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Numerical simulation of temperature field of gears in quenching process

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Abstract. Combining with change of the thermal physical parameters of materials, the temperature field of 45 steel gears in quenching processes has been numerically simulated using the thermal analysis module of ANSY Workbench software. The relationship between temperature of gears parts and quenching time has been achieved, the simulation results are consistent with actual process. The methods is superior to the traditional manual measuring and experience judgment way. The simulation process has provided the due theoretical basis for the calculation of parts thermal stress and residual stress in quenching process.

Introduction

Recently, With development of mechanical equipment to high reliability, lightweight, miniaturization, the gears in machinery have been demand high strength, high reliability.Therefore, in order to improve the strength of the mechanical parts, the various heat treatment and surface treatment have been adopted. At present, the surface hardening of mechanical parts has carried on often by quenching.The production practice shows that the quenching process is the highest return rate and rejection rate process in heat treatment process.In order to reduce the cost, the deviation of the deformation, stress and hardness must be adjusted in the end of quenching, it will become an important work to predict, control this kind of deviation using simulation method, simulation of quenching temperature field is the basis and premise of this type of simulation.

The traditional analysis method of quenching temperature distribution is experimental determination and experience judgment. The quenching process is a complex process from temperature, microstructure transformation and stresses three aspects of interaction [1].Therefore the temperature field of quenching process is not integrated, comprehensive, and accurate analyzed and predicted by traditional method[2]. Numerical simulation of quenching process has brought to high attention of all circles of the heat treatment superiority[3], which only requires mathematical model, rather than by physical simulation for the physical quantity satisfy the similarity principle, Which takes in account the physical parameter is the functional relationship of temperature and microstructure state in the calculation. The superiority is very obvious to applicant in the simulation of quenching process. Although the relationship such as phase distribution, stress distribution and process parameters can not be gotten directly, but the coupling calculation to the temperature field, stress field, the microstructure field can be carried on, the information of the temperature field, stress field, the microstructure field can be given in each moment, and the changes of the physical

parameters can be observed directly. Numerical simulation can not only check the current process, but also can optimize the process and parameters, so that the preparation of quenching process based on more reliable [4].

The mathematical model of quenching process

According to the law of Fourier heat transfer and energy conservation, control equations can be established for heat transfer analysis problem, which is the transient temperature field T (x, y, z) of objects should satisfy the following equation[5]:

$$\frac{\partial}{\partial_x}\left(\kappa_x \frac{\partial T}{\partial_x}\right)+\frac{\partial}{\partial_y}\left(\kappa_y \frac{\partial T}{\partial_y}\right)+\frac{\partial}{\partial_z}\left(\kappa_z \frac{\partial T}{\partial_z}\right)+\rho Q=\rho c_T \frac{\partial T}{\partial_t} \tag{1}$$

ρ —Material density； c_T —Material specific heat, J/(kg•K})； k_x,k_y,k_z,—The heat conduction coefficient in the x, y, z direction, W /(m •K)； Q—The strength of heat source inside the object, W/kg。

The boundary conditions can be expressed by following equation [6]:

$$-\lambda \frac{\partial T}{\partial n}\Big|_s = H_k\left(T_w - T_c\right)+\sigma\varepsilon\left(T_w^4 - T_c^4\right)= H_k\left(T_w - T_c\right)+ H_s\left(T_w - T_c\right)= H\left(T_w - T_c\right) \tag{2}$$

Where H_k is the convective heat transfer coefficient, T_w is the workpiece surface temperature, $T_c$is the medium temperature,σis Stefan-Boltzman constant, ε is the workpiece surface emissivity; H_s is radiation heat transfer coefficient; H is the total heat transfer coefficient.

Numerical simulation and analysis of gear quenching temperature field

The gear materials is 45 steel, heated to 850 ℃, holding a moment, quenching at 0 ℃ water, the temperature distribution of the quenching of 30s has been simulated by ANSYS Workbench. The quenching process belongs to the transient thermal analysis. Figure 1 is the gear section.

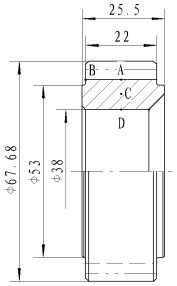

Fig.1 Sectional drawing of the gear

Thermophysical parameters of 45 steel Calculation shows that, when nonlinear properties of the material thermophysical parameters is not considered, the temperature distribution and actual measured value of quenching cooling process has considerable error[7].

Therefore, it is unreasonable that the thermophysical parameters are as constant, the specific heat capacity, thermal conductivity should be as a function of temperature.

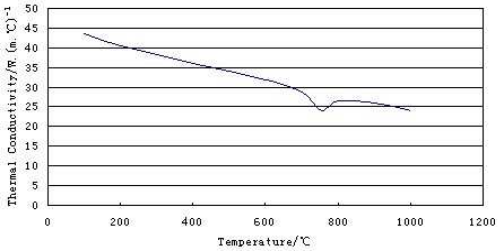

Fig.2 Relationship between thermal conductivity and temperature

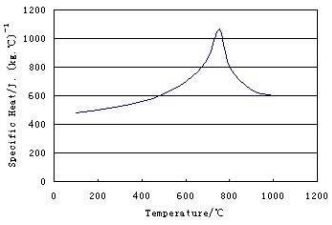

Fig.3 Relationship between specific thermal and temperature

The physical parameters of Steel 45 can be got [7], the curves of the physical parameters changing with the temperature show in Figure 2 and Figure 3 after that is defined in the ANSYS Workbench. In the simulation process, density did not change much with the temperature, so the constant value is 7833kg/m^3.

Modeling

The geometric model In order to maintain the relevance of the geometric model[8], at first the geometric model has been built using CAD, then enter the Design Modeler module of ANSYS Workbench from the embedded software CAD. Since the parts belong to the axis of symmetry, the analysis model of the 1/4 period is desirable. As shown in figure 4.

Finite Element Model Meshing is that the geometric model is transformed into the finite element model with nodes and elements. The density of grid can be adjusted by controlling the dividing unit size, classification accuracy and so on. The model is meshed by automatic mesh generation method using 8 node Solid70 unit [9]. As shown in figure 5.

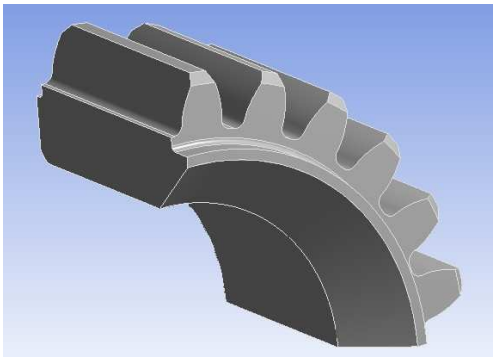

Fig.4 Geometric model

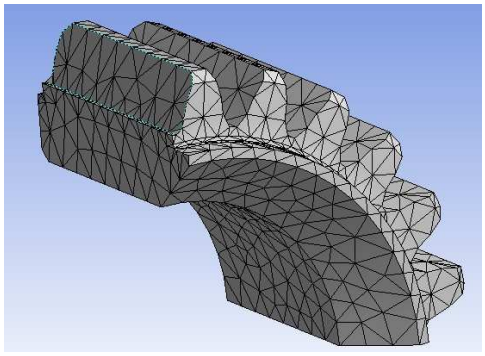

Fig.5 Finite Element model

Solution Firstly, the steady state thermal analysis (1 time steps) has been carried on, in order to obtain the initial condition of the transient analysis. Then Analysis of transient process, the distribution of the temperature field of quenching process focuses on the 30s,a plurality of sub load step has been set, using the automatic time step function. As shown in Figure 6 by setting the convective boundary condition of quenching process.

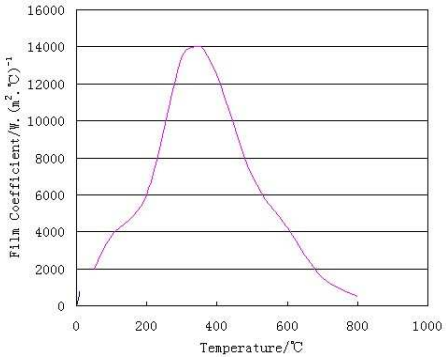

Fig.6 Relationship between film coefficient and temperature

Results and analysis Temperature field distribution of each part of 120s in quenching process can be obtained by the set of solving conditions, and the dynamic changing process of temperature field with time can be simulated. Figure 7- Figure 10 shown that the temperature field distribution of part the surface and the core in the quenching of 0.5s, 10s, 15s 30s.

As can be seen from the graph, the quenching of 0.5s, the surface temperature decreased rapidly, while the core still maintains high temperature. With the extension of the quenching time, surface temperature continued to decline, but the temperature decrease rate dropped significantly, the

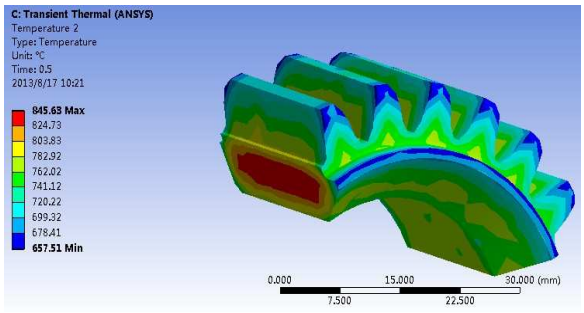

Fig.7 0.5s Temperature field

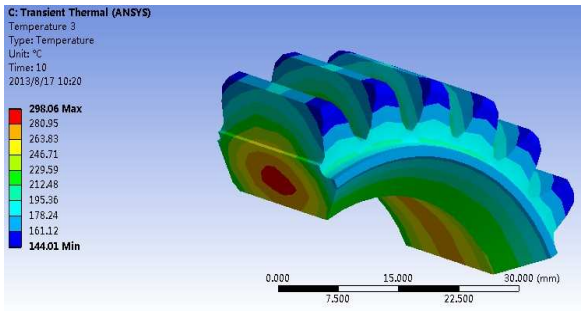

Fig.8 10s Temperature field

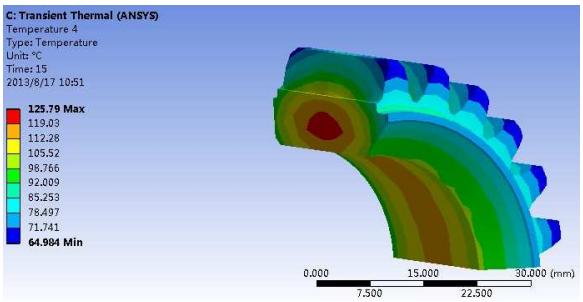

Fig.9 15s Temperature field

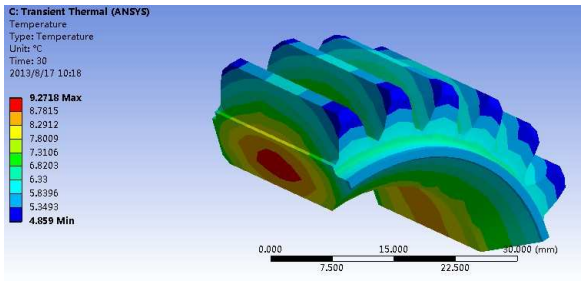

Fig.10 30s Temperature field

internal temperature decreased, the decreasing rate of slightly higher than the surface. Only 15s parts surface is decreased from 850 ℃ to 65 ℃, the core of cooling to 126 ℃. At any time, temperature of parts center is the highest in the whole part, which is in line with the actual production.

A, B, C, D four nodes of parts on Figure 1 has been studied respectively, the temperature variation with time, as shown in figure 11. Each point temperature is decrease with time, the rate of temperature decrease is different, B is the fastest, A is second, C is the most slow. If the temperature field of the other nodes want to be got, only need to choose the node coordinates, to display the temperature field distribution contour map of each node.

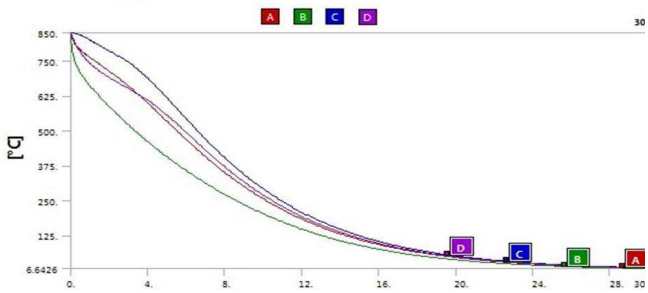

Fig.11 Each point relationship between temperature and time

Conclusion

In this paper, the temperature field of 45 steel during quenching process have been studied based on ANSYS Workbench, the temperature changing process of the gear with the quenching water cooling have been discussed in detail. And some problems needing attention in the temperature field simulation process have been put forward, so as to realize the prediction of the temperature field during quenching. The transient heat analysis have been carried on using ANSYS Workbench, which can provide the preparation to numerical simulation of heat stress and residual stress in the quenching process.

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References

[1] Zhuang. Liu, Numerical simulation of the process of heat treatment, Science Press, Bei Jing,1996.
[2] Xian. Ma, Development of numerical simulation during quenching process, J. Ordnance Material Science and Engineering.3(1999)59-63.
[3] Jan. Sheng. Pan, Ming. Juan. Hu, Dong. Tian, Jian. Feng. Gu, Some development of the researches on computer simulation of quenching processes,J. Heat Treatment of Metals. 12(1998)30-32.
[4] Bin. Zhong, Gang. Chen, Technical research on numerical simulation of quenching process, J. Journal of AnHui Vocational College of Metallurgy and Technology. 14(2004)11-14.
[5] Teng. Lun. Zhao, Application of ABAOUS6.6 in mechanical engineering, China Water & Power Press，Bei Jing,2006.
[6] Pan J S,Li Y J,Gu J F.Research and Application Prospect of computer Simulation on Heat Treatment Process, J. Journal of Shanghai Jiaotong University,1(2000) 1-13.
[7] Zhen. Tan, Guang. Wen. Guo, Thermophysical Properties of Engineering Alloys, Metallurgical Industry Press, Bei Jing.
[8] Guang. Yi. Pu, Basic Tutorial and Examples of ANSYS Workbench12, China Water & Power Press，Bei Jing,2010.pp.22-23.
[9] Hong. Lai, Tian. Mo. Liu, Temperature Filed Ansys Simulation in Quenching Process of 45 Teel Part,J.Journal of chong qing university.3(2003)59-63.