732,2006.

[10] ZHAO Hongbao, YIN Guangzhi, CHEN Lunjian. Experimental study on effect of temperature on sandstone damage [J]. Chinese Journal of Rock Mechanics and Engineering,28(Supp.1):2 784-2 788,2009.

[11] LIU Quansheng, XU Xichang. Damage analysis of brittle rock at high temperature [J]. Chinese Journal of Rock Mechanics and Engineering,19(4):408-411,2000.

.

[12] LIU Quansheng, LIU Xuewei. Preliminary research on numerical manifold method for temperature field of fractured rock mass[J]. Chinese Journal of Geotechnical Engineering,35(4):635-642,2013.

[13] CHEN Yifeng, ZHOU Chuangbing, MAO Xinying, et al. Numerical simulation of coupled thermal elastic behaviors for hard rock pillar in Äspö Pillar stability experiment, Sweden[J]. Chinese Journal of Geotechnical Engineering,32(8):1 200-1 206,2010.

[14] KOYAMA T, CHIJIMATSU M, SHIMIZU H, et al. Numerical modeling for the coupled thermo-mechanical processes and spalling phenomena in Äspö pillar stability experiment(APSE)[J]. Journal of Rock Mechanics and Geotechnical Engineering,5(1):58-72,2013.