# 2018 25th Congress of International Federation for Heat Treatment and Surface Engineering

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11-14 September 2018 | Xi`an China

# PROCEEDINGS

CHTS

Organized by Chinese Heat Treatment Society（CHTS）

# 25th IFHTSE CONGRESS PROCEEDINGS

11-14 September 2018

Xi'an China

Chinese Heat Treatment Society

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# Microstructure and corrosion resistance of Ni-based alloy coated onto gray cast iron using a multi-step induction cladding process

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**Abstract:** Ni-based alloy coatings were fabricated on HT 300 cast iron substrates using a multi-step induction cladding technique. Scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS) and X-ray diffraction (XRD) were employed to analyze the microstructure, elemental distribution and phase composition of the coating. The results indicated that the coatings were metallurgically bonded to the substrate and there were no visible defects and cracks at the interface, resulting in failure of the coating. The part closest to the substrate was rich in γ-Ni solid solution, while the intermediate and top parts consisted of boride-, carbide- and Ni-based solid solution. Potentiodynamic anodic polarization tests and immersion corrosion tests were carried out to investigate the corrosion properties of the coating. The passive anodic current density of the coating was 37.42 $\mu m \cdot cm^{-2}$, which was one order of magnitude lower than that of the substrate. The electrochemical corrosion mechanism of the coating showed the selective corrosion and pitting. Immersion corrosion tests in a 60% $H_2SO_4$ solution at 150 ℃ revealed that the corrosion rate of the coating was steadier and lower than that of the substrate. The formation and dissolution of the corrosion products determined the corrosion resistance of the coating. Therefore, it can be concluded that Ni-based alloy coatings fabricated on the HT 300 substrates considerably enhanced corrosion resistance under both anodic polarization in a 3.5% NaCl solution and immersion corrosion conditions in a 60% $H_2SO_4$ solution at 150 ℃.

**Keywords:** gray cast iron, induction cladding, corrosion behavior, Ni-based alloy coating

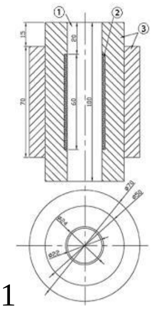
Fig.1

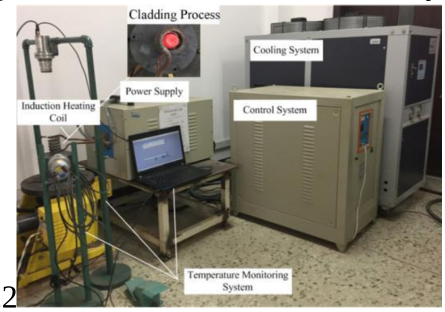

Fig.2

Fig.1 Schematic illustration of the coating deposition mould: ① substrate, ② Ni-based alloy powder mixed with a supersaturated solution of sodium silicate and ③ 3D printed mould

Fig.2 Photograph of the experimental device with the parts labeled

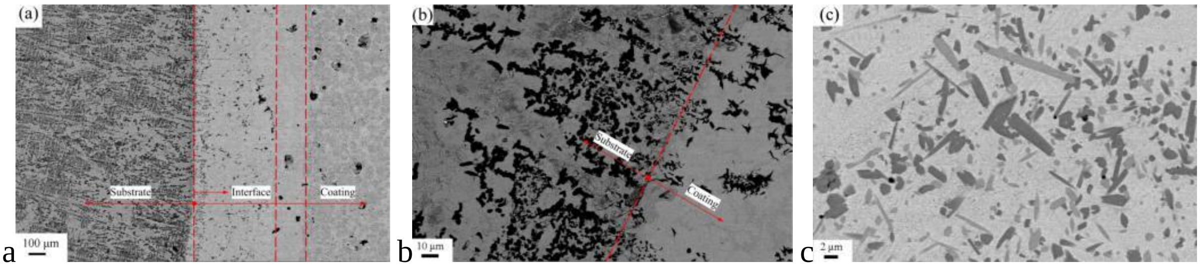


Fig.3 SEM micrographs of the substrate coated with Ni-based alloy coatings: (a) cross-section of the coating; (b) interface between the coating and substrate; (c) intermediate coating

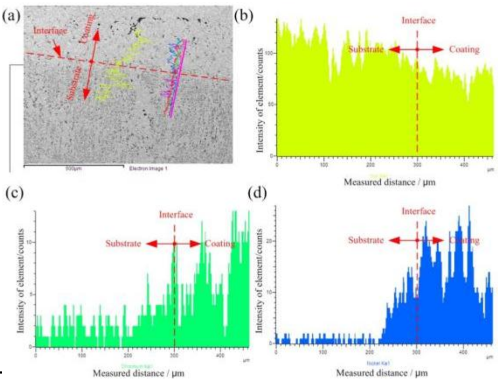


Fig.4

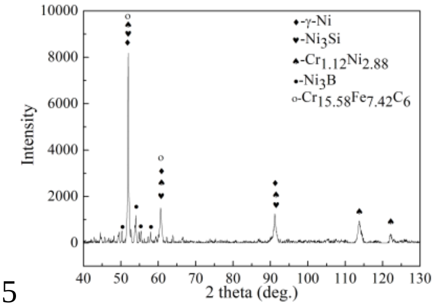


Fig.5

Fig.4 Elemental distribution at the interface (a) SEM image showing the location of EDS line scan distribution of (b) iron, (c) chromium, and (d) nickel

Fig.5 X-ray diffraction spectrum of the coating

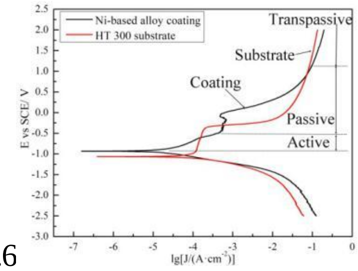


Fig.6

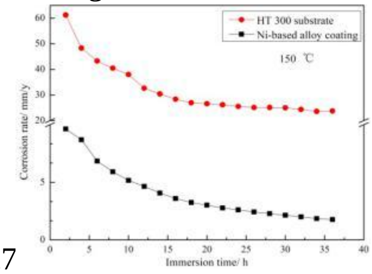


Fig.7

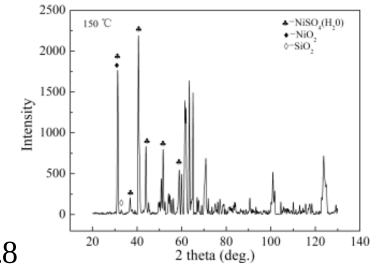


Fig.8

Fig.6 Polarization curves of the induction cladding coating and HT 300 substrate

Fig.7 Corrosion rate as a function of immersion time of the coating and substrate in 60% $H_2SO_4$ solution at 150 ℃

Fig.8 The XRD diffraction pattern of the Ni-based alloy coatings immersed in a 60% $H_2SO_4$ solution at 150 ℃ for 36 h (phases in the coating before immersion test are omitted, and only the corrosion productions are marked)

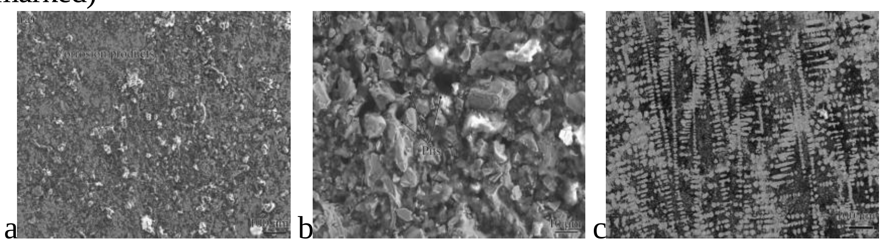


Fig.9 Surface morphology of (a) the coating, (b) the magnification of (a), and (c) the substrate after anodic polarization tests

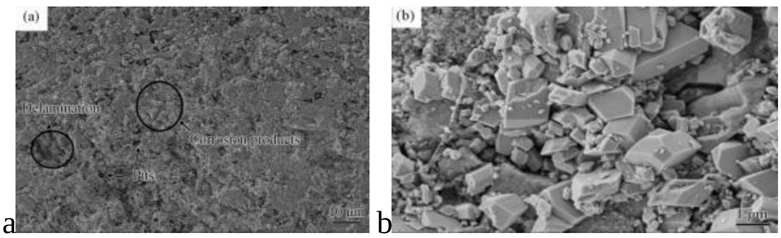


Fig.10 The corroded surface morphology of the Ni-based alloy coating immersed in a 60% $H_2SO_4$ solution at 150 ℃ for 36 h (a) and the magnification of (b)

# Effects of the induction heat treatment on microstructure and properties of hot rolled stainless steel clad plate

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**Abstract:** The stainless steel clad plates can make full use of the superior properties of the two metals, the corrosion resistance of stainless steel and the mechanical properties of carbon steel, which are widely used in many fields, such as petrochemical projects, oceanographic engineering, marine engineering and so on. Excellent bonding performance at the interface is an important guarantee for the quality of stainless steel clad plates, including bonding strength, interface cleanliness, interface diffusion control, and so on. In order to meet the comprehensive performance of the hot rolled stainless steel clad plates, the heat treatment should be carried out in the follow up, normalizing and tempering are generally adopted. On the one hand, this treatment ensures the solid solution effect of the stainless steel layer to satisfy its corrosion resistance. On the other hand, the mechanical properties of carbon steel can be improved by tempering. However, the heat-treatment is affected by the difference of two kinds of material properties and the diffusion of elements in the interface, the process is difficult to achieve a better match. For this reason, the single side induction heat treatment method was adopted to satisfy the solid solution effect of the stainless steel layer, and the mechanical properties of the low alloy steel layer were improved by subsequent tempering treatment. The optimum induction heat treatment process of stainless steel clad plate was studied and compared with the properties of hotrolled stainless steel clad plate in this paper. From the main results, it was found that when the moving speed of the induction coil was 90 mm/min and the distance was 3-5 mm, the solid solution effect of the stainless steel layer was good. There were almost no the third and second kinds of corrosion structures in the stainless steel layer at the interface. At the same time, except for the surface melting phenomenon in some locations, most of the stainless steel surface by heat treatment was in a good condition. Compared with the properties of hot rolled stainless steel clad plate, the interfacial bonding performance of the stainless steel clad plate after induction heat treatment and 450 ℃×2 h tempering treatment was not obviously changed, and the intergranular corrosion property of the stainless steel layer was not deteriorated, but the hardness of the carbon steel layer near the interface was reduced to a certain extent. Through this experimental study, it was found that induction heat-treatment can effectively improve the comprehensive properties of stainless steel clad plate. On the basis of previous researches, the influence of induction coil moving speed on the comprehensive properties of stainless steel clad plate was studied emphatically in this paper. In fact, there are many factors affecting the induction heat treatment of the stainless steel clad plate. Among them, the best combination of various parameters, such as the moving speed of the induction coil, the heating frequency of the coil, the heating power, the distance between the heated surface and the coil, is the direction of the future research. Induction heat treatment is a new process which opens up a new method for obtaining high quality properties for hot-rolled stainless steel clad plates.

**Keywords:** induction heat treatment, hot rolled stainless steel clad plate, corrosion resistance, microstructures, mechanical properties

**Table 1 Chemical composition of stainless steel clad plate**

| Material | C | Si | Mn | P | S | Cr | Ni | Al | Fe |
|---|---|---|---|---|---|---|---|---|---|
| Low alloy steel | 0.12-0.18 | 0.4-1.0 | 1.0-1.5 | <0.01 | <0.01 | — | — | 0.028 | Bal. |
| Stainless steel | 0.05-0.08 | 0.5-1.0 | 1.1-1.3 | <0.01 | <0.01 | 17.00 | 8.05 | <0.01 | Bal. |

**Table 2 Shear strength of three heat treated states**

| Heat treatment state | Shear strength/MPa |
|---|---|
| Hot-rolled | 423 |
| Induction heat-treatment | 415 |
| Induction heat-treatment and tempering | 410 |

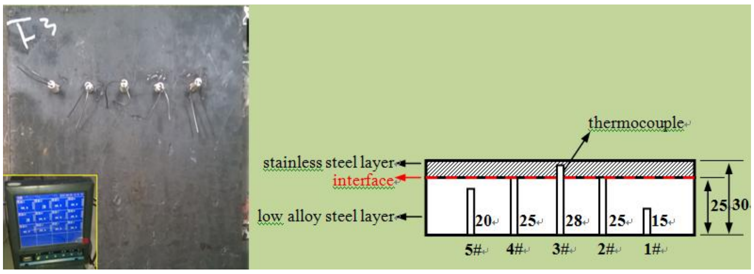



Fig.1 Thermocouple temperature measurement

Fig.2



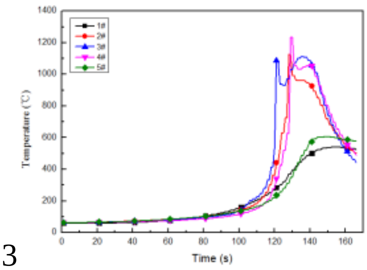
Fig.3


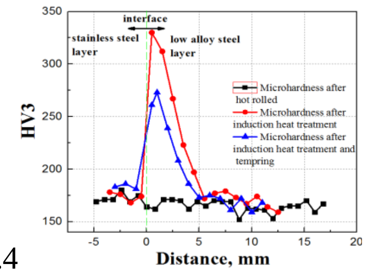

Fig.4



Fig.2 Induction heat treatment of hot-rolled stainless steel clad plate

Fig.3 Thermocouple temperature measurement datas of 5 places

Fig.4 Comparison of microhardness of hot rolled and induction heat-treatment of stainless steel clad plate

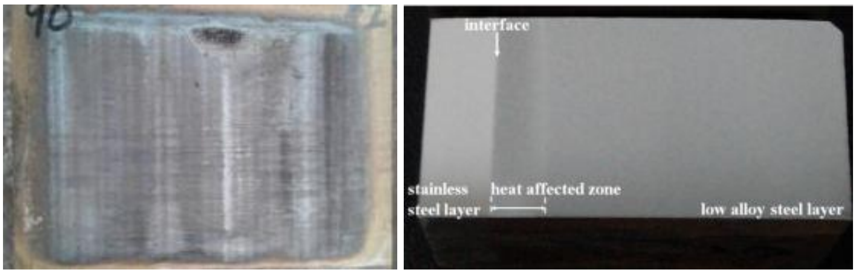



Fig.5 Surface morphology of stainless steel layer and heat affected zone of carbon steel layer after induction heat treatment

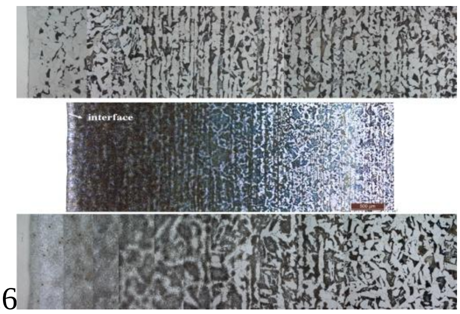
Fig.6


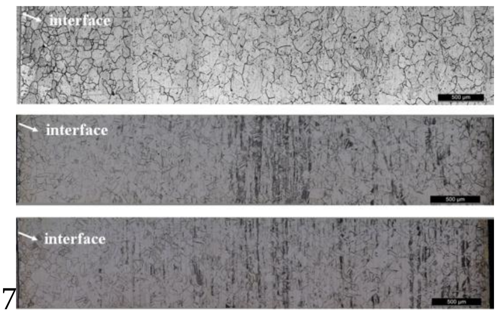

Fig.7



Fig.6 Microstructure of low alloy steel layer: (a) hot-rolled; (b) induction heat-treatment; (c) induction heat-treatment and tempering

Fig.7 Electrochemical corrosion morphology of oxalic acid in stainless steel layer (a) hot-rolled; (b) induction heat-treatment; (c) induction heat-treatment and tempering

# Synchronized vacuum heat treatment for fully integrated manufacturing lines and small batch treatment

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**Abstract:** For decades the automotive- and aerospace- industry have addressed the challenge to produce high performance components in a cost-efficient manner.

To meet quality specifications the components must be heat treated, which traditionally takes place in a centralized hardening shop. This physical separation between machining and heat treatment results in high costs for transportation and logistics within the production facility. Hence heat treat integration with the traditional manufacturing has long been a goal of manufacturing engineers.

Within the last 20 years, the introduction of low pressure carburizing (LPC) and high pressure gas quenching (HPGQ) has created the opportunity to integrate heat treat operations with machining. The components are collected after soft-machining into big batches consisting of multiple layers (“3D-batch”) and treated with LPC- and HPGQ-technology. This means that the heat treatment can be integrated into the manufacturing area. But it is not synchronized with soft and hard machining since the components must be collected in buffers before heat treatment and must be singularized again after heat treatment. For fully integrated and synchronized heat treatment into the manufacturing (machining) line, a new generation of heat treatment equipment was introduced. This vacuum furnace design allows the treatment of small batches in a single layer of parts (“2D-treatment”) which allows for easy automated loading and unloading of the fixture-trays. By using the small batch concept, a continuous flow of parts can be established (“One Piece Flow”). There is no need to wait until enough parts are collected to build a large batch with multiple layers. This compact furnace unit can be implemented into the heart of the production chain. Following the philosophy of “One Piece Flow”, the parts are: 1) taken one by one from the soft machining unit; 2) heat treated in time with the cycle-time of soft machining (“Synchronized heat treatment”) and then 3) passed down one by one to the hard machining unit.

To allow for a rapid case hardening, the components are low pressure carburized at high temperatures followed by gas quenching.

In addition to the cost-savings gained from improved logistics the new concept in equipment offers the following advantages: 1) individual processes customized for each gear-component; 2) homogenous and quick heating of the components and therefore low spread of distortion; 3) homogenous and controllable gas quenching and therefore low spread of distortion; 4) homogenous carburizing for low spread in case hardening depth (CHD); 5)environmentally friendly carburizing and quenching and 6) compact and space-saving heat treat unit.

In parallel this new concept has been introduced for commercial heat treaters. Commercial heat treaters do not establish an integration of production, but they use such systems for “small batch treatment”. A “small batch treatment” guarantees fast turnaround-times and the quality-benefits as described above such as improved control of distortion. The paper introduces the furnace-concept and the development of the process technology. Practical examples illustrate new industrial applications from the automotive-, aerospace- and the tool-industry for both integrated heat treatment and for commercial heat treatment.

**Keywords:** LPC, integration

# Effects of pulse current on tensile deformation behavior of pure titanium

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**Abstract:** The decreasing of deforming resistance resulted by the pulse current is called electroplastic effect or EPE which reveals an approach for improving plasticity of a material. However, the detailed mechanism pertaining to EPE is still under debate. Titanium alloys have been extensively applied in aerospace and biomedical industries due to their unique properties of high strength-to-weight ratio, ideal corrosion resistance and low density. But as typical hcp metals the lack of slip systems causes the difficulty in forming. Therefore, effects of pulse current on tensile deformation behavior of pure titanium were investigated in the present study.

The testing consisted of two parts: one test was began with the pulse current off and then the pulse current with various parameters was introduced at different deforming stages. And the other one, the pulse current was applied at the beginning of the deformation and then withdrew after different extents of deformation to observe the recovery effect.

The density was set to be 2-4 kA/mm$^2$, the frequency was 10-40 Hz and the duration 30 μm of pulse. Tensile tests were carried out at 300 ℃ and the Joule heat effect was eliminated by temperature compensation method using MTS testing system. The fracture surface and microstructure were observed using scanning electron microscopy (SEM) and transmission electron microscope (TEM) respectively.

The results show that the deforming resistance of pure titanium is decreased and the formability is improved after pulse current treatment. The influence degree is related to introducing stages and parameters of EPC, as shown in Fig. 1. When frequency is low (10 Hz), the decreasing of the stress by EPC at different deforming stages is consistent while at high frequency there are clear distinctions in stress-strain curves of specimens applied EPC at different deforming stages. Energy dissipation occurs between two electrical pulses and the contribution of current density to energy accumulation is far greater than that of frequency. But when frequency is low, the time interval of pulse action is so large that the total impact force is weakened severely. The stress recovers immediately to the level of specimens without EPC. After applying EPC, the specimens tend to intergranular fracture compared to specimens without EPC. Owing to the promotion of EPC to dislocations move, dislocation accumulation near the grain boundary results in stress concentration which decreases the elongation of specimens. EPC can also promote the recrystallization of pure titanium. The Joule heat effect and the electric energy of EPC provide temperature and energy conditions for the recrystallization at low temperature.

The following conclusions are obtained: 1) EPC reduces the deforming resistance of pure titanium and improves the formability; 2) EPC frequency and density contribute to the total energy differently. The latter is more efficient but affected by frequency; 3) EPC promotes the recrystallization of pure titanium.

**Keywords:** titanium, pulse current, electroplastic

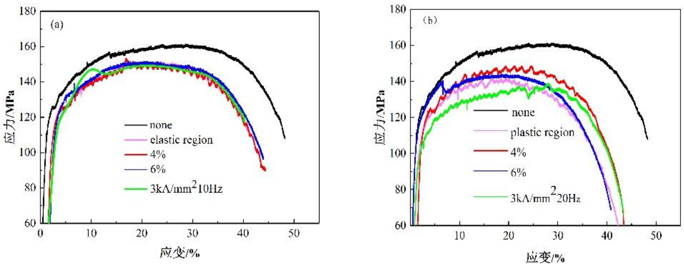


Fig.1 Stress-strain curves of tensile tests for TA1 pure titanium under pulse current with different parameters: (a)3 kA/mm$^2$, 10 Hz; (b)3 kA/mm$^2$, 20 Hz

# Precipitation behaviour of μ phase in new type Co-base superalloys

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**Abstract:** $D_{85}$-μ phase is easy to form in the Co-base superalloys with high contents of W or Mo. The formation of μ phase will lead to the depletion of solid solution strengthening elements in the matrix. And strip-like μ phase can reduce the creep lifetime of the alloys. Therefore, μ phase controlling is important for Co-base alloys. The purpose of this paper is to study the precipitation behaviour of μ phase, in order to provide a fundamental for developing new Co-base alloy.

The microstructures of the testing alloys after different heat treatments were analysed by OM, CLSM, SEM with BSE and TEM. The phase transformation temperature was determined by DSC. The quantitative analysis of phases was examined by Image-J method.

As-cast alloy contains γ, γ′, island-like μ and β phases. When heat treated at 1160 ℃, lath-like μ phases nucleate both in the interdendritic region and dendritic region in the superalloys. At 1160 ℃, γ′ phases dissolves, which leads to the higher amount of W and Ta dissolves in the γ matrix. Moreover, primary μ phases can also dissolve at 1160 ℃, which causes the secondary μ phase nucleation, although the dissolution of Al and Ti from β phase may hinder this transformation. Moreover, when the superalloys are heat treated at 900 and 1000 ℃, secondary μ phase also precipitates, which shows similar precipitation behaviour to that of 1160 ℃ treatment.

Selected-area diffraction pattern of μ phase is obtained. There are two diffraction patterns with obverse and reverse. The twin plane is parallel to (001) with [110] diffraction zone axis, which is similar to the twinning feature of μ phase in Ni-base superalloys. It is found that μ phase in Co-base superalloys also shows some orientation relationships with the matrix. And the lath-shape precipitates indicate the semi-coherent relationship between μ phase and γ+γ′ matrix. The nucleation of μ phase is based on both μ phase {0001} and the matrix {111} planes. It has been reported that μ phase can be described as an intergrowth of $Zr_4Al_3$ and $MgCu_2$ sheets. The distribution of the atoms in (111) plane is similar to the atoms in $MgCu_2$ sheet. And W atom sites in $Zr_4Al_3$ sheet are similar to the atom sites in (111) plane. That is, the amount of W atom in (111) plane is the main factor of μ phase nucleation. According to the early studies, Mo, Ta and Cr in γ′ phase prefer W site. This increases the amount of W, Mo, Ta and Cr in {111} planes, which promotes the nucleation of μ phase. Therefore, the higher total content of W, Mo and Ta in the superalloys as well as adding of μ phase stabilizing element Cr are the main reasons that cause the precipitation. Island-like μ phase is contained in the as-cast superalloys. When heat treated at 1160 ℃, the primary μ phase and γ′ phase dissolve in the matrix, which causes the precipitation of secondary μ phase with lath-shape. And massive random sub-unit cell-twins can be detected in μ phase. μ phase nucleates based on both μ phase {0001} and the matrix {111}.

**Keywords:** Co-base superalloys, μ phase

# Quenching behaviour of a high wear resistant Cr-rich cast alloy

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**Abstract:** Steels with 12% chromium and high carbon contents in the range of 2% are used in many applications such as tools were wear resistance plays an important role. These alloys have a partially ledeburitic microstructure as well as secondary carbides in a metallic matrix and are usually heat treated by quenching and tempering. The microstructure of the matrix after quenching consists of martensite and/or bainite as well as of larger amounts of retained austenite. Especially for large dimensions, quenching rates are limited, resulting in a continuous reaction between the then austenitic matrix and the precipitated carbides during the quenching process. The effect of these reactions on the phase transformation and corresponding hardness will be presented.

The investigation program included the establishment of a CCT-diagram and additional cooling procedure including isothermal holding with two different subsequent quenching rates as well as interrupted quenching by dilatometric test. Besides the evaluation of the dilatometer curves, the microstructure was investigated after polishing and different etching procedures by light optical microscopy (LOM), scanning electron microscopy (SEM) and X-ray diffraction (XRD). Additional hardness tests according to Vickers (HV10) were also conducted.

Different cooling procedures result in different grades of exchange reactions between the matrix and the ledeburitic as well as secondary carbides. Rapid quenching can prevent these exchange reaction between the matrix and the carbides during cooling and the phase transformation is fully martensitic. At lower cooling rate the microstructure changes towards equilibrium conditions at reduced temperatures, which typically consists of a higher carbide content. Thereby the alloy content, especially the carbon content, of the matrix is significantly reduced. A first visible effect of this reaction is an increase in the *M*s-temperature. This reaction is superimposed with a bainite formation at low cooling rates and is than difficult to differentiate. The effect of the carbon depletion on the *M*s-temperature can also be seen in interrupted quenching modes; thereby the bainite formation can be avoided. Initial rapid quenching with isothermal holding above the *M*s-temperature permits the determination of the transformation behaviour when the carbon depletion is avoided. Slow cooling rates also have a major effect on the retained austenite content, which is significantly reduced. Also the hardness depends on the cooling rate. In conjunction with the bainite formation the hardness drops from around 800 HV to roughly 500 HV. In contrast, cooling procedures with initial rapid quenching and long isothermal holing above the *M*s-temperature had little effect, both on the retained austenite content as well as on the hardness, independent whether this treatment was finished with rapid or slow cooling to room temperature. Microstructural investigations proved to be difficult regarding the differentiation of self-tempered martensite and bainite after Nital etching. Additional etching with Fry A provide better indication for the bainite formation.

**Keywords:** cast alloy, microstructure, dilatometry, transformation behavior

# Effects of fiber coating on interfacial reaction and mechanical properties of $SiC_f$/Ti composites

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**Abstract:** SiC fiber-reinforced titanium matrix ($SiC_f$/Ti) composites have high specific strength, high specific stiffness, and high fatigue and creep resistance, thus can be used in the aeroengine fields. However, There exists fiber/matrix interfacial reaction during fabrication process of the composites and during the high temperature service, and there exist high thermal residual stresses in the composites due to the high mismatch of thermal expansion coefficients among fiber, matrix and interfacial reaction layer. Severe interfacial reaction as well as high thermal residual stresses would greatly decrease mechanical properties of the composites. In order to retard the interfacial reaction and improve the interfacial compatibility, our group has studied the effects of some fiber coating systems on the interface and mechanical properties of $SiC_f$/Ti composites. For example, we have studied the Cu/Mo duplex coating, Mo coating and C/Mo duplex coating on the interface and mechanical properties of $SiC_f$/Ti6Al4V, $SiC_f$/γ-TiAl and $SiC_f$/Ti2AlNb composites.

The studies of SiC/Mo/Ti6Al4V and SiC/Cu/Mo/Ti6Al4V composites show that both Mo coating and Cu/Mo coating can retard the direct interfacial reaction between SiC fiber and Ti6Al4V at some extent, and the damage of SiC fiber can be avoided to a certain extent. However, as for the Cu/Mo duplex coating, Mo coating can not prevent the diffusion of Cu coating, thus a mixture of $Ti_2Cu$ and α-Ti (similar to Widmanstatten structure) were formed around fibers, which reduced the toughness of the matrix around fibers. This result shows that Cu/Mo duplex coating is not ideal, while the Mo single coating is comparatively better. Based on above investigations, we proposed to use C/Mo duplex coating to modify $SiC_f$/Ti composites. The studies of C/Mo duplex coating on $SiC_f$/Ti6Al4V composite show that, C/Mo duplex coating can further retard interfacial reaction in comparison with C single coating. Mo coating enables the surrounding matrix to transform into β-Ti. C/Mo duplex coating has excellent thermal stability below 700 ℃. However, when thermal exposure temperature is above 800 ℃, the exhaustion rate of C/Mo duplex coating become fast, and the exhaustion rate of Mo coating is faster than that of C coating, thus the mechanical properties of the composites decreased.

In addition, through the studies of C/Mo duplex coating with different thickness ratio, it is found that different thickness of Mo coating would produce different interfacial phase sequence, and corresponding heat treatment would make the microstructure evolution of the interfacial micro-region different, which makes the mechanical properties of composite different significantly. For example, when the thickness of the Mo coating was 1.2 μm, the mechanical properties of the composites decreased with the increase of the vacuum thermal exposure extent. However, when the thickness of Mo coating was 0.8 μm, the fatigue life of the composite increased with the prolongation of vacuum thermal exposure at 750 ℃. This indicates that the composite has unique mechanical properties, which has very attractive application prospects in the aero-engine field. Moreover, the studies of C/Mo duplex coating interfacial-modified $SiC_f$/γ-TiAl and $SiC_f$/Ti2AlNb composites show that C/Mo duplex coating can significantly reduce the interfacial reaction, and the coating system has excellent thermal stability below 900 ℃. Mo coating is difficult to diffuse into the matrix nearby. Therefore, the C/Mo duplex coating also has attractive application prospects in the interfacial modification of SiC fiberreinforced TiAl intermetallic-matrix composites.

**Keywords:** titanium matrix composites, SiC fiber, interfacial modification, interfacial reaction, thermal stability, thermal exposure

# The oxidation behaviour of NiCrAlYSi coatings at 1100 ℃ by arc ion plating

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**Abstract:** Generally, the blades and other hot gas path components in aircraft and power-generation turbine engines are made of Ni- and Co-based superalloys. Those components serve in high temperature of 1050 ℃ and usually protect by MCrAlY based coatings. With the rapid development of the aviation industry, the blades are expected to use above 1050 ℃. Therefore, a proficient coating with improved properties at a higher temperature will be required and more attractive for in-service engine components. Si, Ta, Hf or other active element in MCrAlY coatings are believed to significantly improve the coating's high temperature oxidation resistance. However the oxidation behavior in higher temperature compared with traditional NiCrAlY coating was less discussed.

In this study, NiCrAlYSi coatings are prepared on nickel-base superalloy DZ22B substrate by arc ion plating technology. After the vacuum heat treatment, the samples were oxidized at 1100 ℃ for 200 h. The microstructure of the coating and oxide scale as well as their relationship with the oxidation properties were investigated. The results show that NiCrAlYSi coatings experience a gentle oxidation process compared to NiCrAlY coatings at 1100 ℃. The NiCrAlYSi coating forms a very uniform and dense α-$Al_2O_3$ protective layer in the early stage of oxidation, which prevents further diffusion of oxygen in coatings. By contrast, NiCrAlY coating forms a large amount of loose $NiCr_2O_4$ in the early stage of oxidation, resulting in a severe scale peeling. The formation of dense α-$Al_2O_3$ scale was promoted by Si in coatings which can enhance the adhesion of the oxide layer and retard the consumption rate of Al. As a result, NiCrAlYSi coating delivers good high-temperature oxidation resistance at 1100 ℃.

**Keywords:** blades, NiCrAlYSi coatings, arc ion plating, high temperature oxidation behavior

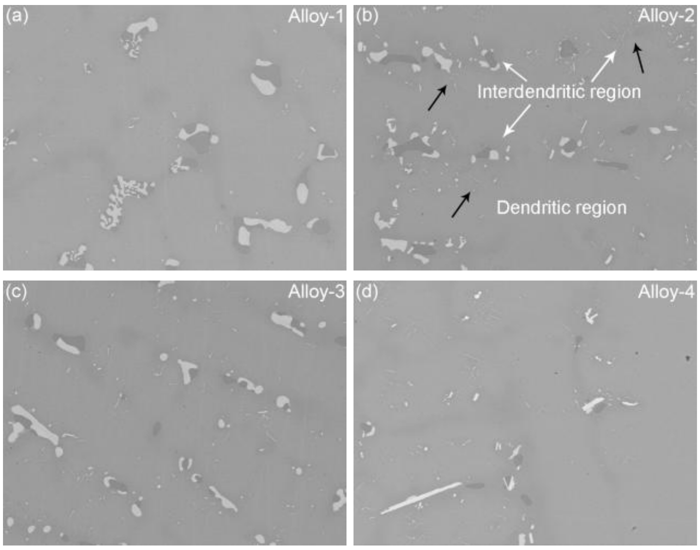


Fig.1 BSE micrographs of the superalloys after heat treatments at 1160 ℃ for 0.5 h (a-d). (The black arrows show the secondary μ phases)

# Microstructural evolution and mechanical properties of Ti-6Mo-5V-3Al-2Fe alloy aged at various temperatures

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**Abstract:** Due to their high specific strength, good match between strength and plasticity, β-titanium alloy is one of the most ideal candidates for load-bearing structural members that aim to reduce weight and take into account strength. It has become an important development direction of high strength and light metal structure materials used in aerospace. For a newly designed β-titanium alloy, the relationship between microstructure and mechanical properties during aging heat treatment is not clear and need to study further. In this paper, a high-strength β-titanium alloy, Ti-6Mo-5V-3Al-2Fe(wt%), that was designed based on molybdenum equivalent and d-electron theory was investigated. Using vacuum consumable electrode smelting technology, the ingot is obtained by secondary smelting. The transformation point of the alloy is 810 ℃ through calculation and differential thermal analysis. Before aging heat treatment, the solution heat treatment at β field was performance at 850 ℃ for 0.5 h followed by water cooling. The temperature of solution treatment was determined according to the transformation point. In order to study the effect of aging temperatures on microstructure and mechanical properties, various aging temperatures was selected in the range of 400-600 ℃. The aging time is 8 h for all. The effect of aging temperature on the microstructure and tensile properties of the hot-rolled alloy was studied by optical microscope, SEM, TEM and tensile tester. The microstructure of the alloy after solution heat treatment is mainly consisted by equiaxed β grains and a small part of primary α phase. The solution state alloy has tensile strength $R_m$ = 939.5 MPa, a yield strength $R_{p0.2}$ = 856.7 MPa and elongation $A$ = 12.0%. The fracture morphology of the alloy delivers a large number of equiaxed dimples, attributing to the microporous polymeric ductile fracture. After aging treatment with different temperatures, secondary α phases possess different amounts and shapes. In general, the precipitation of secondary phase has significant strengthening effect on the alloy. The ω phase has formed when aged at 400 ℃. The strength of the alloy has little changed while elongation has decreased in this aging temperature. The strength of the alloy was improved significantly due to precipitation of fine secondary α phase when aged at 500 ℃. As the increase of aging temperature, secondary  phase gradually grew up and the strength of alloy decreased. The aging temperature has a great influence on the tensile properties of the alloy, which exhibits excellent strength at aging temperature of 500 ℃ and good plasticity at 600 ℃. When the aging temperature is 500 ℃, the optimal match of strength and ductility of the alloy is obtained, which the tensile strength is 1426.52 MPa, yield strength is 1311.34 MPa and elongation is 8.0%.

**Keywords:** β-titanium alloy, hot rolling, heat treatment, microstructure, mechanical property

# Weight-efficient powertrain components—steel grades, heat treatments and performance

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**Abstract:** Powertrains comprise heavy components and thus contribute significant weight to hand-held power tools as well as heavy vehicles. Weight-efficient powertrains require increased component performance; for instance, a 40% strength increase of a torsion loaded shaft allows for 20% weight reduction. On the other hand, for powertrain development, a performance increase can also be used to increase torque while maintaining component size and weight. In order to manufacture these weight-efficient powertrain components, a holistic approach should be used. That is to say, all steel grades, heat treatments and post processes should be considered in the concept stage of a development project.

Weight-efficient powertrain components imply increased performance per weight. Apart from extended transmission lifetime, the result can be realized, for example, as an increase of load-carrying capacity for trucks or weight reduction of hand-held machines. Another benefit can be faster product development, since there is no need for geometrical redesigns, if component size is maintained while increasing performance.

The purpose of this study is to assess performance and how it relates to steel grade and processing. However, this work was planned as a screening study and therefore makes no claim to have reached optimum performance for any given combination.

In this study we survey a wide range of steel grades - from common case hardening steel 20NiCrMoS2-2 to special grades such as Ferrium C64. For each steel grade one or more heat treatments and post processing methods are applied and evaluated. Processing includes case carburizing, induction hardening and nitriding, in some case combined with either shot peening or PVD-coating. Carburizing was preferably done using low-pressure carburizing to avoid internal oxidation.

Processed parts were characterized in terms of microstructure, hardness, residual stresses and retained austenite. Performance was assessed through fatigue testing, which is a vital property for transmission applications. The fatigue testing included both rotating-bending and tooth-bending fatigue testing as well as contact fatigue with FZG and a two roller contact setup. A challenge was to account for surface roughness, since it affects contact fatigue performance and vary with steel grade and heat treatment.

Project members include steel producers, equipment manufacturers, suppliers, sub-contractors and OEMs of hand-held power tools and heavy vehicles. For the result to be applicable to these two product families, testing was done on both small- and large gear wheels with gear module 0.6 and 3.7, respectively. Apart from performance requirements, assessment should also include estimates for production cost and environmental impact. For this reason, the performance results are discussed in relation to weight-savings potential, cost and sustainability. The results show that at least 40% increase in performance is achieved for a number of our surveyed material-process combinations, when compared to conventional manufacturing with case-carburizing steel.

It can be concluded that more weight-efficient powertrain components can be produced by tailoring steel grade, heat treatment and post treatment. Then again, there are many aspects to account for and thus every company needs to make their own considerations and assessments. Accordingly, we aim to assemble a database from which all project members can benefit by facilitating material- and heat treatment selection.

**Keywords:** heat treatment, fatigue testing, powertrain components

# Techniques to improve the performance of Hadfield steel frogs

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**Abstract:** Railway transport is a main travel method for passengers and cargoes nowadays. Highspeed and heavy-load are the developing directions for this transport method. Railway frogs, the role of which is to change the running direction of trains, are mostly made from Hadfield steel (Fe-13%Mn-1.2%C). The service safety of these Hadfield steel frogs is significantly important. Therefore, several techniques i.e., alloying treatment, local thermomechanical control process and surface hardening process were designed to improve the steady-service ability of Hadfield steel frogs. Results showed that the purity and crystalline structure of the Hadfield steel alloyed with nitrogen, chromium and rare earth were improved. The stacking fault energy of the modified Hadfield steel was reduced, which was favorable for the formation of deformation twins. The alloying effect finally resulted in high work hardening ability and insensitive response for strain rates during monotonic deformation. Moreover, planar-slip structured dislocations at low strain amplitudes and deformation twins at high strain amplitudes remarkably prolonged the low-cycle fatigue life. Local areas of Hadfield steel frogs, where abrasion and fatigue failure frequently happened, were subjected to thermo-mechanical control process. The deformation temperature and reduction were controlled to optimize the microstructure of Hadfield steel. The casting defects were significantly removed, and the continuity of microstructures was enhanced after the thermo-mechanical control process. Ultrafine austenite grains were obtained in the work surface of the Hadfield steel frogs. These microstructure features in the Hadfield steel displayed good compatible-deformation and work hardening ability. Effect of surface explosion hardening process on the mechanical properties was investigated. Compared with conventional plastic deformation (e.g., cold rolling), explosion deformation was found to be detrimental to the mechanical properties of Hadfield steel. Dislocations and deformation twins were uniformly distributed in the grain interiors because of the planar and reversal nature of shock wave. Plastic strain seriously concentrated in the vicinity of grain boundaries due to the shock-wave propagation character. As a result, the tensile elongation and strain fatigue life of the explosion deformed Hadfield steel were reduced compared to the cold rolling condition. Therefore, the surface hardening process of the Hadfield steel frogs was adjusted to explosion once with an explosive thickness of 3 mm. Meanwhile, a novel surface hardening method, i.e., high-speed pounding, was invented to harden the work surface of Hadfield steel frogs. Nano-twins, even nanocrystallines, were obtained in the surface of the Hadfield steel after high-speed pounding treatment. The surface wear resistance of the high-speed pounding treated Hadfield steel was increased. Finally, the service life of the Hadfield steel frogs processed with the techniques described above was three times higher compared to the conventional condition.

**Keywords:** Hadfield steel frogs, alloying treatment, thermo-mechanical control process, surface hardening

# Increase efficiency and productivity using Tubothal elements and Kanthal APM™ radiant tubes

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**Abstract:** Chromia forming metallic heating elements normally have an upper temperature limitation of 1100 ℃, in where severe oxidation or severe deformation is normally the cause of failure when reaching these temperatures. Alumina forming FeCrAl alloys that are manufactured through conventional metallurgy will be able to operate at temperatures above 1100 ℃ but will have form stability issues if not supported well enough. Our powder metallurgical alumina forming FeCrAl alloy can withstand temperatures up to 1400 ℃ and still maintain high form stability. Products made from such an alloy like our Kanthal APM™ radiant tubes and Tubothal heating elements makes it possible to increase furnace productivity by increasing throughput of products and longer intervals between maintenance. The protective alumina scale formed on the material increases resistance to carburization and sulfidation enabling it to perform well even in harsh environments where chromia forming alloys would suffer from severe corrosion.

Thanks to the excellent high temperature properties of the alloy it is possible to increase the power output from each heating unit when using Kanthal Tubothal™ elements or Kanthal APM™ tubes as radiant tubes in single ended gas burners. Possible advantages of power increase are; ability to minimize the number of heating units, increase throughput of heat treated goods or increase the intervals between maintenance stops which will affect the productivity of your furnace compared to using standard its nickel chromium counterparts.

The purpose of the paper is to showcase the advantages of using a powder metallurgy produced FeCrAl alloy, Kanthal APM™ compared to conventionally produced heating elements made from FeCrAl or NiCr used in standard heat treatment applications. The paper will present the material properties of the FeCrAl alloy, Kanthal APM™ and briefly discuss advantages of using an alumina forming alloy at high temperature heat treatment compared to a chromia forming alloy. The paper will also show the advantages of using a powder metallurgy as a production method to increase the high temperature mechanical strength of the alloy compared to its casted counterpart. Results on performances of Kanthal APM™ on corrosion resistance and resistance to high temperature mechanical deformation will be shown from both laboratory tested environment but also from exposures in actual working conditions. The results will not only show the possible savings potential from switching to Kanthal APM™ tubes and Tubothal™ but also the increase service life which would directly affect the productivity of the furnace.

**Keywords:** FeCrAl, heat treatment, alumina, high temperature

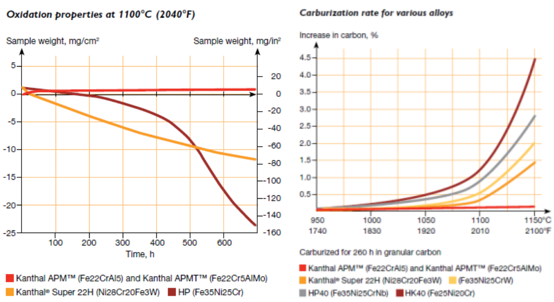


Fig.1

## Endothermic generator design and reactions

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**Abstract:** Endothermic generators have been used for many decades for the control of carbon potential for neutral hardening and carburizing. The endothermic generator produces the primary carrier gas which consists of primarily of hydrogen, carbon monoxide. Additions of propane, natural gas and air are made to the carrier gas to produce specific carbon potentials. To understand the reactions occurring in the endothermic generator, a small laboratory endothermic generator was designed and built. Testing was undertaken to understand the reactions occurring in the generator, and methods to control the output for optimized response. The results of that study are presented in this paper.

**Keywords:** endothermic generator, heat treating

## Case hardening by low pressure carburizing in highly efficient emicontinuous vacuum furnaces

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**Abstract:** Case hardening is a commonly used technology of thermo-chemical treatment; it consists of carbon introduction into a steel surface during the carburizing process after which quenching and then tempering occur. As a result of this process, elements obtain a hardand wear-resistant surface and a flexible, impact-resistant core. These properties are particularly desired in elements applied in motion transmission systems, e.g., wheels and pinions, rings, levers, steering elements, bearings, etc.

Traditionally, case hardening is based on carburizing in atmospheres and oil quenching; this is carried out in sealed quench furnaces and continuous lines (pusher, roller or rotary furnaces). They are technologies and devices developed more than 50 years ago and, over the course of time, they have exhausted their development potential. At present, they hardly meet the requirements of the modern industry regarding quality and replicability, integration and organization of production, and environmental protection.

A solution for weak points of traditional case hardening is the use of vacuum technologies and equipment. Double or triple-chamber furnaces for case hardening using vacuum carburizing and oil or high-pressure gas quenching are the modern and reasonable alternative for the traditional devices. It can replace the classic sealed quench furnaces and lines for high-volume production such as pusher, roller or rotary furnaces. It is distinguished by a significant improvement of the process result quality, capacity and production flexibility, and the compact system. It can be installed directly in production halls (it does not require any separated area) and meets safety and environment protection requirements. The capacity of the single furnace can reach as high as 400 kg/h, and it can be multiplied by using groups of many furnaces. The direct costs of the process are within the range of traditional technology costs.

Triple-chamber furnaces are also an attractive alternative for modular vacuum systems for mass production. The advantages include initial capital costs as well as operating independence and flexibility.

**Keywords:** low pressure carburizing, double or triple chamber furnace

# Application of DSP Intelligent induction heating power supply in induction heat treatment fields of key parts

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**Abstract:** The paper introduces the key parts induction heat treatment power supply development history, discusses the technical level and development direction at home and abroad.

This paper introduces the characteristics of the new DSP power supply in the key parts surface induction heat treatment features, including frequency tracking, loading adaptation, intelligent protection, extended interface, power control, dual frequency, recording characters and so on.

The new DSP power supply use DSP processor as the control core, integrated fast dynamic response frequency tracker program. Also deal with the system dynamic interference, can quickly realize the frequency conversion adaptive characteristics. The system adopts expert control theory in power control, Do the estimate judge for the system running state , the system dynamic response speed is fast and does not overshoot, Ensure the power stability during equipment continuous operation. When system is implementing temperature control, use temperature closed loop control, power limit closed-loop control, Upper current limit closed-loop control, voltage upper limit closed-loop control synchronous quick execution, enhanced the temperature closed loop rapid reaction, expand the applications in temperature control fields. The intelligent protection feature is extended by using FPGA. And also the protection is classified and judged intelligently in the system control, Important protection timely processing to protect the equipment. General protection makes alarm and does not stop, It not only enhances the reliability of the equipment, but also does not affect the usability.

Particularly Introduced the new DSP power supply in the key part heat treatment fields application, including automobile engine and gearbox parts surface hardening, hot coil spring heat treatment, anti-collision rod and pin shaft heat treatment, round steel hot rolling etc.

**Keywords:** induction heat treatment, key parts

# Cost- and resource effective surface layer heat treatment in gear and tool industry by PulsPlasma®-nitriding

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**Abstract:** The PulsPlasma® nitriding of workpieces is used more and more for the improvement of wear and corrosion protection. By this the lifetime will be longer due to advantages by process conditions against the case hardening by high temperature carburizing or by standard Ammonia nitriding (gas nitriding). The PulsPlasma® nitriding is a pollution free technology saving energy and other resources. The total manufacturing costs of workpieces can be reduced significantly. Highly developed concepts of plants and the use of PulsPlasma® technology a uniform treatment of many small parts in one workload is possible as well as the nitriding of large tools or gear parts for wind power plants.

**Keywords:** surface layer, gear, PulsPlasma nitriding

# Fluidised bed furnace technology

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**Abstract:** Modern machinery, equipment and engine designs demand more exacting metallurgical specifications, requiring greater precision in heat treatment operations. Specifically, heat treatment processes require closer control of atmosphere and temperature range and uniformity in order to satisfy stringent metallurgical properties such as microstructure, surface finish and distortion. These are the most important criteria for evaluation of heat treated parts, which subsequently affect hardness, toughness, fatigue, wear resistance and thermal checking.

For heat treatment of tool and alloy steels used as components, there is a wide range of equipment available such as salt bath, gas-fired, vacuum and fluidised bed furnaces. This paper focuses on the technical elements and benefits of fluidised bed in comparison with traditional methods including salt bath and vacuum furnaces.

For individuals less aware of how fluidised bed furnaces work, at a basic level the furnace and cooling chamber may be closely described as a cylinder of aluminium oxide power bubbling away; transferring heat by the injection of an inert gas (air, nitrogen or argon) when in operation. A modern electric fluidised bed furnace is capable of reaching operational temperature of 1150 ℃ with temperature uniformity of ±5 ℃ and heat transfer coefficient of (500-700 W/($m^2$ K$^1$)), which is comparable with salt baths (500-1200 W/($m^2$ K$^1$)) and much faster than vacuum furnaces (120-200 W/($m^2$ K$^1$)). This heating range enables a wide hardening range of carbon, alloy and tool steels.

Industrial applications of fluidised bed technology in the heat treatment of metals are highly versatile both in hardening and tempering, as well as reactive diffusion processes such as nitriding, nitrocarburising, carbonitriding and carburising, without the use of toxic salts and subsequent long-term damage to operators and the environment. Many large heat treatment firms in Australia, New Zealand and USA have replaced salt baths with fluidised bed furnaces for improved economy, performance and to comply with new environmental standards. It is the authors' belief that fluidised bed technology best meets contemporary metallurgical, economic and environmental requirements.

**Keywords:** fluidied bed, furnace, heat treatment, environmental

# Study on hot-shock-resistance of the composite coating of 20 steel substrate by hot dip aluminum and micro-arc oxidation

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**Abstract:** By combined process of hot dip aluminum and micro-arc oxidation, a multilayer composite coating was obtained on the surface of 20 steel plates. The micro-hardness, morphology, residual stress and hot-shocking performance of the coating were investigated by HVS-1000 micro-hardness instrument, SEM, XRD, X-350 stress instrument and etc. The results showed that the micro-hardness of the coating appeared hard-soft-hard from surface to inner, the effective hot-shock times of the coating was 130, its residual stress of the coating was 261.3 MPa after hot shock 80 times.

**Keywords:** hot dip aluminum, micro-arc oxidation, composite ceramic coating, 20 steel

# Applications of laser cladding technology in oil industry

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**Abstract:** The harsh working environment of oil field equipment leads to strict requirement on material properties for the machinery components, in particular those in frequent contact with oil or natural gas. For the oil field equipment, the majority of machine failures result from wear and corrosion of components. Laser cladding is an advanced remanufacturing process. It features bonds with minimal dilution, high quality light energy, small heat affected zone, broad options of material selection, high automation level, and high process efficiency. As such, it is particularly suitable for repairing the failed components and improving the performance of components. In this paper, we summarize the applications of laser cladding technology in remanufacturing various critical components of oil field equipment for extracting oil and natural gas, such as piston rods of reciprocating natural gas compressor, valves, plunger rods of feed pump, and combination valves. For this purpose, a systematic framework for assessment, testing, and verification is developed. The considerations include the analysis of service condition of those components, failure mode, material selection, and process design. Meanwhile, the evaluation methods of laser cladding process are summarized, and the scientific evidence of laser cladding employed as a remanufacturing approach, in additive form, is also discussed. Based on this framework, overall we are able to achieve 50% or more improvement in service life for the remanufactured components, as compared with the original ones.

**Keywords:** laser cladding technology, oil industry

# ECM technologies, low pressure carburizing distortion data comparing oil and high pressure gas quenching

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**Abstract:** This presentation will discuss data on parts tested in low pressure carburizing using oil and gas quenching. We will present data on metallurgy, distortion and load design to optimize each quenching media. As we know oil and gas quench very differently, we will explore the evolution of high pressure gas quenching as it exist in today's market. Low pressure carburizing has been growing among OEM's and now Tier 2 suppliers as well as heat treaters in the automotive and aerospace markets. These details should help show the audience that they also can take advantage of low pressure carburizing's clean environment and just in time processing along with possible distortion control for all their parts currently being atmosphere carburized.

**Keywords:** ECM technologies, low pressure carburizing, oil and high pressure gas quenching

## The analysis and optimization of distortion in die quenching process for spiral bevel gear

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**Abstract:** Spiral bevel gears are widely used in the transmission between intersecting axes. The strength of the gears can be improved by carburizing and quenching process. The distortion can be controlled through a die quenching process. But irregular distortion is inescapable and it is determined by the hardenability variation. The relationship between phase transformation, axial distortion, gear surface distortion and process parameters must be studied to minimize the quenching deformation with consideration of hardenability variation for the gear with big diameter and small thickness. In this paper, material models of gear material (22CrMoH) built based on the phase transformation kinetics, static mechanical properties and phase transformation plasticity equation. FEA (Finite element analysis) models are conducted to study the whole die quenching process based on the production process. Die quenching experiments and testing of microstructures and distortions are conducted to verify the accuracy of FEA models. The effects of loads and bottom die obliquity on the final distortion are studied to get the appropriate range to control distortion. The distortion is very sensitive to the bottom die obliquity and some part of load ranges. The distortion is minimized with little range when the load of inner die is set as 250 psi, the load of outer die is 350 psi. and the inclination angle of bottom die in the range of 0.2 °.

**Keywords:** die quenching, distortion, spiral bevel gear, hardenability

## Improving ductility and toughness of martensitic steels through twice partitioning heat-treatments

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**Abstract:** The processes of quenching and partitioning were believed promising technology to achieve excellent ductility and toughness, through which dispersed austenite was introduced into martensite. Because the complicate process and enormous equipment investment inhibited this technology to put into practice, an improved process named quenching and dynamical partitioning treatment was proposed while failed either due to the worsen portioning condition. In present research, mixed microstructures of martensite and austenite were obtained in medium manganese steel through a practical process named twice partitioning, which can be disassemble into two steps, i.e. intercritical annealing and slacking quenching. About 6%-10% retained austenite was obtained in experimental steel subjected to this treatment, where the austenite was stabilized by alloying elements and carbon enrichments simultaneously. Besides the high ultimate tensile strength of 1700-1800 MPa, excellent ductility of 13.1% for sheet sample and 15.7% for stick sample can be achieved together with high toughness of 47 J for Charpy V-notch impact sample.

**Keywords:** twice partitioning, martensitic steels, ductility and toughness

## Intelligent heat treatment plant system practice

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**Abstract:** This article introduced Fengdong's achievements in practicing of intelligent heat treatment plant system. Through integration application of intelligent heat treatment equipment, logistics system, heat treatment process database system and manufacturing execution system etc. to realize the intelligentization and less-manned or unmanned working in the heat treatment production process, improve parts quality and production efficiency, lower operating costs, save energy and reduce emission, This article also analyzed the difficulties in the process of heat treatment intelligent plant construction and gave some suggestions, such as cross-line production, selection of AGV system for heat treatment, multisystem integration, etc., which will provide reference for heat treatment practitioners in intelligent manufacturing practice.

**Keywords:** intelligent heat treatment equipment, heat treatment process database, MES, WMS, AGV for heat treatment, cross-line production, system integration

## Pre-vacuum series batch furnace and its intelligent controlling system

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**Abstract:** The pre-vacuum type batch furnace is constructed with vestibule by vacuum evacuation and nitrogen purging, the furnace is without fire curtain, the surface quality of the parts is better, and the energy consumption and environmental pollution are reduced. It's intelligent controlling system with SCADA, smart MES, process simulation etc realize less personal operation, high production management and good efficiency.

**Keywords:** pre-vacuum, intelligent, SCADA, MES, batch furnace

## Development of furnace temperature uniformity test function based on the heat treatment DCS system

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**Abstract:** In our institute the testing process of furnace temperature uniformity has some problems, such as inefficiency, human elements and so on. The function of heat treatment furnace temperature uniformity test is developed based on heat treatment distributed control system (DCS) and the data acquisition module is changed. The results showed that testing efficiency increases 60 percent and the whole testing process is automatic without human elements.

**Keywords:** heat treatment, furnace temperature uniformity, testing, development

# The optimization design of large cylinder induction heating equipment and process based on skin effect and Curie point effect

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**Abstract:** At present, the development of clean energy and aviation industry is rapid. The heavy cylinder is the basic component of heavy pressure vessel, which is widely used in nuclear power, petrochemical, coal liquefaction and aerospace industry. The size of heavy cylinder is huge, and the diameter can reach to 10 m, the height is about 3 m, the wall thickness is more than 0.3 m. The heavy cylinder works in high temperature, high pressure and corrosive environment, so it has a key effect on the stability of equipment. The demand and quality requirements for large cylinder are increasingly pressing in related fields. Its heat treatment is carried out in a bogie-hearth resistance furnace or flame furnace, whose disadvantages are inefficiency, high energy consumption, and serious pollution. So in this paper, induction heating equipment and process parameters of large cylinder were optimized to improve its heat treatment efficiency and heat treatment effect.

Because of the skin effect of induction heating, induction heating is widely used for surface quenching of workpieces. The heat preservation of large cylinder must be realized by gradually decreasing the current during the induction heating process, while the temperature of the workpieces will continue to rise in this process, so overheating is always prone to occur during the heating process. Therefore, in this paper, the optimization design of the large cylinder induction heating equipment was carried out. The metal resistance band is arranged in the induction heating equipment, so that the large cylinder can be rapidly heated by induction heating, and the insulation effect can be improved by resistance heating.

In large cylinder induction heating process, when the temperature of cylinder reaches a certain temperature, the relative magnetic permeability of the cylinder will abruptly decrease, and approach infinity to 1, then the penetration depth of the induced eddy current will suddenly increase ten times. And this temperature is called the Curie point of the metal. When the temperature of the large cylinder reaches the Curie point, the magnetic flux density and electromagnetic heating power will decrease as the relative magnetic permeability decreases. At this time, the heating rate of the surface of the large cylinder will become slower. In this way, in the next warming, the increase velocity of temperature difference between the surface and the core will also slow down, thereby reducing the hightemperature holding time of the large cylinder and avoiding austenite coarseness. So based on the Curie point effect of metal, the optimization of the induction heating process route for large cylinder was carried out in this paper.

The electromagnetic-thermal coupling model of large cylinder induction heating was established based on ANSYS Workbench and ANSOFT Maxwell software, and the above optimized design was simulated in this paper. Firstly, the simulation of the optimization design of the induction heating equipment structure was carried out. In this paper, the electromagnetic induction insulation and the resistance heating insulation were simulated and contrasted respectively. The simulation result shows that the resistance insulation is far superior to the electromagnetic induction insulation in both the insulation efficiency and the insulation effect. Then the induction heating process route was simulated and compared to verify the Curie point effect in the induction heating process. The specific simulation steps: The simulation process was divided into two groups. In the first group, the large cylinder was kept temperature when its temperature reached 600 ℃ and then heated to the target temperature. In the other group, the large cylinder was kept temperature when its temperature reached Curie point temperature (about 750 ℃) and then heated to the target temperature. Finally, a comparative analysis of the

temperature difference between the two groups was conducted to prove the feasibility of Curie point effect on improving the heat treatment effect of large cylinder.

**Keywords:** large cylinder, induction heating, rapid heat treatment, FEM, optimized design

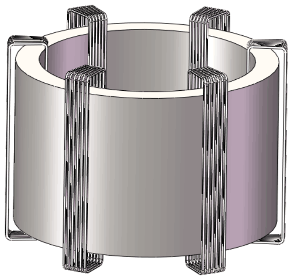

Fig.1 Three-dimensional model of traditional large cylinder induction heating device

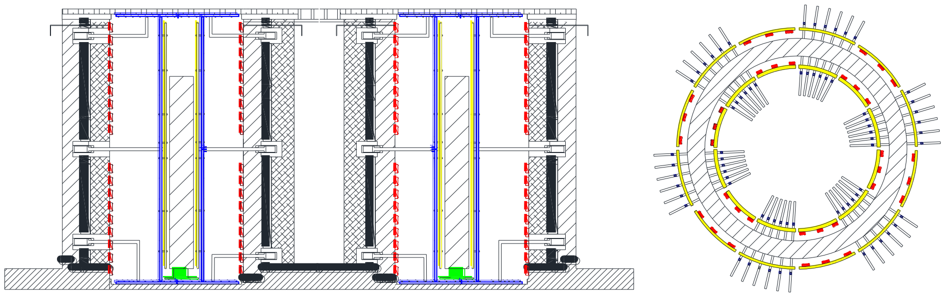

Fig.2 The two-dimensional model of the optimized large cylinder induction heating device

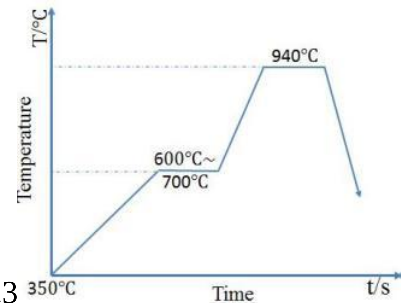


Fig.3

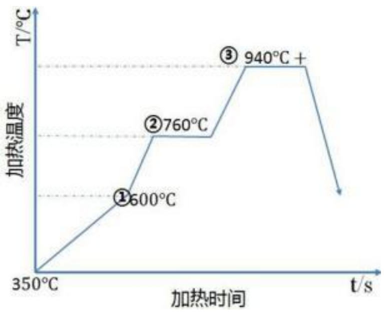


Fig.4

Fig.3 Traditional heating process route

Fig.4 Induction heating process route

# Effect of nozzle distance on nitriding behavior of titanium alloy treated by gas blow induction heating nitriding

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**Abstract:** Gas blow induction heating (IH) nitriding is a surface modification technique that we have developed recently. In this process, nitrogen gas is blown over a material heated by high-frequency induction in nitrogen atmosphere. We have revealed that commercially pure titanium and Ti-6Al-4V alloy can be modified by this technique within a short period of time and that the wear resistance of these materials is improved. In this study, the effect of the nozzle distance on the nitriding behavior of Ti-6Al-4V alloy treated by gas blow IH nitriding was investigated.

The material used in this study was Ti-6Al-4V alloy. Bars of this alloy with a diameter of 15 mm were machined into disk-shaped specimens with a thickness of 4 mm. One end face of these specimens was polished using emery paper and colloidal silica suspension, and a mirror finish was achieved. Gas blow IH nitriding was performed under the following conditions: heating time, 180 s; treatment temperature, 823 K; nitrogen gas flow rate, 120 L/min; internal diameter of gas blow nozzle, 4 mm. To vary the nozzle distance, two types of nozzles were prepared by combining a commercial nozzle and a circular stainless pipe. The treatments were conducted using nozzle distances of 20 and 100 mm. The surface microstructures of the specimens were analyzed using X-ray diffraction, micro-Vickers hardness tester and nano-indentation tester. Reciprocating ball-on-disk wear tests were performed to examine the wear resistance of the specimens. The wear losses during the tests were measured, and the wear tracks were observed using scanning electron microscopy and scanning white light interface microscopy.

It was found that a nitrided layer composed of a nitrogen compound (TiN) layer and a nitrogen diffusion layer with high hardness was created on the surface of the specimen when the treatment was conducted with a short nozzle distance (20 mm). In contrast, no nitrided layer was formed on the surface of the treated material when the nozzle distance was 100 mm. The wear test results showed that the specimen treated with a 20 mm nozzle distance exhibited less wear loss and a smaller wear track than that treated with a 100 mm nozzle distance, indicating that the wear resistance of the specimen treated with a nozzle distance of 20 mm was higher than that treated with 100 mm nozzle distance. These results indicate that formation of the nitrided layer on Ti-6Al-4V alloy during gas blow IH nitriding was accelerated by shortening the nozzle distance. The velocity of nitrogen gas blown onto the treated material is thought to be increased by shortening the nozzle distance. In particular, when nozzle distance was 20 mm, the velocity of gas blown onto the specimen rose to sound speed in theory. The higher gas velocity led to higher temperature inside the specimen and higher IH power during treatment. These factors are assumed to have accelerated the diffusion of nitrogen atoms into titanium and formation of the nitrided layer during gas blow IH nitriding.

In conclusion, the formation of a surface-modified layer during gas blow IH nitriding was accelerated by reducing the nozzle distance because the velocity of nitrogen gas blown onto the specimen was increased.

**Keywords:** nitriding, induction heating, titanium alloy

# Influence of solution and aging treatment on microstructure and mechanical properties of Al-7.0Zn-2.1Mg-2.3Cu-0.1Zr(-0.2Sc) alloy

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**Abstract:** Al-Zn-Mg-Cu series aluminum alloys have high strength and hardness, good corrosion resistance and toughness, excellent formability and weld ability so they were widely used in aerospace, transportation and other important industries structural materials. Al-Zn-Mg-Cu series aluminum alloys have an important strategic position in the military and the economy of nation in the future. Micro-alloying and heat treatment can improve the comprehensive property of Al-Zn-Mg-Cu alloys.In this investigation, Al-7.0Zn-2.1Mg-2.3Cu-0.1Zr(-0.2Sc) alloys were taken as the experimental materials, and through performing the hardness and tensile tests, the influence T6 treatment on the mechanical properties of Al-7.0Zn-2.1Mg-2.3Cu-0.1Zr(-0.2Sc) alloys were studied. Brinell hardness curve of Al-Zn-Mg-Cu-Zr-Sc alloy after solution treatment of 480 ℃ for 1.5 h and aging treatment at 120 ℃ for 66 h shows that both Al-Zn-Mg-Cu-Zr alloy and Al-Zn-Mg-Cu-Zr-Sc alloy appeared the first peak value at 24 h, then the hardness decreased. The two alloys reached the second peak value at 54 h and 48 h, respectively, and the hardness difference between the two peaks was about 20 of Brinell hardness.It can be seen that the effect of aging time has a great influence on hardness. Brinell hardness of Al-Zn-Mg-Cu-Zr-Sc alloy after solution treatment of 480 ℃ for 1.5 h and 60 h aging treatment at 160 ℃ shows that Al-Zn-Mg-Cu-Zr alloy and Al-ZnMg-Cu-Zr-Sc alloy reached the peak hardness at 6 h and 4 h, respectively, and then the hardness decreased sharply with the increase of aging time. With the increase of aging temperature, the time of reaching peak hardness is shortened, the hardening rate is accelerated, and the peak value is lower. The related results show that the tensile strength of as-cast Al-Zn-Mg-Cu aluminum alloy is only about 200 MPa, and the elongation is not more than 2%. But after the homogenization treatment, the tensile strength and elongation of the alloy were not obviously increased. The curve of tensile strength of T6 Al-ZnMg-Cu-Zr(-Sc) alloy with different aging time shows that the tensile strength of Al-Zn-MgCu-Zr and Al-Zn-Mg-Cu-Zr-Sc alloy was increased first and then decreased during the period of 2-66 h,the alloy goes through three stages: under aging, peak aging and over aging within 66 h, and reached their peak at 48 h, at this time, the maximum tensile strength were 570. 54 MPa and 730.34 MPa, respectively. With the aging time continues increasing, the tensile strength of the alloy began to decrease gradually.The yield strength curve of T6 Al-Zn-Mg-Cu-Zr(-Sc) alloy shows that the yield strength of Al-Zn-MgCu-Zr alloy increased within aging time for 24 h, but decreased slightly at 28 h, then increased and reached its peak at 48 h. After 48 h, the yield strength of Al-Zn-Mg-Cu-Zr alloy began to decrease gradually. But for Al-Zn-Mg-Cu-Zr-Sc alloy, the yield strength increased within aging time for 24 h. When aging 36 h, the yield strength reaches lowest and then increase, reached its peak at 48 h. Then the yield strength keep stable until 66 h. The curve of elongation T6 Al-Zn-Mg-Cu-Zr(-Sc) alloy shows that aging 10 h reaches the maximum elongation about 17.55% and 14.4%, respectively. And the elongation gets lowest at aging 48 h. The fracture surfaces show that under peak aging time, the tensile fracture surface of Al-Zn-Mg-Cu-Zr(-Sc) alloys observed a large number of dimples, performing ductile fracture characteristic. The strength models of Al-Zn-Mg-Cu-Zr(-Sc) alloy are η' precipitates strengthening and a large amount of fine disperse Al3(Sc, Zr) particles having petal-like shape precipitate during homogenization which can pin dislocation and sub-boundaries also have strengthening effects.

**Keywords:** T6 treatment, hardness test, tensile test, microstructure

# Improvement in resistance to surface pitting fracture of medium carbon steel by induction-heating and quenching after salt-bath nitrocarburizing

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**Abstract:** Improvement in contact surface strength of gear teeth and pulleys, such as wear and/or pitting-fracture resistance, is most important to reduce the size and weight of continuously variable and multi-step transmission components to improve fuel consumption of automobiles. Carburized- or carbonitrided-quenching, which can harden more deeply than nitriding or nitrocarburizing as a surface heat treatment, has been generally used for these power-transmitting steel parts in consideration of increasing contact pressure on the order of 3.5 to 4.0 GPa. However, the distortion of nitriding and nitrocarburizing, which are conducted below austenitizing temperature, is less than that of carburized-/carbonitrized-quenching. Nitrogen-containing martensite (nitrogen martensite) is well known as an effective microstructure to increase pitting resistance. Therefore, we investigated the pitting resistance of 0.45% carbon containing induction-heated-and-quenched steel after nitrocarburizing by using a molten salt bath having oxidation property. To create nitrogen martensite effectively at the surface layer, the nitrocarburized steel surface was coated with special paint for denitrification before induction-heated quenching. Cylindrical specimens of 26 mm in diameter made of JIS S45C steel were nitrocarburized with a salt bath composed of $CNO^-$, $CN^-$, $Na^+$, $K^+$, and $Li^+$ ions at 600 ℃ for 120 min. Specimens were then coated with denitrification paint containing silicon. The denitrification-paint-coated and uncoated specimens were induction-heated until 1035 ℃ for 1.4 s then quenched with a waterjet (specimens NPQ and NQ, respectively).

Salt-bath nitrocarburized only (specimen LN), and induction-heated-quenched only (specimen IQ) specimens were prepared for comparison. The pitting resistance was estimated from pitting-fracture life, i.e., number of cycles to pitting at surface, using a double-cylinder-type roller-pitting fatigue tester. The pitting test was conducted under the conditions of Hertz's stress of 3.91 GPa, slip ratio of minus 40%, rotation speed of 1500 rpm, and lubrication using automotive transmission oils at 95 ℃. The results indicate that nitrogen martensite formed at the surface layer in NPQ had nitrogen of more than 0.4% until at least 30 μm deep, and its maximum nitrogen concentration was around 0.9% (0.15% higher than that of NQ). In NQ and NPQ, a surface nitrogen compound layer formed due to the nitrocarburizing disappearing almost completely by induction-heating. The pitting life of NPQ was also found to be 7.0 times longer than that of IQ and 1.8 times longer than that of NQ. The reason NPQ has excellent resistance to pitting is because nitrogen martensite with a high amount of nitrogen has superior resistance to softening during tempering at around 300 ℃ in addition to having a deeper hardened case and a generous amount of retained austenite, compared with LQ, NQ, and IQ.

**Keywords:** salt both nitrocarburizing, induction heating, nitrogen-martensite, contact fatigue strength, pitting fracture

# Boro-austempering treatment in ductile cast iron alloyed with niobium

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**Abstract:** Austempered ductile cast irons (ADI) possess good mechanical properties such as high tenacity, high tensile and fatigue strength, good vibration damping capacity, lower production costs and lower densities when compared to steels. These characteristics and mechanical properties are attributed to the microstructure formed in the austempering of ductile cast iron. During these treatment, ferrite ($\alpha$) plates nucleate and grow in the boundaries of austenite grains ($\gamma_o$), being separated by thin layers of carbon saturated austenite ($\gamma_{HC}$). Over time, the diffusion of carbon becomes more difficult and the growth of the plates is interrupted. The remaining austenite becomes stable and the material can be cooled to room temperature without the formation of martensite. The result of the treatment is a microstructure formed by retained austenite and acicular ferrite, also called ausferrite. Although austenite treatment practice gives ductile irons an improvement in wear resistance, the application of surface treatment techniques further extends its field of use, increasing the life of the part and decreasing the downtime caused by maintenance. Boriding is one of the methods used to increase the resistance to surface wear, in addition to providing high resistance to corrosion. These advantages are obtained through the production of iron boride layers (FeB and $Fe_2B$) from the treatment, with hardnesses that can reach values higher than 2000 HV. The diffusion of boron on the surface can result in layers with a depth between 40 and 270 μm, always depending on the chemical composition of the material, temperature and treatment time. Performed between 800 and 1100 ℃, during 1 to 8 h, boriding in salt bath (borax) is a highly promising technique for surface treatment of the ADIs for being a simple, inexpensive method and allow the austempering to be held directly from the boriding, what reduce the processing cost. The junction of these two treatments is called boro-austempering. These characteristics enable ADI to replace forged steels in various applications in the automotive, defense, agricultural, railway and heavy equipment industries. Increasing the surface hardness of these materials using thermochemical treatments, such as boriding, can further enhance it's performance improving wear and corrosion properties among others. In the present work, layers of iron borides (FeB and $Fe_2B$) were produced in samples of ductile cast iron with contents of 0.5% Nb and 1% Nb by means of boro-austempering thermo-chemical treatment. The samples were borided in salt baths at 900 ℃ for 2 and 4 h, and them directed cooled from this temperature using salt baths at 240, 300 and 360 ℃ for 1 and 3 h, with subsequent air cooling to room temperature. This procedure avoids the need for additional heating for the austempering treatment. The substrates and the layers produced were characterized by optical microscopy, Vickers microhardness and microadhesive wear tests. The tribological characteristics of the layers were compared with those of the substrate. The addition of niobium increased the hardness of the substrate, and in the case of the addition of 1% Nb, precipitation of carbides of Nb. The boriding treatment produced high hardness borides layers with a marked increase in the wear resistance with respect to the substrate.

**Keywords:** ductile cast iron, ADI, boro-austempering, microhardness, micro adhesive wear

# Production and characterization of carbide layers by the TRD process on graphite steels

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**Abstract:** Graphite steels can be considered a subset of the spheroidal graphite (or ductile) cast irons, in which they possess a similar microstructure but a slight different composition. In order to better comprehend the effect of this composition, it is necessary to understand the characteristics of the ADI. The use of austempered ductile cast iron (ADI) has grown over the years due to some advantages compared to forged steels, such as lower production cost, good machinability, higher wear resistance, castability and higher vibrations damping capacity. This results in the possibility of obtaining near net shape parts, due to the low distortion caused by the austempering treatment, which greatly reduces production costs. However, with the increasing demand to produce lighter machines, the parts have become thinner, which has become a problem for ADI made parts. They have an elastic modulus around 20% lower than steel, thus having a greater tendency to buckling. This context led to the development of graphite steels in which graphite is in nodular shape and present is less quantity than in nodular cast irons, since they contain about 11.5% carbon against 3.5% of the ADI, which resulted in an increased yield strength and elastic modulus. In addition, austempered graphite cast steels have an average resistance limit of 200 MPa higher than ADI, which results in a material with a higher strength/weight ratio. The addition of niobium to such steels may have the grain refining effect, as well as the possibility of formation of hard carbides (NbC) in the matrix. It is possible to further improve the tribological characteristics of these steels by the production of surface high hardness layers using TRD (thermo-reactive diffusion) treatments, in the range of 2500 to 3500 HV, far superior to traditional thermochemical treatments such as cementation, nitriding or even boriding. In addition, these layers may exhibit high corrosion resistance, which considerably increases the possibility of using this material. Such treatments uses a borax salt bath with addition of vanadium, chromium and/or niobium. These elements combine chemically with the carbon of the substrate, producing carbide layers of high hardness. In this work, three compositions of graphite steels containing 0, 0.5 and 1.0% of niobium were produced. Samples of these materials were submitted to TRD treatments followed by direct austempering, which allows a reduction of treatment costs. The boriding treatments were performed in a fused borax bath at 900 ℃, with the addition of ferro-niobium, during 4 h. For the subsequent isothermal treatment of austempering, a molten salt bath at the temperature of 320 ℃ for 2.5 h was used. Optical microscopy, SEM imaging, X-ray diffraction, Vickers microhardness and calotest type wear tests were used to characterize the materials produced. The substrate presented ausferritic microstructure after TRD-austempering treatment. The TRD treatment produced homogeneous layers of high hardness, above 2300 HV, which resulted in superior wear resistance when compared to the substrate. Therefore, these steels treated with TRD are highly promising substitutes for ADI and forged steels in a number of specific applications.

**Keywords:** graphite steel, austempering, TRD, wear

# Production and characterization of borided layers on AISI 15B30 and AISI 8640 steels

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**Abstract:** Engineering components such as pipes, valves, bearings, gears and pistons are often subjected to frictional wear in numerous industrial processes. As a result the financial costs tend to increase due to machine downtime halting the processes, increased maintenance and replacement of components. Such context led to the development of Surface Engineering, with the production of surface layers highly resistant to wear. Among the available treatments boriding stands out, due to its simplicity, low cost and by having levels of hardness higher than the majority of the treatments. This treatment chemically modifies the surface of the metal substrate by diffusion of the boron atoms and their subsequent chemical combination with atoms from the base metal. This mechanism is dependent on temperature and boron content, which can result in layers consisting of a single $Fe_2B$ or double $Fe_2B$ and FeB phases. These layers attain high hardness levels, between 1400 to 1800 HK, exhibiting high resistance to frictional wear and improved corrosion resistance. In this work boride layers were produced on samples of AISI 15B30 steel and 8640 steel to evaluate properties such as hardness, adhesive wear resistance, adhesion strength of the layer to the substrate and the identification of the phases present. Samples of these steels initially annealed were borided in a molten salt bath followed by air cooling. The treated materials were characterized by optical microscopy, SEM analysis, X-ray diffraction, Knoop micro-hardness, “calotest” micro-adhesive wear test and Rockwell C indentation adhesion test according to VDI 3198. The resulting layers presented an average thickness of 170 μm with a saw-tooth morphology at the substrate-layer interface in AISI 15B30 steel, which is typical for low carbon steels. The AISI 8640 steel samples had smooth layers interface with the substrate, which is a consequence of the diffusion barrier created due to high carbon content and the alloying elements present in the substrate. Regarding the average hardness and the micro-adhesive wear resistance of the boride layers produced, the values indicated high surface hardness and high resistance to microadhesive wear when compared to the substrates. The boride layers presented maximum hardnesses of 1800 HK for the case of the two steels under study and excellent adhesion to the substrate according to VDI 3198. The hardness of the substrates was about 375 HK. In the case of wear resistance, the 15B30 boron sample had a wear resistance of about 6.5 times the sample without this treatment. For the 8640 sample, the borided layer had a resistance to wear about 1.5 times higher than the untreated substrate. By means of the results of the X-ray diffraction analysis, it was verified that layers composed of FeB and $Fe_2B$.

**Keywords:** AISI 15B30, AISI 8640, boriding, micro-adhesive wear test

# Influences of thermal and surface treatments on thermal fatigue resistance of AISI H11 modified steel

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**Abstract:** Thermal fatigue is a dominant mechanism that causes premature failure in materials under high temperature. In order to extend the useful life of tools for hot work, studies have been conducted trying to understand the mechanisms involving thermal fatigue. Thus, different types of materials combined with different parameters of thermal and surface treatments have been investigated using thermal fatigue tests.

Thermal fatigue is one of the first failure mechanisms to occur in tools and dies for hot work. The failures originate in the surface layer of the material and influence the productivity and quality of the surface, thereby reducing the useful life. Thus, for higher durability tools and dies, it is desirable that better properties are created in the surface layers.

In this context, in order to better understand the influence of various types of heat treatments and surface on thermal fatigue resistance of AISI H11 modified steel, this work evaluated and compared, in the laboratory, thermal fatigue resistance AISI H11 modified tool steel subjected to various combinations of thermal and surface treatments.

For thermal fatigue testing, automated equipment has been specially developed and built for the carrying out of tests. The operation of the equipment consists in the realization of thermal cycles with temperatures varying from 150 ℃ to 630 ℃. The heating was performed by electromagnetic induction, and the cooling performed by injection of water mixed with air.

For the carrying out of the tests were used twenty specimens (dimension: 20 mm×20 mm×90 mm), which were divided into five groups of four specimens. Each group was submitted to a different combination of thermal and surface treatment, with varying hardness between 44 and 46 HRC.

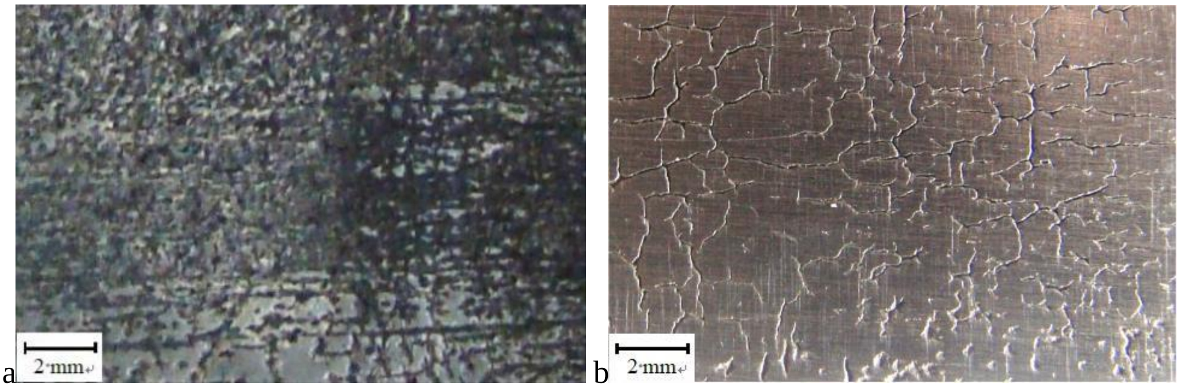
In the first group of specimens was conducted quenching and deep cryogenic treatment followed by double tempering. The second group was submitted to quenching with triple tempering. In the third group, the specimens were submitted to quenching, three tempering, nitriding and post-oxidation. The fourth group was submitted to quenching, three tempering, nitriding and PVD coating (TiN). The fifth and final group received quenching with triple tempering and post-oxidation.

In order to check the appearance and evolution of surface cracks caused by thermal cycles, each of the four specimens of each group was subjected to a different number of thermal cycles. The first specimens was subjected to 200 cycles, the second to 400 cycles, the third to 600 cycles, and the fourth specimens subjected to 800 thermal cycles. After each thermal cycling, a great oxidation of specimens was evidenced. The higher the number of thermal cycles increased the oxidation, which masked the cracking. A good contrast to observation of the cracks has been obtained by polishing on oxide layer (Fig.1a and Fig.1b).

The specimens coated with TiN presented a lower oxidation during the cycles; however, a spallation in coating was observed from 200 thermal cycles. The pattern of cracks formed on the surface of specimens of were similar, however the appearance and intensity of thermal cracks varied depending on the type of treatments of the specimens, indicating a greater resistance to thermal fatigue of specimens without nitriding.

The plasma nitriding failed to offer any improvement on thermal fatigue performance at high temperatures. In this case, the limiting factor of life for steel nitrided tool can be attributed to the extensive oxidation suffered during the thermal cycles. In addition, the surface nitrated, for having a limited ductility, unable to sustain the tension produced in the thermal cycles.

**Keywords:** thermal fatigue, thermal cycles




a b

Fig.1 (a) Image of the surface (with oxidation) of the specimens H11 modified after 800 thermal cycles; (b) Image of the surface (without oxidation) of the specimens H11 modified after 800 thermal cycles Surface quenched and tempering

# Evaluation of hard coatings obtained on AISI 15B30 and AISI 8640 steels by thermo-reactive deposition treatment

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**Abstract:** The wear of the components in the industrial processes constitutes one of the main problems encountered during the operation in the manufacturing processes. Because of this, a great deal of scientific and technical effort has been devoted to the development of layers or coatings with superior performances to the substrates, which results in one of the most versatile ways to improve wear performance, thus obtaining components that perform well surface, allied to the mechanical properties of the substrate. The TRD process by immersion in salt bath was developed by Toyota Motor Corp. for more than 30 years in Japan, specifically to solve problems related to wear. The method uses the borax salt (sodium borate - $Na_2B_4O_7$) fused with additions of elements in the form of powder for the formation of carbides. These elements are introduced into the bath as ferro-alloys or oxides, and addition of a reducing agent such as $B_4C$ or aluminum is also required. The carbide forming elements combine with the substrate carbon for the production of high hardness layers (the substrate must have a carbon content of more than 0.3% by weight for the production of carbides). Since the growth of the layers is dependent on carbon diffusion, the process requires a relatively high temperature, between 800 and 1250 ℃, with treatment times ranging from 10 min to 12 h. The temperature of the bath can be selected to correspond to the austenitizing temperature of the substrate, which allows the piece to be tempered or austempered directly after treatment. The objective of this work was to verify the effect of TRD treatments, performed under different conditions, on the properties of an AISI 15B30 and AISI 8640 steels, evaluating microstructural changes, resistance to wear and hardness. The components used to produce the salt baths were borax (sodium borate: $Na_2B_4O_7$), iron-vanadium (55wt% vanadium), iron-niobium (63wt% niobium) and aluminum (97wt% purity). Each salt bath used for TRD treatment was composed of 81wt% borax, 16 wt% iron alloy (iron-niobium or iron-vanadium) and 3 wt% aluminum. The ferro-alloys were added to the baths in powder form, with particle size less than 45 μm. The temperature used in the treatments was 1000 ℃ during 2 and 4 h. After the TRD treatments, the samples were characterized by optical (OM) and scanning electron microscopy (SEM), X-ray diffraction (XRD) and Knoop micro-hardness (hardness average of the layer and cross-section of hardness), as well as calotest type test of micro-adhesive wear with fixed sphere. Layers adhesion to substrates were verified by Daimler-Benz Rockwell-C qualitative tests (as stated in standard VDI-3198). The treatments of TRD produced layers of uniform carbides, with hardness above 2000 HK, presenting a flat interface with the substrate. The sharp increase in micro-adhesive wear resistance indicates the possibility of expanding the field of application of AISI 15B30 and 8640 as well as reduce maintenance costs, thus increasing the service life of parts and components.

**Keywords:** AISI 15B30, AISI 8640, TRD Treatment, carbide layer, micro-adhesive wear test

# The transpassive behavior of Inconel 625 alloy in 0.05 M sulfuric acid

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**Abstract:** Inconel 625 alloy, as a high corrosion-resistant alloy, is commonly used in chemical industry, and its performance degradation is often related to the dissolution of passive film in transpassive state. Common electrochemical approaches can not describe the transpassive behavior of each element in alloy. Herein, inductively coupled plasma source mass spectrometer (ICP-MS), combined with potentiostatic polarization, was used to observe the dissolution behavior of each element in the film and analyze the effect of elements on the stability of the passive film in 0.05 M sulfuric acid.

Electrochemical work station was used to characterize the electrochemical behavior in transpassive region. Then, ICP-MS (NexlON 350D, USA) was used to analyze the concentration variation of each element with the transpassive potential in 0.05 M sulfuric acid.

The composition of the wrought alloy 625 was shown. Electrochemical tests (IM6eX ZAHNER, Germany) were conducted in 0.05 M $H_2SO_4$ solutions in a 250 mL three-electrode cell with a saturated mercurous sulfate reference electrode (MSE, 0.616 V & SHE). The concentration of each element in solution was collected by pipette, when potentiostatic polarization was applying.

The surface morphology of alloy 625 in transpassive state was shown. The thickness of the passive film increased rapidly, otherwise the film could not be observed by SEM. In the meantime, the film started to dissolve in solution. The variation of steady state current density (Iss) with time indicated that the oxidation rate of the film in transpassive region, comparing that in passive range, rose by two orders of magnitude or more. The increase of the anodic current indicated the acceleration of oxidation reactions which was due to the soluble oxidation products formed with high valence. Thus, the concentration variation of a solute is consistent with the oxidation rate of the corresponding metal element at the film/solution interface. The concentration of each element of alloy 625 in solution when different potentials were respectively applied with varying time was shown. The relative content of each element in solution was compared with that in matrix. The stability of iron oxides was the worst, as the content of iron products at 0.8 V in passive range was much higher than the content of iron itself in matrix. When the potential entered the transpassive range, the corresponding increase of anodic current was attributed firstly to the oxidative dissolution of Ni and secondly to the oxidative dissolution of Cr. For the element Mo, the relative content in solution was nearly independent of the applied potential.

In passive range, the oxidation current was mainly due to the oxidation reactions of iron. In transpassive range, the instability of the passive film on alloy 625 was related firstly to Ni and secondly to Cr. Metal Mo played a significant role in the corrosion resistance of the passive film due to its independence of the potential.

**Keywords:** transpassivity, inconel 625, dissolution behavior

## Effect of nitriding potential and temperature on surface phase after austenitic nitriding in JIS-S25C steel

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**Abstract:** To clarify the surface phases obtained after austenitic nitriding, gas nitriding was performed at 899, 920, and 940 K under several nitriding potentials in JIS S25C steel and pure iron. In pure iron, the obtained phases mostly matched the Lehrer diagram except for a part of the results, especially at 920 K. At 920 K, γ' had the lower ε phase which forms under the nitriding potential lower than that of γ' although the lower ε phase is formed at more than 923 K in the Lehrer diagram. In S25C steel, the obtained phases were mostly ε phase under the conditions with a compound layer formation, so the results hardly matched the Lehrer diagram except for the result of 899 K-KN=0.16 because of the single γ' formation. The carbon concentrated compound layers were confirmed in the high nitriding potentials, e.g. 899 K-KN=0.5, while the decreased carbon compound layers were confirmed in the low nitriding potentials, e.g. 899 K-KN=0.16. Therefore, ε phase was stabilized in high nitriding potentials because of the high carbon and nitrogen concentration, while ε phase was not stabilized in low nitriding potentials because of the low carbon and nitrogen concentration. The decrease in carbon concentration in low nitriding potentials is caused by the promotion of surface decarburization due to the delay in the compound layer formation initiation time.

**Keywords:** austenitic nitriding, carbon steel

## Quenching homogenization in nozzle-type high pressure gas quenching furnace

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**Abstract:** Compared with oil or other liquid media quenching, high pressure gas quenching has the advantage of reducing risk concerning environment and operator. However, static shows that inhomogeneous flow has result in different level of hardness in the same batch high pressure gas quenching.

In this paper, numerical simulations based on nozzle-type high pressure gas quenching furnace have been carried out to analyze the quenching homogenization involving that two different form and position of charge. Besides, different air duct structure also was simulated. Result shows that, the form and position of charge has great effect in quenching homogenization, some suggestions were presented to improve the homogenization. Simulation also find that air duct with uniform distribution doesn't mean a flow homogenization, the nozzle-type high pressure gas quenching furnace as a most popular high-pressure equipment need to more studied on the quenching homogenization.

**Keywords:** gas quenching, quenching homogenization, numerical simulation

# Ultra-high strength steel 50CrNiMoVA austempering process on the strength and toughness

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**Abstract:** This paper take the high strength steel 50CrNiMoVA used in the chain of the automotive sub-actuator as the study object. Using different processes of austempering process validation and metallographic analysis to investigate the quenching temperature effect on the material microstructure and mechanical properties. On this basis, the best heat treatment process of the steel can be obtained. The results showed that: The 910+320 ℃ heated salt bath austempering process, significantly improving the strength and toughness.

**Keywords:** ultrahigh strength steel, chain, austempering, mechanical properties

# 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 work-pieces 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

# Development of induction heating and tempering production line of high-diameter ratio bar

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**Abstract:** The development process of induction heating and tempering production line of high-diameter ratio bar was introduced, and the development and debugging methods of equipment such as continuous heating induction furnace and spray quenching mechanism were described. Practice has proved that: the production line of core and table heating is uniform, high production efficiency, green energy-saving pollution-free, high degree of automation; the bar dealed with the production line has uniform hardness, small deformation, order the rack machining requirements.

**Keywords:** high-diameter ratio bar, induction heating, conditioning treatment, quenching deformation, energy-saving

# Nanoindentation and nanoscratch behaviors of TiN films fabricated by plasma immersion ion implantation and deposition on bearing steel

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**Abstract:** In order to enhance the critical scratching resistance of TiN film and improve the mechanical property of bearing parts, TiN hard protective films were fabricated by plasma immersion ion implantation and deposition (PIIID) technique on AISI52100 bearing steel. The microstructure and chemical composition of TiN films were characterized by X-ray diffraction (XRD), atomic Force microscope (AFM) and scanning electron microscopy (SEM). The nanohardness, elastic modulus and nanoscratch behavior of TiN films were carried out by nanoindentation and nanoscratch process. The XRD result show that the surface film layer includes three kinds of titanium compounds, TiN, $TiO_2$ and $TiO_xN_y$. The growth of TiN films on (200) plane exhibit a preferred orientation. AFM indicates that the TiN films have extremely smooth surface, high uniformity and efficiency of space filling over large areas. The maximum nanohardness and elastic modulus of TiN/AISI52100 sample are 22.5 GPa and 350 GPa, which increase by 104.5% and 50% respectively than those of bearing steel substrate. The nanoscratch optical microscope (OM) and scratching displacement-depth (D-D) curves reveal that the TiN films have three stages in the process of scratching: elastic recovery, elastic-plastically deforming, cracking loading and delaminating unloading. The three stages occur successively with the increase of load during nanoscratch. The PIIID TiN films have good elastic recovery behaviors and its critical scratching resistance reaches 80 mN.

**Keywords:** plasma immersion ion implantation and deposition (PIIID), nanoindentation, nanoscratch behaviors, TiN film, bearing steel

## Oxidation behaviors and self-healing performance of MoSiAlY coating on γ-TiAl substrate by a surface alloying method

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**Abstract:** A novel MoSiAlY coating was developed on γ-TiAl alloy to improve its oxidation resistance by double glow plasma surface alloying technology. This study focused on the oxidation behaviors and self-healing performance of MoSiAlY coating at isothermal oxidation test for 100 h. The coating transformations were analyzed by observing its morphologies, element distribution and phase structure using electron microscopy equipped with an energy-dispersive spectrum and X-ray diffraction. The results indicated that the oxidation resistance of γ-TiAl alloy was effectively improved by MoSiAlY coating at 900 ℃. Since reacting with element Al dispersing in the coating to Ti-Al intermetallics, the outward diffusion of element Ti from substrate γ-TiAl was suppressed successfully. The volume expansion of phase $SiO_2$ from $MoSi_2$ was responsible partly to the self-healing ability of MoSiAlY coating. The original MoSiAlY coating transformed to a multilayered coating after oxidation test which consisted of an oxide scale, an oxygen-depleted area and a diffusion layer.

**Keywords:** self-healing performance, oxidation resistance, double glow plasma alloying, diffusion suppression

## Effects of percent reduction in area on the S-phase formed on low temperature plasma nitrocarburized austenitic stainless steel

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**Abstract:** The S-phase behavior of the STS316L steels was investigated in response to the variation of percent reduction in area during plasma nitrocarburizing process. Plasma nitrocarburizing treatment at 400 ℃ was applied to the specimens (0%, 30%, 50%, 70% percent reduction in area) obtained by rolling the STS316L steel plate using a rolling mill after the solution heat treatment. The maximum thickness of hardened layer was obtained at 30% percent reduction in area. The thickness of the hardened layer (S-phase) was about 11 and the surface hardness was about 870 HV0.1, which was about 2.6 times higher than before treatment (hardness of about 330 HV0.1 before treatment). However, the thickness of the hardened layer of samples with increasing percent reduction in area higher than 30% decreased slightly, since the crystal grains of those samples were oriented perpendicular to the direction of nitrogen and carbon penetration. Compared with before plasma nitriding treatment, the specimens with a 30% percent reduction in area showed improved corrosion resistance due to lower corrosion current density and higher pitting potential.

**Keywords:** plasma nitrocarburizing, percent reduction in area

# Effect of intercritical quenching on microstructure and microhardness of a low carbon carburized steel

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**Abstract:** The microstructure and microhardness of the low carbon carburized steel after quenched from different intercritical temperatures have been investigated. The results indicate that the number of the carbides in the carburized layer and the ferrites in the center both decrease with quenching temperature increasing. On the other hand, increasing quenching temperature brings a slower trend of carbon content distribution gradient in the carburized layer, resulting in the presence of a crosspoint on the distribution curve of carbon content for lower and higher temperature quenched specimens. The microhardness distribution characteristic is in well agreement with the profiles of carbon content, which is due to the effects of carbon content and microstructure.

**Keywords:** low carbon steel, intercritical quenching, microhardness, carburization

# Optimization of processing parameters on low temperature plasma nitriding of AISI 420 martensitic stainless steel

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**Abstract:** Low temperature plasma nitriding was performed in order to study the effect of processing parameters like processing temperature, treatment time, nitrogen and carbon content on the expanded martensite layer (α'N layer) of the AISI 420 martensitic stainless steel. Plasma nitriding was carried out at various temperature from 370 ℃ to 430 ℃ and various times from 4 to 15 h, with changing the nitrogen content from 10% to 35% and carbon content from 0% to 6%. After treatment the sample were characterized by optical microscopy, X-ray diffraction, GDOES analysis and micro-hardness testing. The surface hardness and α'N layer thickness values increases with increasing processing time and increasing the nitrogen content. Contrary, these values decreases with increasing the methane content. The highest surface hardness (around 1330 HV0.1) and highest α'N layer thickness (around 24 μm) were achieved when treated with 25% nitrogen content for 15 h. Although, this longer processing time exhibits poor corrosion resistance. The corrosion resistance decreases with increasing methane content. Best corrosion resistance is achieved when treated with 25% nitrogen content for 6 h, without any methane content.

**Keywords:** plasma nitriding, martensitic stainless steel

## Effect of heat treatment on micro arc oxidation coatings of Ti-5Al-1V-1Sn-1Zr-0.8Mo alloy

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**Abstract:** In order to reveal the influence of heat treatment on the formation process and characteristics of micro arc oxidation (MAO) coating on Ti-5Al-1V-1Sn-1Zr-0.8Mo alloy. MAO coatings were prepared on Ti-5Al-1V-1Sn-1Zr-0.8Mo alloy with different heat treatment process. The characteristics of coating were studied by using scanning electron microscope (SEM), energy-dispersive spectroscopy (EDS), laser scanning confocal microscopy (CLSM) and X-ray diffraction (XRD). The results show that the microstructure and element distribution of the substrate alloy was changed with heat treatment. With the comparison of casting alloy, the electrical resistivity of alloy with 800 ℃ solution heat treatment was decreased which lead arced and oxidized easily. With 950 ℃ heat treatment process, the element of the substrate alloy uniformly distributed, the roughness and micro cracks on the coating surface were decreased which mean that the compactness of coating is better. It is also found that the surface morphologies of the coatings on the substrate with heat treatment were changed. The roughness of coating on the substrate with heat treatment was reduced by about half. By XRD result, the MAO coating is composed of two phases, the rulite phase and anatase phase.

**Keywords:** heat treatment, micro arc oxidation, coating, Ti-5Al-1V-1Sn-1Zr-0.8Mo alloy

## The development of multi-functional coating on high level mini endoscope lens

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**Abstract:** The anti-reflection(AR) coating used in many devices like glasses lens, camera lens, microscope lens and monitor panel for increasing the light transmittance by reducing the reflection loss. Now the reusable medical image instrument still needs to be improved in antisticking and wear resistance properties.

In this research, the new multi-functional coating on high level mini endoscope lens had been developed. The coating has very high hydrophobic properties that the water contact angle above 110° and the synthetic synovial fluid contact angle above 95°. It also shows high visible ligh transmittance above 99% at 550 nm wavelength and the corrosion resistance of coating passes 100 h sterilization test in the activated glutaraldehyde solution. The hardness of coating is higher than 10.8 GPa provides excellent anti-wear protection for the lens substrate. The prototype of anti-sticking mini endoscope device been fabricated and confirmed its effect above 50% by domestic medical center.

**Keywords:** endoscope lens, sputtering, anti-reflection

# Effect of programmable ion permeation (PIP) technology on microstructure and corrosion resistance of 304 stainless steel

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**Abstract:** In this paper, the “orthogonal test” method was used to study the main process parameters of PIP ion infiltration process: temperature, time and effective infiltration agent concentration on the microstructure and corrosion resistance of 304 stainless steel, and the optimal process parameters were obtained. The microstructure, phase composition, wear morphology and electrochemical polarization curves of the PIP treated modified layer were studied by metallographic microscope, X-ray diffractometer (XRD), scanning electron microscopy (SEM), friction and wear tester and electrochemical workstation. The results show that supersaturated $\gamma_{NC}$ single phase is formed after treated by PIP optimization process in 304 stainless steel, no CrN phase is precipitated; PIP layer hardness reaches 994 HV0.025, and the wear mechanism changes from adhesive wear before PIP treatment to abrasive wear after PIP treatment, the wear resistance is significantly improved. After PIP treatment, the corrosion potential ecorr increases from -0.183 mV to -0.162 mV, and the breakdown voltage $E_p$ increases from -0.25 mV to 0.10 mV. The above results indicate that the single $\gamma_{NC}$ phase formed by PIP treatment can not only improve the wear resistance of stainless steel surface but also increase the pitting resistance of stainless steel.

**Keywords:** programmable ion permeation, 304 stainless steel, wear resistance, corrosion resistance

# Study of plasma electrolytic oxidation coated light-weight AlSi10Mg cellular lattice structures fabricated via selective laser melting

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**Abstract:** Aluminum alloy lattice structure has been applied in thermal protection system of hypersonic aerospace vehicle that works under harsh environment due to its high strength-to-weight ratio and reliability. However, conventional manufacturing method such as casting is difficult to achieve complex cellular lattice structures with designed cell shape and size. Furthermore, the insufficient durability of aluminum alloys to high temperature and periodic loading limit its application under harsh environment. The current study evaluates the manufacturability and performance of plasma electrolytic oxidation coatings on AlSi10Mg cellular lattice structures. Due to the self-supported feature of designed unit cell, 19%-50% volume fraction AlSi10Mg cellular lattice structures can be fabricated by selective laser melting (SLM) process. PEO coatings were deposited on the structures under pulsed DC power in $Na_2SiO_3$ electrolyte. Uniform discharging was observed during PEO deposition and a 10 μm coating was observed with good adhesion on the surface of AlSi10Mg cellular lattice structures. The heat conductivity coefficient and coefficient of thermal expansion were evaluated and mechanical properties such as compressive strength and fatigue resistance under periodic stress of the PEO coated structures were measured.

**Keywords:** plasma electrolytic oxidation, selective laser melting, AlSi10Mg cellular lattice structure, thermal protection system

# Application of Profibus-DP fieldbus in data communication of heating furnace control system

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**Abstract:** This paper introduces the data communication operation of SIEMENS S7-300PLC and Delta VFD series frequency converter and FP93 series temperature control meter through Profibus-DP fieldbus. According to the actual project, the problems that can not be configured the inverter and the temperature control meter in the field debugging process are carried out analyzed and explained from two aspects of hardware and software respectively. The analysis and processing measures include the relevant parameters of the frequency converter communication and the communication between the temperature control meter Modbus-RTU through the PM127 gateway and the Profibus-DP communication, and the real-time communication between the PLC and the frequency converter and temperature control meter in the programming software environment of the TIA Portal. The communication scheme designed in this paper has been successfully applied to the field control system, with high control accuracy and reliable operation.

**Keywords:** Profibus-DP, PLC, communication, configuration

# The novel coating technology in steel remanufacturing industry and construction of international standards

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**Abstract:** With the increase of high value-added steel products and the demand for energy conservation in steel enterprise, higher requirements of surface coating re-manufacturing technology were proposed for metallurgical equipments. This study introduced the latest applications of laser, thermal spraying and physical vapor deposition (PVD) technologies in the metallurgical industry. The laser surface alloying and cladding were applied to repair and remanufacture the GCr15 and cast iron roller and the gradient multi-layer cladding layers were designed to achieve the composite coatings with high surface integrity and superior property; high-velocity oxygen fuel (HVOF) and air plasma spraying (APS) technologies were used to produce inorganic sealing-ceramic-metal multi-scale composite coatings on sink roller and high-temperature furnace roll; the research on the new PVD method to replace the electroplating on the application of surface reinforced silicon steel cold roll was carried out for the first time in China, which would develop the PVD production line to realize the mass application for rollers. Finally, the construction of international standards on thermal spraying and PVD were introduced in this report. The ISO subcommittee of ISO/TC107/SC9 PVD coatings was approved at Anhui University of Technology, which would play an important role in set up the direction of international standards in this area for China.

**Keywords:** surface coating, PVD, thermal spraying, laser, international standards

## Effect of electromagnetic fields on microstructure and properties of Cr(Ti)AlN hard coatings prepared by arc ion plating

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**Abstract:** A series of CrAlN and TiAlN hard coatings were prepared by industrial arc ion plating with or without embedded axial electromagnetic filtration technology. The microstructure evolution and mechanical properties of the hard coatings were compared after annealing. The results show that the grain size of the hard coatings prepared with electromagnetic fields were decreased significantly and the quantity of hard particulates was reduced, leading to the improvement of compactness. Furthermore, the wear resistance and thermal stability of them were improved significantly. In addition, the CrAlN and TiAlN coatings were deposited on different types of dies. Compared with the uncoated dies, the coated dies show excellent service life.

**Keywords:** arc ion plating, axial electromagnetic field, microstructure evolution, mechanical property, wear resistance

## Research on the control of heat treatment deformation of the thin and carburized compound planetary line gear ring

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**Abstract:** The structure of the thin and carburized compound planetary line gear ring is complex and the diameter is large. During early trial-manufacture, the gear ring cannot meets machining requirement because of the heat treatment deformation exceeding allowable limit. According to this condition, the control of heat treatment deformation was carried out during carburizing and quenching treatment. The heat treatment deformation of the gear ring is controlled under the machine-finishing requests by optimizing the pre-carburizing process and pressure quenching molds. The product quality is ensured and the production goes on well.

**Keywords:** thin wall, carburization, gear ring, heat treatment, deformation, pressure quenching mould

## Fabrication and characterization of a highly corrosion-resistant nanocrystalline $Al_2O_3$/MgO composite coating on magnesium alloy AZ33

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**Abstract:** A dense nanocrystalline $Al_2O_3$/MgO composite coating was successfully fabricated on the Mg-3.0Al-3.0Zn (wt%, AZ33) alloy by a facile chemical conversion method for the first time. The new conversion solution by introducing EDTA-2Na successfully promote the reactivity of $Al^{3+}$ on the surface of substrate. Then, a dense and even nanocrystalline conversion coating was obtained through heat-treatment, which greatly improved the corrosion resistance of the substrate according to the electrochemical tests. The composition, structure and morphology of the coating was investigated via Transmission Electron Microscope (TEM) and Scanning electronic microscope (SEM), etc. The hydrogen evolution measurements in 3.5wt% NaCl solution indicated that the composite coating could kept stable and protect the substrate from corrosion during 336 h immersion. It was believed that this effective and low-cost method could provide a new idea for the protection of magnesium alloys.

**Keywords:** magnesium, nanocrystallin7e composite coating, corrosion resistance

## Research of high precision tempering furnace cover with revolution and rotation of the workpiece

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**Abstract:** The high-precision tempering furnace cover, which consists of hoisting furnace cover, furnace cover rotating seat, driving device, water cooled oil seal device, control system and so on, is introduced in this study. The planetary structure is applied to this tempering furnace cover, which makes the workpieces rotate as well as orbits along the center axis of the furnace when the they are tempered. Compared with the conventional static hanging furnace tempering cover, the workpieces are tempered more uniformly, and high mechanical performance workpieces are reaped.

**Keywords:** rotating furnace cover, revolution and rotation, uniform tempering, deep hit furnace