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**Technical regulation for simulation on heat treatment
process of heavy steel forgings**

大型锻钢件热处理工艺模拟技术规范

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Technical regulation for simulation on heat treatment process of heavy steel forgings

1 Scope

This Standard specifies basic procedures, numerical simulation technical specification for heat treatment process, physical simulation technical specification for heat treatment process, safety and hygiene requirements, and heat treatment process simulation report of simulation on heat treatment process of heavy steel forgings.

This Standard is applicable to quenching, tempering, annealing and normalizing process simulation of heavy steel forgings used for heavy equipment in industries such as energy, metallurgy, transportation. It is not applicable to chemical heat treatment and surface heat treatment process.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

GB/T 228.1, *Metallic materials - Tensile testing - Part 1: Method of test at room temperature*

GB/T 229, *Metallic Materials - Charpy Pendulum Impact Test Method*

GB/T 231.1, *Metallic materials - Brinell hardness test - Part 1: Test method*

GB/T 2975, *Steel and steel products - Location and preparation of samples and test pieces for mechanical testing*

GB/T 6394, *Metal - Methods for estimating the average grain size*

GB/T 6803, *Test method for drop-weight test to determine nil-ductility transition temperature of ferritic steels*

GB/T 7232, *Terminology of metal heat treatment*

GB/T 9452, *Testing method for working zone of heat treatment furnace*

GB/T 13298, *Inspection methods of microstructure for metals*

GB/T 13324, *Terminology of heat treatment equipment*

GB 15735, *Requirements for the safety and health in production process of metal heat treatment*

GB/T 15749, *Measuring method in quantitative metallography*

GB/T 30825, *Pyrometry for heat treatment*

GB/T 31054, *Computer aided engineering for mechanical products - Finite element numerical calculation - Terminology*

GB/T 32541, *Quality control system for heat treatment*

3 Terms and definitions

For the purposes of this document, the terms and definitions defined in GB/T 7232, GB/T 13324 and GB/T 31054 as well as the followings apply.

3.1 numerical simulation

computer simulation

A method that combines the concepts and methods such as finite element method, finite volume method, finite difference method, that uses computer, through numerical calculation and image display, to achieve a purpose of researching engineering and physical issues and even various issues in nature.

NOTE: In this Standard, it refers that performing analysis on physical quantities such as temperature, tissue and stress of heavy steel forgings during the given heat treatment process, to obtain details of their distribution and evolution in heavy steel forgings, so as to provide temperature curve for simulation on heat treatment process of heavy steel forgings. It can also be used directly as a basis for the development of heat treatment process.

3.2 physical simulation

A method that simulates real physical process through physical experiment in the laboratory. Usually, place the reduced model of the actual object into the experimental body (such as heating furnace, wind tunnel, sink, etc.). Based on the satisfaction of basic similar conditions (including geometry, motion, thermal, dynamic and boundary conditions), it simulates the main features of the real process.

NOTE 1: Since all similar conditions cannot be fully satisfied, proper selection of similar

a) Mathematical model

Numerical simulation on temperature field for heat treatment process of heavy steel forgings usually contains transient heat transfer model with internal heat source.

b) Boundary conditions

- Interface heat transfer boundary conditions refer to the quantitative expression of heat exchange between heavy steel forgings and heating or cooling media interface. It usually uses the third type of boundary conditions, that is, set the heat transfer coefficient and ambient temperature.
- Internal heat source boundary conditions refer to the release or absorption of latent heat due to phase change during heat treatment process of heavy steel forgings. It can be treated by equivalent specific heat method or internal heat source method.

c) Input parameters

Input parameters of numerical simulation on temperature field for heat treatment of heavy steel forgings include density, specific heat, thermal conductivity, latent heat of phase change and heat transfer coefficient. In order to improve the accuracy of numerical simulation, it shall consider the influence of tissue type and temperature change on density, specific heat and thermal conductivity, as well as the influence of phase change type and phase change temperature change on latent heat of phase change.

5.2.3 Numerical simulation on tissue field

Numerical simulation on tissue field of heavy steel forgings takes phase transition kinetic model as basis. It calculates the phase transition during heat treatment process through numerical method so obtain detailed information on the evolution of the tissue field during the whole process of heat treatment of heavy steel forgings, including tissue type, mass or volume fraction and distribution. Numerical simulation on tissue field contains the following two parts:

a) Mathematical model

Numerical simulation on tissue field of heavy steel forgings contains Austenite grain growth model and phase variable calculation model. In the analysis of temperature-tissue-stress three-field coupling, the phase transition kinetic model shall consider the effect of stress on the tissue field.

b) Input parameters

coefficient. In order to improve numerical simulation accuracy, it shall consider the influence of tissue type and temperature change on mechanical properties of material as well as the influence of phase transformation type on phase transformation strain coefficient and phase transformation plastic coefficient.

5.2.5 Numerical simulation on multi-field coupling

Numerical simulation on multi-field coupling for heat treatment of heavy steel forgings uses numerical method to simultaneously find solution for multiple physics fields with mutual coupling during heat treatment process, to obtain detailed information of distribution of physical quantities such as temperature, tissue, stress in heavy steel forgings as well as evolution over time. There are usually three heat treatment process numerical simulation levels, that is, single field simulation of temperature field, two-field coupling simulation of temperature field-tissue field, temperature field-stress field, three-field coupling simulation of temperature field-tissue field-stress field.

According to the material properties and heat treatment process characteristics of specific heavy steel forgings, it can select numerical simulation on different levels of heat treatment process so as to support or optimize the heat treatment process from different degrees.

5.3 Solution calculation

Solution calculation mainly refers to use computer, according to specific settings, to perform solution calculation of large linear equations in the background. These settings include numerical methods used, accuracy requirements, storage frequency, thread allocation.

5.4 Post-processing

Post-processing outputs the numerical simulation results into graphical images and 3D animations with engineering implications for guiding process analysis so as to realize the visualization of numerical simulation results.

5.5 Benchmark experiment

5.5.1 If it needs to evaluate the applicability of the numerical simulation tool, it can entrust a third party or a numerical simulation tool provider to conduct the benchmark experiment.

5.5.2 The benchmark experiment shall select a sample made of heavy forged steel, of which the diameter is 20mm~50mm, the length is 60mm~200mm, for temperature, tissue, distortion and residual stress testing.

5.5.3 According to supercooled austenite continuous transformation kinetic

time-temperature curve at sampling position of heavy steel forging that is extracted from numerical simulation results of heat treatment process as the process curve of heat treatment simulation experiment. According to performance testing requirements, prepare the sample of heat treatment simulation test. In the simulation experimental furnace, conduct heat treatment experiment during the entire processes such as heating, insulation and cooling. Perform performance testing and microstructure analysis to the sample that has been subject to heat treatment simulation experiment.

6.2 Simulation experimental furnace

6.2.1 Simulation experimental furnace shall integrate heating, insulation and cooling functions, for easy operation.

6.2.2 The temperature uniformity of the effective heating zone of the empty furnace of heat treatment simulation experimental furnace shall be less than or equal to 3°C. The effective heating zone is tested according to the method of GB/T 9452 or GB/T 30825.

6.2.3 Temperature measurement and temperature control shall be conducted according to the following methods:

- a) Temperature control system that meets the requirements of GB/T 32541 shall be configured according to the heat treatment process requirements;
- b) Recording devices that track the temperature of heating, insulation, and cooling processes shall be equipped;
- c) Calibration period and calibration tolerance of the temperature sensor shall meet the requirements of GB/T 9452 or GB/T 30825;
- d) It shall ensure the temperature curve of the temperature-controlled thermocouple be consistent with the temperature curve of the physical simulation process;
- e) Calibration period and calibration tolerance of the load thermocouple shall comply with the provisions of GB/T 30825;
- f) Accuracy requirements of instrument system shall meet the requirements of Class I equipment in GB/T 32541.

6.2.4 Cooling rate shall meet the following requirements:

- a) It may use wind cooling and/or water-spraying cool, equipped with fans, pumps, nozzles and control valves, to make gas and/or water go through furnace interior. And evenly cool the sample.
- b) Cooling rate of heat treatment simulation experimental furnace can be

6.6 Metallographic analysis

The microstructure analysis and grain size analysis of the physical simulation samples are carried out according to the methods specified in GB/T 13298 and GB/T 6394, respectively.

7 Safety and hygiene

The safety and hygiene of heat treatment operations shall meet the requirements of GB 15735, good ventilation and dust removal conditions in the workplace.

8 Report of heat treatment process simulation

Heat treatment process simulation shall issue a report. The report shall contain:

- project name;
- project number;
- organization's name;
- report writer;
- report date;
- basic information of heat treatment process simulation, including material composition, geometry and dimensions, sampling, performance requirements, process information and tools used for numerical simulation of heat treatment of heavy steel forgings;
- numerical simulation results, including temperature curve of the sampling position of heavy steel forging, temperature distribution of heavy steel forging at different times, tissue distribution cloud map, stress distribution cloud map and final geometry and dimensions. If multiple numerical simulations are performed, the above results obtained by simulation under each heat treatment process condition shall be included;
- physical simulation results, including actual sample temperature curve, sample tissue and performance testing data;
- final recommended heat treatment process.

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Linkin: <https://www.linkedin.com/in/waynezhengwenrui/>

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