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Quenchant, Quenching and Distortion Control

Non-ferrous Metals, Cu, Al, Mg, Ti alloy, and etc

New development of theory and applications for alternately timed quenching technology

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Abstract: Quenching is one of the most important heat-treatment processes for improving the mechanical properties of steels. Water is the most clean quenching media, but pollutional oil or aqueous polymer solution are still widely used to quenching in engineering because water quenching easily causes the cracking of component or workpieces. Water-air alternately timed quenching (ATQ) technology proposed by us solves the issue of cracking. ATQ technology includes ATQ process and equipment, in which the base of ATQ process design is the finite element simulation (FES) of temperature field, microstructure field and stress field, and the design of equipment must ensure the precise execution of ATQ process. ATQ process performs a fast water quenching to a temperature T_q, a subsequent partitioning above T_q during air cooling to accomplish the partitioning (diffusion) of carbon from supersaturated martensite into retained austenite in steels so as to keep carbon-enriched retained austenite stable during subsequent cooling to room temperature if these steels have more than 1.0% Si, as shown in Fig.1. In fact, ATQ process performs a quenching-partitioning-tempering (Q-P-T) process proposed by Hsu in 2007. Based on plenty of theoretic and experimental investigation we summarize four advantages of ATQ process as follows. 1) Water-air ATQ technology can replace any oil or aqueous polymer solution quenching technology, and exhibits the feature of environmental protection (Fig.2); 2) ATQ technology reduces quenching stress and avoids cracking of workpieces. Fig.3 shows FES of radial quenching stress of the driving shaft in different quenching ways, and engineering application verified the correctness of FES, that is, 100 pieces of driver shaft were quenched by ATQ1 (water-air quenching once), four pieces of which generated the cracking, while driver shaft are quenched by ATQ2 (water-air quenching twice), no cracking occurs so far, while direct water quenching (DQ) often causes cracking;3) Water-air ATQ process raises the volume fraction of retained austenite (V_{RA}) and enhance ductility. For example, Fe-0.42C-1.46Mn-1.58Si-0.028Nb (wt%) steel were treat by Q-P-T process (abbreviated as Fe-0.4C Q-P-T) and quenching and tempering (Q&T, T_q is room temperature), respectively. The result indicates that this Q-P-T steel has the ultimate tensile strength (UTS) is 1558 MPa and elongation of 20.3%, and the product of strength and elongation (PSE) is high up to 31600 MPa%. The UTS of Fe-0.4C Q&T steel is 1628 MPa and total elongation of only 10.2% and its PSE is 16606 MPa%, as shown in Fig.4. The XRD spectrum of the Q-P-T steel demonstrates the V_{RA} in the Q-P-T steel before tensile test is determined as 16.0%, while the V_{RA} in the Q&T steel is too small to be detected; 4) ATQ process refines martensitic matrix and raises toughness of steels. For example, a Fe-0.25C-1.2Si-1.48Mn-1.51Ni-0.05Nb (wt%) low carbon steel was treated by Q-P-T process and Q&T process, respectively, and the average impact toughness of three Q-P-T samples is 36 J (45 J/cm^2), which just is twice of three Q&T samples (18 J, or 22.5 J/cm^2). Microstructural characterization by SEM reveals the packet and block sizes of martensite in Q-P-T sample is much less than those in Q&T sample, as shown in Fig. 5. The heat treatment of dozens ton of casting steel components (Fig.6) and the heat treatment of heavy loading rail on line (Fig.7) as two new applications of ATQ technology were briefly introduced. In view of four advantages, ATQ technology proposed has been recommended as one of new technologies in heat treatment and surface engineering in the twenty-first century.

Keywords: alternately timed quenching (ATQ) technology, quenching stress, finite element simulation, quenching-partitioning-tempering (Q-P-T), retained austenite

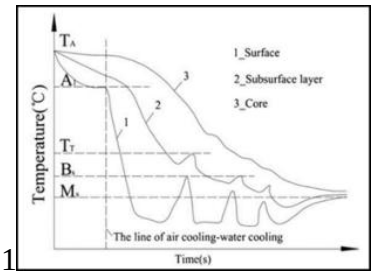
Fig.1 

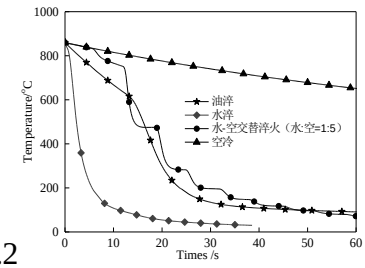
Fig.2 

Fig.1 Design principle of ATQ process

Fig.2 Principle of oil quenching replaced by water-air alternative timed quenching

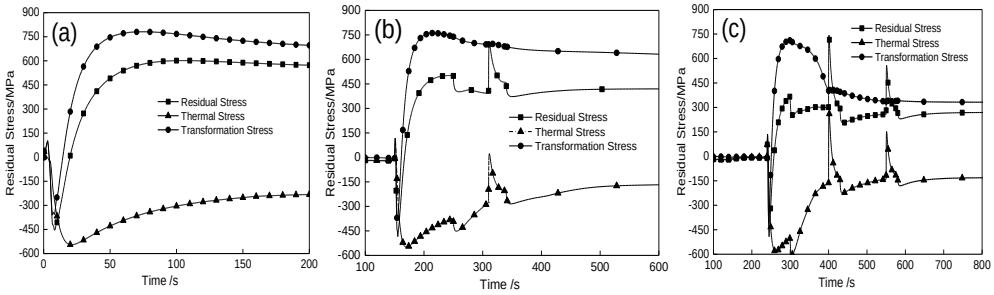


Fig.3 Finite element simulation of radial quenching stress of the driving shaft in different quenching ways: (a)DQ; (b)ATQ1; (c)ATQ2

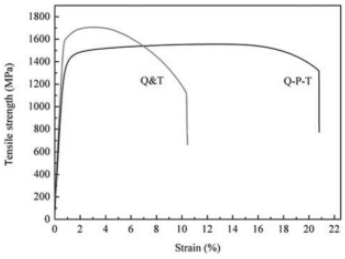
Fig.4 

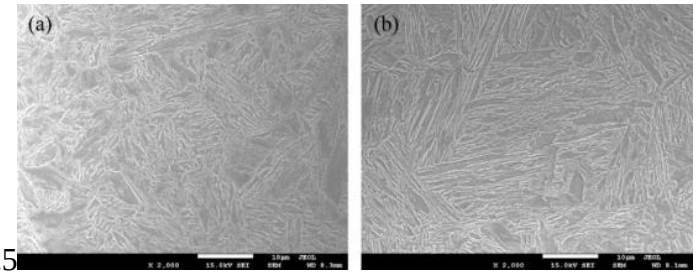
Fig.5 

Fig.4 Stress-strain curves of Fe-0.4C Q-P-T and Q&T samples at room temperature

Fig.5 SEM micrographs of samples treated by Q-P-T and Q&T process, respectively (a) Q-P-T process; (b) Q&T process

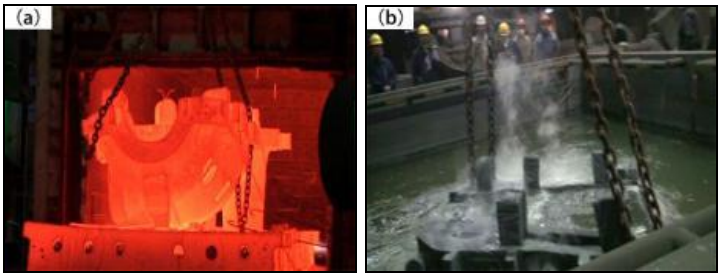


Fig.6 Photographs of casting steel work piece treated by ATQ process (a) out of furnace; (b) out of water after quenching

Fig.7 Photograph of heavy loading rail treated by ATQ process on line

Evaluation of distortion in vegetable oil quenched medium carbon steel

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Abstract: Quenching to develop martensitic structures without warping or cracking is one of the most important processes of heat treatment that can improve the performance of steel greatly. However, one of the major drawbacks associated with quenching is high thermal and transformational stresses which may lead to distortion and possibly cracking. When heat-treated parts suffer from distortion beyond the allowable limits, it can lead to rejected component and production losses. Quenching medium serves to enhance heat transfer rate of extraction from the hot metal, wet steel during cooling process to produce the desired metallurgical transformation and minimize the formation of undesirable thermal and transformational gradients which may lead to distortion. Therefore, the technical challenge of quenching is to select the quenching medium and process that gives optimum mechanical properties with least amount of distortion.

Over the years, water, brine and mineral based oils are the most commonly used to harden steel because they are readily available. Although water quenching is faster and less costly than oil quenching, the degree of distortion that accompany water quenching can be very high, therefore oil quenching which is less severe than water quenching is generally preferred. Petroleum based oils are prone to environmental, soil and water pollution, therefore, the need for more environmentally friendly oil increases. Vegetable oil has been identified as safer, renewable and biodegradable alternative quenchant to petroleum based oil.

This work investigates the dimensional changes that arise after quenching medium carbon steel in four selected vegetable oils and compares the result with values obtained by quenching in conventional petroleum derived oil SAE 40. Modified C-ring specimens of medium carbon steel (see Fig.1) were quenched in melon seed oil, ground nut oil, palm oil and wal-nut oil. The gap openings of the C-ring were measured before (G_o) and after (G_1) heat treatment with the aid of a digital vernier caliper and the average percentage gap openings ΔG_o (%) was calculated. The results were compared with medium carbon steel quenched in water and SAE 40 under the same condition. The hardness values were obtained using a Digital Micro Hardness testing machine (Model: LecoLM700AT) under applied load of 490.3 MN and dwell time of 10 s using a "C" scale (HRC). Hardness numbers taken at four (4) points of the C-ring were automatically read from the digital counter and the average value was taken. Four repeat tests were performed on each specimen and the average taken as representative of the hardness obtained for the corresponding treatment. Metallographic observations were performed with a metallurgical microscope. The results show that percentage distortion G_0 % decreased with increasing viscosity of the oil. The highest distortion value was obtained for samples quenched in melon oil whereas palm oil gave rise to the least distortion value. Mechanical properties, such as hardness were highly dependent on heat transfer coefficient and the final structure of the material which supports earlier work in the literature with respect to quench severity. Among the oils investigated, palm oil assures high hardness value (51.68 HC), uniform hardness variation in the entire volume of the specimen and the least distortion value.

Keywords: quenching, distortion, steel, vegetable oil

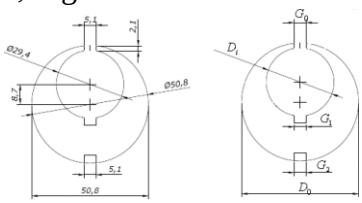

Fig.1 Modified C-ring

"Cooling engineering" for steel's quench-hardening derived from "cooling modeling": a technology overview

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Abstract: It is cooling mode that determines the type of heat treatment process and so-obtained microstructure. Due to the principle of non-equilibrium microstructure possessing specific mechanical properties, cooling and phase transformation are the core technology in metal heat treatment, so the most critical operation for steel parts' quench-hardening should be the cooling. Since steel parts were imposed quench-hardening on, the cooling theory research on quenchant and quenching technology has never been terminated. The classical cooling model of most quenching process represented by evaporating liquid media and on the basis of analysis of cooling curves (T-τ relations) measured by non-phase change standard probes. i.e. three-stage heat transfer model consisting of vapor blanket, nucleate boiling and convection, could be considered the first type of cooling model, and has been widely circulated since the early time of last century. This model, differentiating different phases of quenchant, reveals the principle of heat transfer in a whole quenching process, but it is long-term marginalized, because it merely analyzes the heat transfer behaviors of cooling medium on hot solid articles' surface in labs, and does not include the influence of the surrounding liquid volume (immersed pool boiling system) and the latent heat of steel parts. Therefore so far no satisfactory corresponding relations between the cooling model and hardening results in any effective way, shape or form have been expressed in heat treatment practice.

Physical metallurgy presented two classic cooling models for steel's phase transformation upon quench-hardening measured in non-phase change quenchant, i. e. the TTT-diagram and the CCT diagram, which could be considered the second type of cooling models (T-τ relations) and reveals the solid-state phase transformation law of steels under non-equilibrium cooling conditions. In order to avoid the bulk effect and eliminate the influence of complex factors of non-linear heat transfer, a series of small specimens are employed, moreover, the cooling behavior of steels upon transformation was studied at a series of specially designated temperatures (for TTT-diagram) or constant cooling rates(for CCT-diagram). Although the TTT/CCT diagrams have been played a pivotal role in heat treatment, it is still difficult to establish a direct connection between the models and quench-hardening effects of actual steel parts, because the initial cooling way reaching the designated temperatures (for TTT-diagram), and the three-stage cooling characteristics of common evaporating media (for CCT-diagram) are both neglected. Meanwhile, the distortion of parts caused by quenching stress in quenching process and the hardenability issue of steels involved are also not included in these models.

Therefore, in order to achieve the target of precision and flexible heat treatment with "zero distortion", "zero dispersion of quality", as well as "zero pollution", current heat treatment technology proposes a task of establishing a novel cooling model for quench-hardening of real parts, in which steel and quenchant are both phase-changeable in most cases, i.e. the third type of cooling model (T-τ relations), established on the basis of a deep understanding of the relations between theoretical cooling model and physical metallurgical behavior of quenching parts, and focused on guiding the actual hardening operation of specific steel parts via such an innovated quenching technology. The third type of quench-hardening model must meet the cooling requirements of actual parts during their heat treatment. It should combine the cooling process of specific steel parts with the other two types of cooling models to integrate a series of factors related to hardenability, distortion/residual stress and the overall quenching effect of steel parts, and satisfy quality standards of hardening, such as surface hardness, hardness distribution, distortion variables and the consistency of hardening effect, so as to then really establish the concept of cooling engineering. Based on cooling characteristics of available quenching media and steels' physical metallurgical behaviors of phase transformation, combined with modern computer technology, sensor technology, fluid mechanics technology and 3D printing technology, a combined automatic cooling device with unique cooling characteristics could be constructed. Therefore, a correlation model between physical metallurgical phenomena and engineering cooling conditions of any specific steel parts for their quench-hardening process could also be obtained, as well as the target of the consistent heat treatment technology.

Keywords: cooling, quench-hardening, steel, technology overview

Polymer quenchants for induction hardening - alternatives without boron and formaldehyde releasing biocides

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Abstract: The demand is steadily rising for process fluids with significantly less impact on the environment and occupational health. The increased demand is driven by new legislations and public attention to environmental issues. Regulations, such as REACH and CLP, identify substances that may have serious and often irreversible effects on human health and the environment as substances of very high concern (SVHCs). Hence, process fluid suppliers are forced to replace such chemicals in new products. Also new technical solutions are presented and may be interesting options.

When regarding polymer quenchants used for induction hardening, the new products and technologies should enable a process without boron or formaldehyde releasing chemicals. The present work reports on a case study where a polyalkylene glycol (PAG) quenchant is used for induction hardening of shafts. To improve this process we consider either to adopt new technology or to introduce a new quenchant. That is:

-New quenchant: Implementation of a commercial available quenchant for induction hardening, which better comply with legislation.

-New technology: UV treatment of polymer quenchant as an alternative to biocides and biostats for bacteria control. When substituting a quenchant with another quenchant or technology the technical function of the quenchant is of most importance; it should quench fast enough to secure hardness and microstructure, but not too fast in order to avoid cracking, where the latter is the most difficult part. Other important factors include microorganisms and foaming tendency.

For a manufacturing company, it is costly and risky to replace a product already in use, which fulfills quality and production aspects. Many processes, as induction hardening, are very sensitive to changes in the production, e.g. change of process fluid, which makes it difficult to test new alternatives without jeopardizing product quality and production reliability. In many cases, it is very complex to carry out tests with a new product during normal production, without great disturbance. In addition to the new process fluids, or new technology, interactions from less controllable parameters will impact the result. Another draw-back is that, in many cases, large volumes of process fluid are needed. For this reason this work has been made in laboratories and using FEM-calculations when applicable.

For evaluation of cooling characteristics, cooling curves have been measured according to ISO 9950 using the ivf SmartQuench system. This has been used to compare the different products and to evaluate the UV compatibility of the quenchants. The UV equipment and treatment has been performed by Wallenius Water Innovation using a UV lab unit. The UV treatment done here on the polymer quenchants should be comparable to six months use in a production unit. After treatment the quenching properties of the fluids were analyzed.

FEM-calculations were used to study risk of cracking and its dependence on cooling path, which will be compared to experimental work done in a lab unit.

The result shows that both implementations of new products as well as UV treatment are feasible methods in order to replace products in industrial use today. The influence of the UV treatment on cooling characteristics is comparable to the degradation of a polymer quenchant when used in production. UV treatment has a bigger impact on the cooling performance at higher concentrations of the polymer.

Further work is needed for a more accurate assessment of the risk of cracking of the quenched component. This is applicable both for new commercial products as well as UV treated products.

Keywords: polymer quenchant, UV treatment, induction hardening, biocides

Experimental method for emulating the cooling conditions of massive components

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Abstract: During the heat treatment of thick steel components the mechanical properties are limited not only by the quenching conditions but also by the wall thickness being quenched in a tank. The thicker the component, the lower the mechanical properties for a given tempering condition. This is, hardness and tensile strength are reduced for the same tempering temperature as a consequence of lower cooling rates associated with a thickness increase. In industrial practice, the tempering temperature is lowered to compensate the loss in strength of a particular grade when the wall thickness increases. This temperature reduction in conjunction with the lower cooling rate cause a drop in toughness even for similar hardness and strength. This represents a challenge in the design of massive components for nuclear, oil & gas, energy and other industries since the actual cooling conditions will affect the mechanical response to the heat treatment and the tempering temperature needed for achieving the desired properties is selected based on experience on that specific thickness and steel grade. It is very expensive to run trials for determining the heat treatment conditions for massive components. Laboratory testing usually leads to totally different conditions if the same quenching media is used because of the small thickness of the sample. The Charpy V notch values obtained in small samples are typically very high compared with a full size forging, although the strength might be similar. In this work a laboratory method is presented for reproducing the cooling rate of big components by immersion with small probes using water and polymer. Maximum cooling rates ranging from 1 to 10 ℃ per second were obtained by immersion quenching using different quenching conditions. Using a reservoir with fix volume of 20 liters, different containers were place inside the tank at the center to restrict the flow around the sample promoting a local rise of temperature of the quenchant. The inner containers were tested in a blind condition and with different configurations with small holes on the side walls to allow quenchant flow. The size of the probes was 1, 1.5 and 2 inches thick to obtain different cooling rates for each container configuration. The temperature of samples was recorded at three locations with 3 embedded thermocouples and the cooling curves for each condition is presented. Additionally, an industrial heat treatment was carried out and the cooling rate from a forging with a wall thickness 4 inches and a mass of 1.5 tonne was experimentally obtained with a embedded thermocouple at the center of the thickness. The total mass of the batch was 30 tonnes and it was quenched in a 420 cubic meters tank. The cooling rate obtained was compared with the curves obtained at laboratory scale and one configuration a was selected to emulate the cooling condition. Mechanical testing as carried out for both the full size component and from samples treated in a laboratory tank that produce similar cooling rates were compared using the same tempering temperature. The cooling curves of the actual component and the laboratory test were very similar. The mechanical properties showed similar results particularly on CVN, where typically it can be observed a major improvement when treating small samples in laboratory conditions. This methodology is used to approach the cooling conditions of massive components with small probes, thus reducing or eliminating the trial and error testing of mechanical properties whether for feasibility of new alloy composition or complex geometries where mixed microstructures are developed and toughness is uncertain. A good approach of CVN toughness of thick components can be obtained with an inexpensive and rapid testing.

Keywords: quenching of massive components, controlled slow cooling, immersion

Application of integrated computational materials engineering in heat treatment of steel forgings

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Abstract: Integrated computational materials engineering (ICME) integrates database and computational models of material properties into computational modeling and simulation of manufacturing processes to achieve optimal design of materials chemistry and parameters of manufacturing processes. This presentation introduces applications of ICME in the heat treatment of large steel forgings on the platform finite element analysis software ABQUS, leveraging its preprocessor, solver, postprocessor and its open architecture for researchers to include self-developed user subroutines to define boundary conditions and materials constitutive behaviors.

Coupled temperature-displacement analyses are performed to simultaneously compute temperature, microstructure evolution, material properties, stress and strain in the steel forgings during heat treatment by integrating thermal constitutive model of UMATHT and mechanical constitutive model UMAT of materials. State variables are used to represent components of microstructure, properties, stress and strains, that are computed and updated in every iteration. Generic kinetic models of austenite transformation are included in UMATHT. Computation of thermal strains, elastic strains, plastic strains, transformation strains and transformation plasticity and stresses are included in UMAT. This approach is applied to the quenching and tempering of low pressure rotor forgings of 30Cr2Ni4Mo1V steel. Analyses reveal the transformation plasticity contributes most to the plastic deformation of the forgings and thermal strains also contribute to the plastic deformation of the forging during heat treatment.

Keywords: integrated computational materials, heat treatment, steel forgings

New era in designing and governing cooling intensity of liquid quenchants to decrease distortion

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Abstract: It was proved in last decade that very intensive and uniform cooling decreases significantly distortion of quenched steel parts as compared with their slow cooling in mineral oils. That opened a new era in designing and governing cooling intensity of liquid quenchants to decrease their distortion after quenching. The new approaches were developed by authors to provide accelerated and uniform cooling steel parts during quenching by creation on their surface thin insulating layer. For this purpose low concentration of water polymer solutions of inverse solubility are used as a quenchant. Along with decreasing distortion of steel parts, such approach decreases cost of bath's coolant which less affects environment. It is shown in presentation that accelerated cooling should be interrupted at proper time to decrease more distortion and prevent quench crack formation. To govern process of quenching and make cooling interruption, software IQCalc2 is available.

Keywords: distortion, quenchant

Parallelized particle swarm optimization to estimate the heat transfer coefficients of several vegetable oils and compared to conventional and accelerated petroleum oil quenchants

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Abstract: An inverse solver for the estimation of the temporospacial heat transfer coefficients (HTCs), without using prior information of the thermal boundary conditions, was used for immersion quenching into: cottonseed, peanut, canola, coconut, palm, sunflower, corn and soybean and two commercial petroleum oil quenchants included for comparison. The Particle Swarm Optimization method was used on near-surface temperature-time cooling curve data obtained with the so-called Tensi multi-thermocouple 12.5 mm dia×45 mm Inconel 600 probe. The fitness function to be minimized by a particle swarm optimization (PSO) approach is defined by the deviation of the measured and calculated cooling curves. The PSO algorithm was parallelized and implemented on a Graphics Processing Unit architecture. This paper describes in detail the PSO methodology to compare and differentiate the potential quenching properties attainable with vegetable oils vs an accelerated and conventional petroleum oil quenchant.
Keywords: vegetable oils, quenchant

Investigation of longitudinal quenching crack by finite element simulation

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Abstract: Longitudinal quenching crack is very common in the heat-treatment industry. The quenching crack test of 16 mm diameter 42CrMo bar was investigated by using experiment and finite element simulation. The bar was quenched by water, oil, brine, and water oil two-liquid quenching technology. All of the samples were cracked when quenched in water, but no cracking was found for the bars that were quenched by brine, oil, and water oil two-liquid quenching technology. The quenching stresses of the bars were calculated by using finite element simulation. The residual stress distributions of the through-hardened bars were analyzed. The calculated residual stresses demonstrated that the crack of the water quenched bars was due to the high level of tensile stress at the surface. The high level compressive stress at the surface of the brine quenched bar which is beneficial for avoid of cracking was due to the high thermal stress. Two ways of decreasing the tensile stress at the surface for the through-hardened quenched parts in order to avoid cracking were proposed based on the simulated results of thermal and phase transformation stresses. By analyzing of the stress history of the water quenching bar, the time that the crack occurred was evaluated.
Keywords: longitudinal quenching crack, finite element simulation, quenching, residual stress

"Uphill" quenching of aeronautical aluminum alloys: comparative of influence from mechanical properties for AA7075-T6

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Abstract: This work presents the concept of uphill process applied in heat treatment of aluminum alloys. This process was developed and applied by Alcoa for the first time more than 50 years ago, with the aim to reduce residual stress mainly after quenching, and can be higher than 80% as has been reported. This gain tends to provide an increase in fatigue life during part or component operation at the same time that is waited a good performance related to corrosion resistance. Starting from the principle that quenching is considered the phase of heat treatment with most residual stress formation tendency, uphill process is applied following this phase and before aging. Thus, this process consists to the immersion of the part in cryogenic environment to obtain proper temperature stabilization. So, following, the part is transferred to a hot steam chamber to generate a temperature gradient to maintain the mechanical properties gained with the heat treatment. This results in low residual stress and better dimensional stability. The aim of this paper is to present results related to tensile test behaviour and to compare the results for some quenching media types with uphill process variations.

Keywords: uphill process, quenching, heat treatment, aluminum alloys, tensile test, mechanical properties

Cooling curves characterization of less commonly encountered vegetable oils for quenchant applications

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Abstract: Vegetable oils are of interest as biodegradable, renewable basestocks for quenchant formulation as an alternative to less biodegradable and often toxic petroleum oil based quenchants. To obtain an overview of the quenching performance, the cooling curves properties were determined. The vegetable oils that were studied included: olive oil, flaxseed oil, grapeseed oil, and high oleic canola and safflower oils. The cooling curves were obtained using the Tensi multiple surface thermocouple 15 mm dia × 45 mm cylindrical Inconel 600 probe. For comparison, similar data was obtained with Houghtoquench H100, a conventional petroleum quenchant oil and Houghtoquench HKM, an accelerated petroleum oil quenchant. These data will be compared to results previously obtained for more commonly encountered vegetable oils. The results of this work will be discussed here.

Keywords: vegetable oil, quenchant

Vegetable oil and petroleum oil cooling curve characterization using Matlab to assess cooling and heat transfer properties

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Abstract: There is an ongoing interest to evaluate the potential of renewable basestocks such as vegetable oils to replace petroleum oils as metal quenchants. Perhaps the most critical part of this process is to characterize and compare the cooling and heat transfer performance of potential candidates. In this work, cooling curves of two vegetable oils were obtained along with a conventional and an accelerated commercially available petroleum quenchants were obtained using the so-called Tensi multiple thermocouple probe. Matlab was used to quantify the cooling and heat transfer properties and the results showed a fundamental difference in the cooling properties between the vegetable oils and also between both vegetable oils and the petroleum oils. The focus of this paper will be on the use of Matlab to perform these analyses.

Keywords: vegetable oil, Matlab

Prediction of thermal boundary conditions by using FWA

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Abstract: Inverse Heat Conduction Problems (IHCP) are known as “reverse engineering” problems, due to the reversal of a cause-effect sequence, in the field of heat transfer analysis. An inverse problem means that some of the initial, boundary conditions or material properties are not fully specified as determined from the measured temperature profiles at some specific locations. The inverse problems in most situations are likely to be ill-posed. Solutions of the inverse problem are very sensitive to measurement errors, i.e. small errors in the measured data values can produce very large errors in solutions. In general, the exclusivity and stability of an inverse problem solution is not guaranteed. In recent years, the inverse problems have been studied extensively due to their applications in various engineering disciplines.

In this work, an inverse analysis for the reconstruction of local coordinate and a timevarying Heat Transfer Coefficient, in two-dimensional cylindrical coordinates is investigated. The inverse heat conduction analysis is based on the applications of a Nature-Inspired approaches. Transient temperature measurements at multi-locations in the body of the work piece, obtained by the solution of the direct heat transfer problem, served as the virtual experimental data required to solve the inverse analysis. The fitness function which is defined by the quadratic residual between the measurements and the calculated temperatures is minimized. The Nature-Inspired algorithms have been parallelized and implemented on a GPU architecture. Numerical results are demonstrated that the determination of Heat Transfer Coefficient functions can be performed by using the novel computational method, as well as, the GPU implementation; provide a less time consuming and accurate estimation.

Keywords: IHCP, particle swarm optimisation, quenching

Online database for liquid quenchants

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Abstract: In the last three decades the simulation of the quenching process became a widely accessible engineering tool. One of the most important input for computer models is the adequate heat transfer data of the quenching process. Yet there is no a generally recognized method and technique for measurement, recording and comparison of relative cooling intensities of different quenchants. The database should therefore encompass a range of selected quenchants under specified conditions, data of which could be used worldwide. The whole project is two phase. During Phase 1 the main purpose is to compile the experimental results of participating investigators (institutions or companies) and establish the database, that will be used as input for the following Phase 2. The aim of Phase 2 is further development of numerical models and production of adequate software. The Liquid Quenchant Database is a global project with more the 30 contributors from 14 countries is led by the International Federation for Heat Treatment and Surface Engineering (IFHTSE). The Database of Liquid Quenchants are available on the webpage of the IFHTSE.

Keywords: quenchant, online database, IFHTSE, IHCP

Maintenance of oil quenchants

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Abstract: Oil quenchants are universally used in the heat treatment of ferrous alloys. These quenchants represent a sizable investment for the commercial or in-house heat treater. This paper discusses the proper care and maintenance of quench oils to achieve consistent quenching, and long life. The use of filtration to maintain quenchant quality is discussed. Other methods of monitoring quenchant performance is reviewed.

Keywords: oil quenchants, oxidation, filtration, cooling curve

Distortion in hollow cylinder with thin wall during high pressure gas quenching

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Abstract: A clear understanding needs to be made for distortion in a hollow cylinder parts with thin wall during quenching, especially using high pressure gas quenching, which become more popular in recent heat treatment industry. Hollow cylinder, as well known, is easily happened an unsymmetrical distortion arising from external influence.

This work will discuss such distortion occurred in a large cylinder parts with thin wall via simulation and present a model explaining the changes in size and shape during gas quenching.

Keywords: distortion, cylinder, gas quenching

Holistic problem of cooling effect of vertically oil quenched shaft type work-piece

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Abstract: During the process of vertical oil quenching, the sides of a shaft with the same effective thickness often do not obtain the same quench cooling effect. Therefore, the quench cooling effect of such kind of work-piece can only be described with the distribution of measured values on the whole surface instead of measured values at individual spots. This is the holistic problem of quenching effect of work-pieces of the kind. The holistic problem is caused by two factors: (1) the gas flow within the vapor blanket and (2) the order of the transition of vapor blanket to boiling on the surface of the work-piece. Through experimental observation, analysis and inference, a general model is summarized for the holistic problem of work-pieces with shafts of different lengths in quenching process. By using the general model and the law disclosed by it, a new technique is developed to solve the holistic problem of the work pieces. With the new technique, higher and more uniform quenching hardness can be achieved, the quenching period of the work-piece can be shortened substantially, and steels with lower hardenability can be used to make the workpieces and achieve the same hardening effect. Moreover, oil quenching can replace induction quenching and achieve the same case hardening effect. By comparing the characteristics of the holistic problem and the distortion problem of work piece in quenching, we arrived at two inferences that (1) quenching distortion and the holistic phenomenon have the same driving factors, and that (2) quenching distortion is just one of the detriments caused by the holistic problem. Therefore, the quenching distortion problem of most work-pieces can be solved from the angle of their holistic problems.

Keywords: quenching in oil, quenching of long shafts, uniformity of quenching hardness, quenching distortion, selection of steel for parts, refined quenching technique

Application value and controllability analysis of supercritical CO_2 as a new quenchant

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Abstract: To obtain an ideal quenchant for steal parts has been the main effort of most researchers in the heat treatment technical field all the time. The ideal quenchant should be ecofriendly, inexpensive and by which the ideal cooling curves of steel parts during quenching can be obtained. In recently decades, the utilization technology of supercritical CO_2 (SCO_2)has been developed rapidly in the heat transfer process in nuclear, solar and geothermal power generation, or as a new refrigerant in the refrigeration field. CO_2 is an unreactive, nontoxic, non-inflammable, non-explosive and low price industrial gas. The supercritical state of CO_2 is easier to get than that of most other gases. In the supercritical state, CO_2 has the density close to that of liquid, the viscosity close to that of gas and nearly 100 times the diffusion coefficient of liquid. Recently, we explored the technique to realize ideal controllable cooling process by adjusting the pressure and temperature of CO_2 so as to change its state and cooling performance drastically.

Keywords: quenchant, supercritical

New method for controlled-cooling of high-carbon chromium bearing steels after forging

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Abstract: This paper introduces the formation mechanism of carbide in high-carbon chromium bearing steels, and puts forward the new opinions of controlling the cooling path after forging. The forging blank of bearing is cooled in liquid by using uniform uniform. The purpose is improve the cooling rate after forging. At the same time, it can effectively improve the carbide size and distribution uniformity with appropriate forging process and low temperature spheroidization annealing. After the forging, the microstructure can effectively improve the heat treatment deformation, improve the uniformity of the quenching microstructure and the fatigue property of the products.

Keywords: high-carbon chromium bearing steels, forging controlled cooling, uniform cooling medium, band carbide, net carbide

Impact of the vegetable oil variability on quenching performance

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Abstract: Vegetable oils are of interest for use as basestocks for biodegradable, renewable industrial oils as an alternative to the relatively non-biogradable and often toxic petroleum oi - based quench oils. Although it is well-known that the composition of vegetable oils can be quite variable depending not only on the region and type of growing season but it may even vary with respect to the position in the field where it is grown. However, the vegetable oil quenching work performed thus far would suggest that its quenching performance variation within the normal compositional range would not be expected to be particularly significant. However, recent work with palm oil and canola oil suggests that the quenching performance may vary considerably with the degree of refining and the presence of impurities as yet unidentified. The primary variability is in the presence of significant film boiling behavior. This is important because as a group, vegetable oils don't boil. Therefore they would be expected to exhibit little or no film boiling and therefore would provide superior uniformity of heat transfer throughout the cooling cycle and correspondingly less distortion and cracking. Thus, the presence of any film boiling behavior must be considered deleterious.

The objective of this report was to compare the normal quenching variability of canola oil and palm oil when evaluated in the as-purchased condition.

Keywords: vegetable oil, quenching

Heat transfer coefficients from cooling curves of vegetable oils obtained with the Tensi probe

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Abstract: Vegetable oils are currently used a basestocks for biodegradable, renewable basestocks for quenchant formulation. However, there are relatively few references relating to their true equivalency, or lack thereof, relative to quenching performance of petroleum oil based quenchant formulations. To obtain an overview of the variability vegetable oil quenching performance, the cooling curves and rewetting properties were determined and the heat transfer coefficient profiles were calculated at the Institute of Materials Modification and Modeling School of Materials Science and Engineering in Shanghai, China. The vegetable oils that were studied included: cottonseed, peanut, canola, coconut, palm, sunflower, corn and soybean oils was determined. The cooling curves were obtained using the Tensi multiple surface thermocouple 15 mm dia × 45 mm cylindrical Inconel 600 probe. For comparison, similar data was obtained with Houghtoquench H100, a conventional petroleum quenchant oil and Houghtoquench HKM, an accelerated petroleum oil quenchant. The results of this work will be discussed here.

Keywords: vegetable oil, heat treatment

Numerical simulation of slender rod in high pressure gas quenching process

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Abstract: The quenching uniformity and deformation control of slender rod (up to length-diameter ratio of 25-35) has been a difficult problem in the heat treatment industry for a long time. While using clean heat treatment technology-high pressure gas quenching process to treat such workpiece is a new challenge. It was shown that the deformation of workpiece can be effectively reduced when adopting static alternating flow pattern (upper and lower alternating blow). In this paper, Ansys Fluent software is adopted, combined with vertical vacuum high pressure gas quenching furnace (LZGQ80) and heat treatment process of slender rod, to establish numerical model and simulate the flow/temperature field in high pressure gas quenching process of slender rod. As a result, the gas reversing time in different quenching condition is obtained.

Keywords: slender rod, high pressure gas quenching, static alternating flow pattern, numerical simulation

Numerical simulation research and experimental verification of continuous quenching process of high precision rack bar

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Abstract: Using the DEFORM analysis software, combined with the heat transfer coefficient of quenching obtained from the experimental data, a three-dimensional model of the continuous quenching of the bar has been established. In the process of spray-quenching of bar, it is affected by factors such as roller speed, spray quenching water pressure and others. In this paper, simulations of control variables are performed. The simulation results show that: 1) The speed of roller movement and the pressure change of quenching all can play a role in adjusting the quenching effect of bar, but the adjustment effect of moving speed is more significant; 2) For the final microstructure of the martensite, it is recommended to set the combination of less moving speed and large quenching water pressure, in which the line speed plays a major control role; however, if the final quenched structure is the bainite , it is recommended to use a higher moving speed and a smaller spray quenching water pressure, both of which can play an important control role. Based on the simulation results, two sets of processes were selected to conduct experiments. By observing the microstructure of the outer surface, 1/4D and the core of the bar section, the simulation was verified .It's effective and instructive.

Keywords: rack material, DEFORM software, quenching process parameters

Effect of quench methods on distortion, microstructure and mechanical properties of selected laser melted 316L stainless steel thinwall part

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Abstract: In order to avoid serious distortion as well as keep the better mechanical properties of 316L stainless steel thin-wall part fabricated by select laser melting (SLM), effect of cooling rates on distortion, microstructure and mechanical properties was investigated. Four cooling rates caused by quenching in water, oil, high-pressure gas and air mediums were experimental studied. The results demonstrate that distortion of thin-wall part reduces significantly with decreasing the cooling rate. The maximal and minimal distortion occurs during quenching in water and air, respectively. Meanwhile, the strength reduces but ductility increases slightly with decreasing the cooling rate. With the integrated consideration of distortion and mechanical properties, the optimal quenching method was air cooling after solution treatment process, the yield, ultimate strength and elongation to failure are 567±7 MPa, 362±13 MPa and 46±1%, respectively, which fully meet the geometrical and mechanical requirements of aerospace product.

Keywords: quench methods, distortion, select laser melting, 316L stainless steel, thin-wall part

The wetting process during quenching and its experimental assessment

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Abstract: The wetting behavior during quenching process strongly influences the cooling efficiency and therefore the achievable hardness. The wetting kinematics is influenced by a lot of factors and some of them cannot be quantified even today. It is quite difficult for the experimental assessment or computer simulation of the wetting process, since the none-steady conditions. In this brief review, some common factors that may greatly influence the wetting process are listed, and some experimental methods used to study the wetting process are also mentioned.

Keywords: wetting process, Leiden frost temperature, quench fluid

Numerical simulation study of abnormal-shaped aluminum wheel quenching

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Abstract: To ensure that aluminum wheels less deformation and uniform performance while quenching, finite element software was used to simulate the quenching process of aluminum wheel, and designed three kinds of cooling simulation experiments: 1) the wheel was cooled into the water directly; 2) a group of the sprinker was added below the quench tank when the wheel was cooling; 3) two groups of the sprinkers were added above and below the quench tank respectively when the wheel was cooling. Several speed clouds of three kinds of quenching mode were obtained,among them, the fluid flow rate was low and bubbles exist by using the first cooling way, the wheel into the water directly; when adding the sprinkler below, the cooling water circulation below the wheel was better while the top was relatively poor; cooling water circulation was all better by adding the above and the below sprinklers. The result show that the cooling effect of the water can be enhanced if the above and the below water sprinklers were added during the cooling, moreover, the quenching effect also can be boosted.

Keywords: aluminum wheel, quenching, finite element simulation, velocity field