COMPUTER SIMULATION OF THE MEDIUM IN QUENCH TANKS

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Finite element method is used to simulate the complex flow fields of the medium in quench tanks. The simulation results lead to an improvement of the design of the quench tanks as well as the flow equalization device inside the tank to get an uniform fluid field. This flow field simulation lays the foundation for further research on other fields during the quenching processing.

Introduction

Many complex physical phenomena interior of the work-pieces, such as temperature variation, microstructure transformation as well as the following change of mechanical properties, generation and redistribution of residual stress, etc. interact during heat treatment processing and are influenced by the quenching medium. Quench hardening of a given material is, therefore, determined by the state of the quenching medium. In the past, quench hardening of work pieces has long been successfully used in industry. But the real state of the quenching mediums in different kinds of tanks has less been investigated. Since the 1970's, computer simulation of heat treatment and calculation has been an important research area and great attention has been paid.

During quenching process, the cooling intensity (H value) of the medium influences the quenching hardening results of work-pieces greatly. The intensity of cooling not only depends on the cooling capacity of quench medium but also depends on the cooling power of the quench tank. Even if the quench medium is identical, the construction of quench tank and the way of stirring will cause different results. So the structure of a quenching tank as well as the stirring device will influence the quenching processing significantly.

In this paper, computer simulation using finite element methods (FEM) is used to investigate the complex flow field of the quench medium in a quench tank and the results are used to help the design of the tank.

2. Quenching process

When a work-piece is quenched, the cooling procedure can be divided into three stages as following:

1) Formation of a steam film on the quenched work-piece.

When a hot work-piece is immersed into a quench medium, the surface of the work-piece will be covered with a steam film immediately. This steam film will inhibit heat transfer and reduce thermal conductivity greatly. Heat transfers slowly in this stage because the heat of work-piece is delivered mainly by thermal conductivity of the steam film.

2) Ebullition of the medium on the surface of the work-piece.

Because of the huge quantity of heat in the work-piece, the steam film can not maintain for a long time. The steam film will break and the quenching process enters into an ebullition cooling stage. In this stage, the work-piece contact the quenching medium directly, and the quenching medium boils on the surface of the work-piece. The heat of the work-piece is absorbed quickly by the quenching medium due to steaming. As a result, the heat transfer accelerates and reaches maximum.

3) Contra-flow cooling stage.

When the surface temperature of work-piece is lower than the boiling point of the quench medium, it enters contra-flow stage. In this stage, elimination of heat from the work-piece proceeds in the way of contra-flow, natural convection caused by temperature difference of medium itself and heat conductivity caused by the temperature difference between medium and work-piece.

The velocity of fluid flow in the quenching tank has a determinative effect on the cooling of the work-piece. Change of the flow field will impact the cooling process greatly. The change of the flow field can be realized by stirring the medium by a propeller. Powerful stirring of the quench medium can not only reduce the stabilization of steam film formed during quenching process, but also strengthen the relative movement between the work-piece and the quench bath. As a result, the cooling rate is accelerated. This can further help erase quenching soft spots, deepen the depth of hardening zone and reduce distortion of the work-piece. Proper stir can break steam film in advance, raise maximum velocity of cooling. When the work-piece has a lower hardening-ability but requires a higher hardness, properly selecting the concentration of the medium and powerful stir must be adopted to get ideal quenching results. Researches have indicated that good stirring of the medium can not only

increase the cooling rate of the work-piece, improve the temperature uniformity in the cooling medium, but also can improve the temperature uniformity inside the work-piece, which can further lead to a better quenching result. In the first stage of quenching, stir can break steam film on a higher temperature to let quenching process enter into boiling stage in advance. In the boiling stage, stir can reduce bubbles on the surface of the work-piece and make them depart from the work-piece easily. The impact force from the stirring can remove jelly-like and solid particles on the work-piece and accelerate the cooling rate. Stir can also remove the medium that has been hot and uniform the temperature distribution of the medium in the quench tank.

3. Computer simulation of quench medium

Quenching process is a complex interactivity-coupling process that can hardly be solved by analytic solution. Physical simulation methods have many limitations, because there is not a model that can cater for any physical factors. Temperature field, structure field, stress field and strain field of a test sample in a small size that are measured in laboratories can hardly be used on a real work-piece with real dimensions. In fact, *in situ* measurement will be very difficult and even impossible in the real industrial activities because quenching process involves high temperature. Till now, measurements have been proceeded mainly after quenching process. So, the quenching processes were staying at a qualitative analysis level made according to experience.

As the development of computer technology and its comprehensive application, computer simulation or numerical simulation has made a big progress in dealing with quenching processes. Numerical simulation is based on physical models which are further connected to mathematical models to determine those fields quantitatively with a computer. Computer simulation of quenching process is only a process to give the numerical solution of those fields by computer. Although this kind of method can't directly give functions among structure, stress distribution and processing parameters, it can proceed coupled calculation among temperature field, structure field, and stress field, giving visual distribution of those fields at any instance of quenching. And any change of all those fields in quenching process can be observed. Numerical simulation requires only to be concordant with the mathematical model, so the same program that is used to calculate laboratory samples can be used to calculate the real work-piece in the same accuracy. Thus we can save a large amount of valuable human power, time and financial to get an overall analysis of the quenching process. In this way, the quenching processes can be determined before the production without any testing and the microstructure as well as the properties of the work-pieces can be forecast accurately.

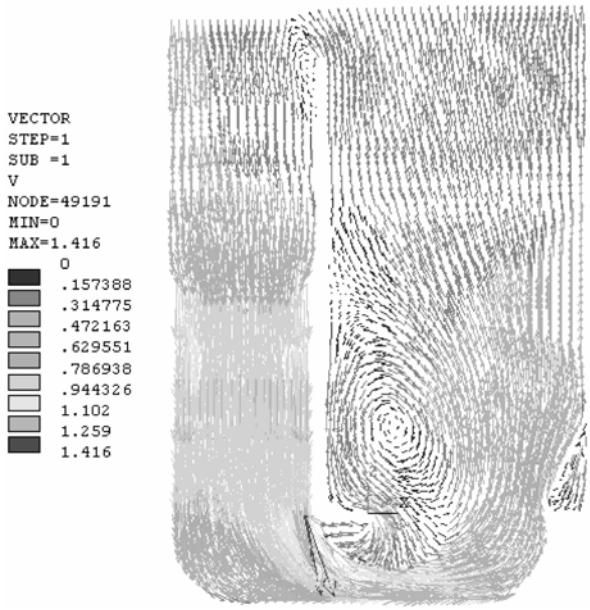

Fig.1. Flow field of the medium without flow adjusting plate

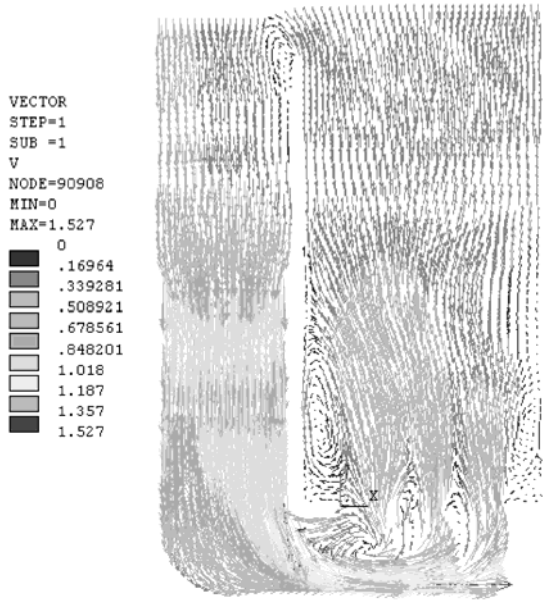

Fig.2. Flow field of with an adjusting plate

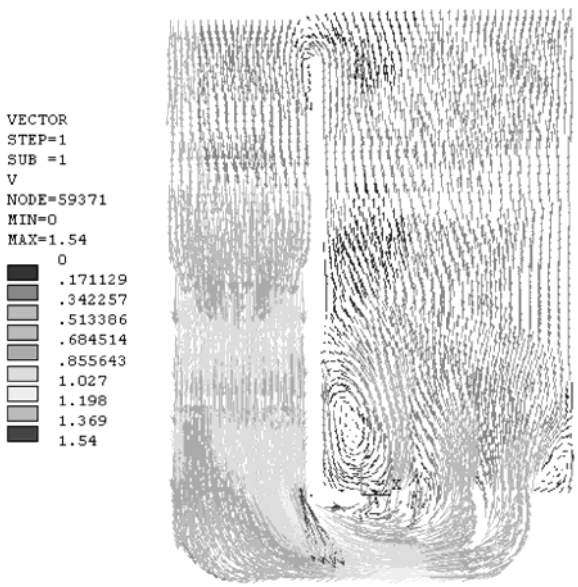

Fig. 3. Flow field with an improved adjusting plate

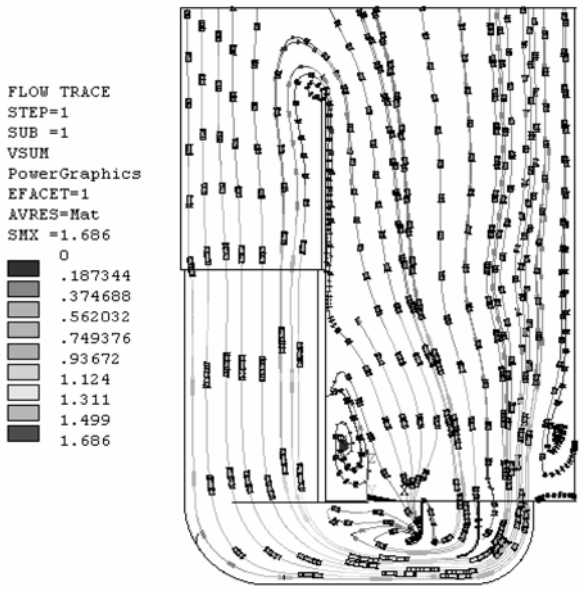

Fig. 4. Flow traces of Fig.3

Computer simulation on the flow field of the fluid in a quenching tank is a very important and foundational work. The simulation results can be used to guide the design of the structures of the quenching tank and the stirring device in order to obtain an uniform flow field and to adjust and control the fluid velocity. The computer simulation of the fluid field in the quenching tank can also be used to study the cooling intensity, the contra-flow coefficient of heat transfer and the inner fields in the work-piece. As the development of computer simulation of hydro-mechanical processes, computer simulation of the fluid field in a quenching tank is developing step by step and is becoming an important research field.

4. Analysis of results

The results of simulation on three-dimensional complex flow field indicate that flow equalization system (flow adjusting plate) take a very important effect on the uniformity of the flow field in a quenching tank. It can be seen from the following pictures that uniform-flow plates can improve the distribution of flow field greatly and make it uniform, shown as following:

5. Conclusions

1) Computer simulation on a three-dimensional complex flow field was realized, which can be used to lower the production costs and to save time for quenching processes.

2) The cooling capacity of a quenching tank takes a great important effect on intensity of cooling of the work-pieces, and stirring of the medium takes a determinative effect on the cooling capacity of the quench tank and is very significant for quenching processes.

3) Improvement on the structure of the quench tank can get a uniform flow field, and can further improve the cooling capacity.

4) The current research on the flow field can further lead to an understanding of the coupling effect among flow field, temperature field, stress field, structure field.

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