# 27th IFHTSE CONGRESS & EUROPEAN CONFERENCE ON HEAT TREATMENT 2022

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Wyndham Grand Salzburg Conference Center

# Book of Abstracts

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**SURFACE ENGINEERING / 1**

## Carbo-nitriding of CVT pushbelt components for further optimization of wear and fatigue properties

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In recent years the use of pushbelt Continuously Variable Transmissions (CVT) in automotive applications has seen a strong worldwide growth. Currently over 75 million pushbelts have been produced by Bosch Transmission Technology, while Bosch continues to respond to market demands regarding electrification, efficiency, NVH, cost, and power density. Power density comprises the transmittable power & torque, transmission size, ratio coverage, and durability. Enhanced power density of the pushbelt CVT can be achieved by further improving the wear and fatigue properties of pushbelt components, via optimization of hardening heat treatments and resulting component microstructures. Test results will be presented at the 27th IFHTSE Congress & ECHT2022 to demonstrate that the wear and fatigue properties of 75Cr1 pushbelt elements can be further improved when these elements are subjected to carbo-nitriding treatments. These results represent the potential for a further increase in power density of pushbelt designs.

Keywords: Carbo-nitriding, 75Cr1 steel, pushbelt components, wear and fatigue properties

**Speaker Country**:

The Netherlands

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**STEEL / 2**

## The hydrochloric acid corrosion susceptibility of steel rebars exposed to heat treatments

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Steel rebars are widely applied in the construction field. They are combined with concrete to obtain one of the most used construction composite material: reinforced concrete. The steels are responsible for the high tensile properties. In special chemical environments they suffer from corrosion. With low pH's caused by carbonation they exhibit uniform corrosion, while in the presence of NaCl salts they show localized corrosion, which in turn may have detrimental effects on the rebar sections. The properties of steels can be modified by several thermal treatments. The corrosion resistance may also be affected by the temperature. Changes on the surface and in the microstructure takes place. In this work a conventional rebar B 500 type with a diameter of 12 mm is exposed to shock heat treatments with the temperature ranging between 900 oC to 1400 oC for a time period between 5 minutes to 120 minutes and water quenched. Hardness measurements were carried out to evaluate the local changes from the surface to the interior of the rebar and the related modification of the microstructure. The specimens were subsequently exposed to a 10 wt. % HCl solution up to 30 days to determine the intensity of the localized corrosion phenomena. The changes in the microstructure

and in the corrosion properties of the rebars were investigated by means of visual inspection, optical microscopy and scanning electron microscopy with EDAX.

**Speaker Country**:

Switzerland

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**STEEL / 3**

## Hardenability of PM steel alloyed using tailored Master Alloys

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The ferrous powder metallurgy industry is facing major upheavals currently, which however also offer opportunities. New materials and concepts, made possible by tailored design, are a way to prepare for new tasks. Alloying of PM steel through the the master alloy route is a concept that combines efficient usage of alloying elements, also of such with high oxygen affinity, with accelerated homogenization via liquid phase sintering. Thus, improved properties can be attained while maintaining dimensional precision, which makes the PM route more attractive. In the present study, different master alloys containing Fe, Si, C, Cr and/or Mn are admixed to various ferrous base powders, the mixes then being consolidated by pressing and sintering. The materials thus produced are compared to a commercial sinter hardening PM steel grade in terms of hardenability. CTT diagrams are presented for all materials, and hardness data from quenching dilatometer experiments are compared to the hardness values achieved by sinter hardening in the lab furnace.

**Speaker Country**:

Austria

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 4**

## Visualization of vapor film collapse mode during unsteady boiling on oil quenching by using cellular automaton simulation

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The vapor film collapse that occurs in the quenching process is complicated and affects the heat treatment quality.
However, in the past, in order to formulate the vapor film collapse on a simulation, it was necessary to perform a very large amount of computational calculation (CFD), which was a problem in terms of computer resources.
In this study, the vapor film collapse phenomenon is easily visualize using cellular automaton simulation, and the heat treatment quality is predicted by the heat treatment simulation using the heat transfer coefficient coefficients obtained by this, so that the heat treatment considering the influence of the steam film collapse phenomenon is taken into consideration. Succeeded in reproducing the strain

**Speaker Country**:

⊠⊠

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 5**

## Discussion on energy saving and emission reduction technology of heat treatment equipment

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Global warming is one of the biggest threats to our environment. Therefore, energy efficiency measures as well as emission reduction have become a top priority for large energy consuming industrial sectors like the field of industrial furnaces. The change in the European energy police has important significance for the industry in terms of reducing CO2 emissions. Based on these challenges, this paper highlights potential savings, which can be practically implemented today, as well as forward-looking solutions.
In order to detect saving potential a mass- and energy balance was set up for a gas-fired pusher type furnace. Focusing on the exhaust gas losses the burner technology itself, but also alternative energy sources like H2 – even the changeover to electrical heating systems – were discussed in detail. In parallel NOx emissions have to be taken in account. Furthermore, secondary energy saving measures like heat extraction were taken into consideration and incorporated into the evaluation. With respect to maintenance issues the aspect of improving thermal insulation of heat treatment furnaces was analyzed under economic aspects as well.
It has to be pointed out, that modern process control systems already offer numerous options to get an overview of the energy consumption and provide (partly) an energy-saving mode like standby mode and / or opportunities to optimize process parameter in terms of energy saving like adjustment of process gas flow rate for individual parts.
Anyhow, new technological developments are already in the pipeline and changes in the legal resp. political framework will open up many possibilities with a different perspective on ROI.

**Speaker Country**:

Austria

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 6**

# Determination of machining parameters for a specific adjustment of the residual stress profile by induction hardening

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Within the research work of the transregional collaborative research centre TRR136, the so-called Process Signatures were determined for some processes that result due to an exclusively thermal load for the component surface layer. These Process Signatures represent correlations between material modifications (e.g. residual stress and hardness profile) and characteristic values of the material loading (here e.g. maximum temperature, maximum temperature gradient). The underlying idea is that the material does not know any processes but only loads caused by processes. In particular, the same loads lead to the same material modifications regardless of the process. A decisive advantage of this concept over conventional approaches is the possibility of calculating the necessary internal material loads backwards on the basis of concrete specifications for the material modifications. If there are additionally correlations between internal material loads and process quantities as well as between process quantities and machining parameters, the process quantities and ultimately the necessary machining parameters can be determined, too.
In this paper, this procedure is introduced using the example of one-sided induction hardening of cuboidal components made of quenched and tempered 42CrMo4. The necessary Process Signature and the two correlations just mentioned were determined by experimental and numerical investigations. The specifications for the material modifications consist of the surface residual stresses and the depth for the sign change of the residual stresses from compression to tension. This quantity characterizes the position of the hardness drop, too.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 7**

# Quenching with Aqueous Polymer Solutions

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Quenching with aqueous polymer solutions has some distinct advantages over classical oil quenching. Among these are the good environmental properties and the possibility to adjust the quenching performance between oil and water quenching.Nevertheless, critical aspects must also be taken into account. When quenching steel parts with polymer solutions, explosive phenomena can occur, often accompanied by large cooling rate changes. These "explosions" can lead to pressure waves and vibrations in the quenching tank, which in the long run can even destroy weld seams of the tank. They are also capable of displacing even heavy components in a batch, creating a risk to worker

safety. In order to be able to counter these risks, a research project was initiated by the AWT technical committee "Quenching" and carried out by Leibniz-IWT, in the framework of which, among other things, experimental investigations were carried out in a laboratory quenching bath and in an industrial quenching tank. The polymer type, the type of incident flow, the flow velocity, the bath temperature and the size of the test shafts were varied. Near-surface temperature measurements inside the shafts were performed to characterize the resulting quenching processes. Simultaneously, electrical conductivity measurements and audio and video recordings were made to localize insulating films on the surface and their collapse.
To systematize the large number of measurement results, four characteristic types of cooling processes were identified. These are defined by the following four characteristics: Speed of degradation of the insulating layer, existence of rewetting fronts, reheating and temperature plateaus. In this paper, the approach and specifics of the four types are explained and the assignment of the different quenching processes to the types is presented. Furthermore, results from tests in the industrial quenching tank are presented and conclusions for a follow-up project are derived.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 8**

## Salt Bath Nitrocarburizing: Technology ready for future including environmental challenges

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Rich of more than 60 years development in industrial conditions, Salt bath nitrocarburizing (SBN) has been able to adapt itself to match standards in so different fields (Aeronautics, Energy, Automotive, Construction Equipment, Military…).

Thus, SBN is nowadays an essential surface treatment solution, globally established and recognized with more than 500.000 tons of parts yearly treated with SBN process.

The HEF's SBN leads to a unique combination of surfaces performances, like high corrosion resistance, friction properties, wear protection which allow increasing drastically lifetime of treated components. The safe liquid medium, in situ regenerated, used as nitrogen and carbon source permits homogeneous treatment of complex parts' shapes. It also represents the highest robustness, stability and productivity compared to others thermochemical treatments (gas and plasma).

Based on its worldwide presence, its continuous improvement and high industrial maturity, HEF's SBN is the easy-operate technology ready for future with its " road to CLIN 4.0" program. Indeed, SBN is released as replacement of others surfaces treatments solutions such as hexavalent chromium plating. That's why HEF's SBN is proven to be not only an alternative on both technical aspects and price competitiveness but also a real solution answering environmental challenges.

Environmental constraints are the highest priority in the continuous development of this treatment worldwide. This process has already replaced and will keep on substituting pollutant technologies. Aiming to reach and to overtake current legal local regulations and their future releases, HEF develops its SBN activities in compliance with the most severe environmental standards in the world. The recent HEF's development of an industrial recycling of consumables leads to a liquid effluent free operation. Finally, this nitrocarburizing process does not contain any COV (no use of organic solvents), any NOX (no need of burners used for gas detoxification), or other hazardous compounds.

**Speaker Country**:

French

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**Poster** / **9**

## Deep Cryogenic Treatment of AISI H11, AISI H13 and AISI H21 Hot Work Tool Steels

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Manufacturing industry is one of the world leading industries, as its end products (tools, gears, bearings, shafts, beams, bolts etc.) influence our everyday life. The performance of used metallic materials and products is subjected to the selection of steel type (main alloying elements), proper design, manufacturing accuracy and application of proper heat treatment. One of the options is deep cryogenic treatment (DCT; temperature below -160 ℃), whose implementation in industry has emerged in the last years, despite its long history. Hot work tool steels, which were selected for detailed investigation of DCT effect are AISI H11, AISI H13 and AISI H21, showing certain differences in the chemical composition. For selected group of tool steels, study showed that DCT also induces precipitation of different types of carbides by 56 %, M23C6, by 25 % M7C3 and as well M6C carbides by 28 %. This additionally indicates the complex DCT mechanism, which does not universally modify all ferrous alloys in the same manner, but is strongly related to characteristics of each ferrous alloy. DCT induced also the transformation of retained austenite into martensite in hot work tool steels. DCT induced also a finer homogenous microstructure of bainite and martensite, with preferable orientation of martensite along [101] and [001] directions. Temperature effect of heat treatment in correlation to DCT performance showed that subgroups with higher austenitization and lower tempering temperature had a stronger impact of DCT on steel properties (hardness, fracture toughness and impact toughness). The observation of DCT effect on hot work tool steels showed that the chemical composition, heat treatment temperature and phase transformation within the material influences the DCT performance.

**Speaker Country**:

Slovenia

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**STEEL** / **10**

## Corrosion resistance of cryogenically treated tool steels.

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[2] *Poznan University of Technology*

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Corrosion resistance may be of some importance if the tools are operated in harsh environments that contain acids, seawater or other chemical substances. Therefore it is appropriate to control this property carefully, by using proper heat treatment route. One of possible ways how to change the corrosion resistance of tool steels is the application of cryogenic treatment. This treatment reduces the retained austenite amount, produces extra carbides in steels microstructures, changes the precipitation of nano-sized carbides, and makes an overall microstructural refinement. These microstructural alteration change the corrosion potentials of exposed surfaces, and thereby the materials resistance against corrosion. In this paper the impact of cryogenic treatments on corrosion resistance is demonstrated upon an example of Vanadis 6 steel. This steel was subjected to different combinations of cryogenic treatments (-75, 140, -196 or -269°C) and tempering (no, 170, 330, 450 or 530°C). Then, the steel specimens were tested by potentiodynamic polarization method, in 3.5% NaCl solution. A general improvement of corrosion resistance of the material was recorded due to cryogenic treatment, with the maximum improvement after cryogenic treatment at -140°C. It was suggested that enhanced number and more uniform distribution of carbides can more than sufficiently compensate lowered retained austenite amounts, thus induce improved corrosion resistance.

**Speaker Country**:

Slovakia

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**Poster / 12**

## Plasma nitriding properties of sintered body formed using CoCrFeNiMn high-entropy alloy powder by varying ball-milling duration

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**Co-author:** Akio NISHIMOTO [1]

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Recently, it has been reported that CoCrFeNiMn high-entropy alloy (HEA) has excellent tensile strength and ductility at HEA at low temperatures. Through plasma nitriding at 673 K, an expanded fcc structure was formed on the surface of the HEA. Another study observed that dislocations were introduced on the surface of CoCrFeMn alloy powder through ball-milling. Simultaneously, strength improvement and strain hardening were observed. This study aims to evaluate the characteristics of the nitrided layer by performing DC plasma nitriding (S-DCPN) treatment on the sintered body of the HEA powder after ball-milling. The ball-milling was conducted on gas-atomized CoCrFeNiMn HEA powder samples for time periods ranging from 0 to 15 h to prepare a sintered body. Subsequently, this sintered body was subjected to S-DCPN treatment at 673 K for 15 h, at a gas pressure of 200 Pa under 75%N2-25%H2. During the plasma nitriding process, an austenitic stainless-steel screen was installed as an auxiliary cathode to ensure uniform heating and an increased nitrogen supply. Furthermore, the nitrided sample was subjected to X-ray diffraction (XRD) test, cross-sectional microstructure observation, surface morphology observation, cross-sectional hardness test, glow discharge optical emission spectroscopic analysis (GD-OES), corrosion test, and wear test. The XRD and GD-OES results showed that N concentration on the surface decreased with the ball-milling duration. After a wear test, the width and depth of the wear marks decreased with increasing ball-milling duration, thus exhibiting an increased wear resistance.

**Speaker Country**:

Japan

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**SURFACE ENGINEERING / 14**

## Improved fatigue performance of stainless steels by low temperature surface hardening

**Author:** Alexandra BAUER[None]

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Almost all components in technical applications experience alternating mechanical stress during their use. This can cause damage to the material, which increases with each load cycle and can ultimately lead to a fracture of the component. With regard to harsh, corrosive environments, austenitic stainless alloys are the material of choice. However, this highly favorable property is often opposed to relatively modest mechanical properties, particularly low fatigue and wear resistance.
Interstitial hardening accompanying low temperature carburizing prolongs the fatigue resistance, while maintaining the superb corrosion properties of this material class. This effect is due to the generation of large compressive residual stresses within the outermost surface of the component, which increases the surface hardness and prevents the surface nucleation of cracks.
Rotating bending fatigue tests acc. ISO 1143 on non-hardened and surface hardened AISI 316L (1.4404) were performed to generate a fatigue-life curve. The tests indicated that low temperature carburizing enhances the fatigue strength by more than 40 % (521 MPa) versus untreated material (366 MPa). Additional testing at a fixed stress level of 400 MPa conducted in a corrosive environment resulted in an at least 10 times longer fatigue life with surface hardening, compared to the untreated material, which failed after 1 million cycles. The untreated sample parts even show signs of corrosion due to crevice conditions at cracks, while the surface hardened samples remained free from corrosive attack.
Based on these test results, application examples for different industrial sectors are presented (e.g. drive shafts in pump technology or springs in injection systems for automotive applications).

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 15**

## Combined CFD and heat treatment simulation of high-pressure gas quenching process.

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**Co-author:** Stefan LUTZ [1]

[1] *Schaeffler*

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In contrast to conventional quenching processes in liquids, the quenching intensity and characteristics
of high-pressure gas quenching can be adjusted by variation of the gas velocity and pressure. The

local
quenching intensity and hence the resulting hardness or distortion are not only depending on the quenching parameters but are also influenced by the batch built and the part itself. The traditional approach until now was to determine the optimum quenching parameters by performing several expensive and time-consuming test trials.
To improve the process development a digital quenching simulation model that combines the fields of
computational fluid dynamics (CFD) and heat treatment process simulation was developed. It was found that the gas flow and hence the quenching properties depend on both local (geometry of parts, carrier, and chamber) as well as global influencing factors (fan characteristics, system pressure and hydraulic resistances). Therefore, a CFD model that includes all these factors was realized. The approach includes a heat transfer analysis to determine the local heat exchange coefficients on the component level. By connecting the CFD and heat treatment simulation the local quenching characteristics are used to compute the temperature history of the quenched part. Based on a thermo-
metallurgical heat treatment simulation the computed local cooling curves and metallurgical phase compositions are used to accurately predict the part properties like microstructure and hardness. Hardness results for different batch positions, batch setups or tray systems can now be computed enabling an efficient virtual development of the gas quenching process. This method has been successfully validated and applied for spindles to homogenize the heat transfer on the part and in the
batch resulting in constant core hardness over the part. The simulation can also be used to identify causes of inhomogeneous distortion within batches by identifying unfavorable flow configurations.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**Poster** / **16**

## Gas-Cyclic Nitriding of Corrosion Resistant Steels

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Gas nitriding processes with cyclical rotation of ammonia and ammonia/air atmospheres are studied for surface strengthening of Cr-Ni corrosion resistant steels. One-, two-, and three-staged processes were experimentally investigated differing by gas atmospheres at the final stage of the processes. Gas-cyclic nitriding provides an intensification of saturation of alloyed steels with nitrogen due to the local effects of thermo-cycling. Microstructure and phase composition of diffusion layers are examined. During the final stage in the ammonia/air mixture, iron oxides remain in the compound zone; and a sharp decrease of micro-hardness is observed at the border of the layer with the core. Completion of the cyclic process with the stage of saturation in ammonia forms a nitride zone of γ'-phase. It was shown that three-staged process increases the thickness of the diffusion layer, and makes the micro-hardness profile smooth. Results of wear and impact toughness tests are discussed in correspondence with the layers' structure. After three-staged nitriding, the steels have the best wear resistance and keep satisfactory toughness due to the absence of ε-phase.

**Speaker Country**:

Russia

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**HEAT TREATMENT / 17**

## Carburizing atmospheres in heat-treatment furnaces - Contribution of industrial gases for reducing the carbon footprint

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The 2050 carbon emissions targets aiming to limit the global temperature increase to 1.5°C are particularly impacting the industrial sector including heat-treatment processing with high energy intensity and significant needs of industrial gases. Thus the reduction of the CO2 emissions linked to heat-treating of metals is becoming critical and the related carbon footprint must be carefully evaluated for new investments as well as for retrofitting of production equipment.

Within heat treating, carburizing is one of the most important processes, widely used for surface hardening of low carbon steels. Usually carried out in batch or continuous furnaces, the related CO2 footprint of carburizing can be assigned to furnace heating energy, cooling and quenching energy, carburizing atmosphere generation, power consumption, peripheral devices and the processing itself.

This study presents an estimation of the CO2 footprint linked to different sources of furnace atmospheres used for atmospheric carburizing, like endogas and nitrogen/methanol and for different kinds of furnaces. A comparison with the low pressure carburizing process and the related CO2 footprint of the required hydrocarbon gas supply is then performed. Several solutions developed by Air Liquide to reduce the carbon footprint of heat-treatment atmospheres will be also presented.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 18**

## Vacuum heat treatment of Ti6Al4V alloy produced via SLM additive manufacturing

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One of the main advantages of additive manufacturing processes is the fabrication of near net shape components of complex shape. Among the materials that can be processed with this technique, the Ti6Al4V alloy has proved to be an excellent candidate in several application fields, including aerospace, biomedical and dental.
Several works are present in the technical and scientific literature describing the good properties of this material obtained through selective laser powder bed melting technology and highlighting the need for an effective melt pool protection systems to avoid contamination by harmful species, such as oxygen and nitrogen. Products made from this alloy, in the as-built state exhibit a non-neutral internal stress state that can lead to cracking or deformation. Due to the martensitic transformation

undergone by the material during the process, the microstructure is also hard and brittle. Therefore, heat treatment is required to reduce the internal stress state and recover the ductility required under operating conditions. The high reactivity of Ti6Al4V even at this stage requires the use of a suitable shielding atmosphere or vacuum furnaces.
In this work, a study was conducted aimed at determining the correlations between heat treatment parameters and the microstructure, mechanical properties and deformations of some reference specimens made of Ti6Al4V. Heat treatments were performed in high vacuum varying the annealing temperature between 600℃ and 1100℃ and followed by cooling in Argon.
Finally, tensile tests were performed on specimens without any post-treatment surface finish to assess the influce of heat treatments on the mechanical properties of the samples.

**Speaker Country**:

Italy

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**SURFACE ENGINEERING / 19**

## Active-Screen Plasma Nitriding and Carburizing of an Austenitic Stainless Steel Small-Diameter Thin Pipe

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Surface hardening treatments such as nitriding can improve the mechanical properties to extend the applicability of austenitic stainless steel (ASS) fine and precise machining. Improving these characteristics without changing the design and material is highly advantageous, particularly for medical and surgical instruments. In particular, an improved bending rigidity of medical injection needles is desirable because a small needle diameter reduces invasiveness. However, no method has yet been reported for improving the bending strength of ASS without reducing its corrosion resistance. Moreover, nitriding has not been applied to thin pipes with a small diameter such as medical injection needles.
In the present study, low-temperature active-screen plasma nitriding (ASPN) and active-screen plasma carburizing (ASPC) are applied to improve the bending rigidity and corrosion resistance of an ASS pipe with a small diameter. The inner and outer diameters of the pipe were ⌀0.3 and ⌀0.4 mm, respectively, and the pipe length was 50 mm. ASPN and ASPC were conducted for 4 h at 578–638 K at 200 Pa.
The nitriding and carburizing layer thicknesses increased monotonically with the processing temperature. These results were consistent with the nitrogen and carbon concentration distributions measured using an electron probe micro analyzer. The existence of expanded austenite (S phase) was revealed using the X-ray diffraction patterns for ASPN and ASPC. Nanoindentation confirmed that the Young's modulus was improved in the nitrided region of ASPN. Bending strength increased with the nitriding temperature because the nitriding layer became thicker and the surface hardness increased. In the corrosion test, the nitrided and carburized samples did not corrode at low temperatures. These results indicated that low-temperature ASPN and ASPC achieved flexural rigidity and corrosion resistance in the small-diameter thin pipe comprising ASS.

**Speaker Country**:

Japan

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**STEEL / 20**

## New laws and formulae for making steels more efficient

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This paper presents new material laws and material formulae for development of safe, property-balanced, economical and efficient steels required for the entire manufacturing activity ranging from a safety-pin to spacecraft. These laws and formulae, called Nori Material Laws and Nori Material Formulae, will precisely balance the ductility and strength parameters of steels by using all the four fundamental mechanical properties like - ultimate tensile strength (T), yield strength (Y), reduction of area (R) and elongation (E) that are routinely obtained from the engineering stress-strain curve resulting from the globally standardized tensile test. Thus, the vast amount of data on T-Y-R-E currently available with the world is put to effective use for evaluation and balancing of mechanical properties. Hence, application of Nori Material Laws and Formulae does not call for generation of additional data that often demands huge investment of time and money. Work in this direction, hitherto unavailable, is found essential since various national and international material codes, standards, and steel manufacturers have been adopting different approaches, and providing steels whose mechanical properties are feebly balanced to support product economics. Further, the demand for efficient usage of steels is increasing along with the necessity for conservation of our rapidly depleting natural resources.

**Speaker Country**:

India

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 21**

## Effects of Chromium and Nickel Screens on Plasma Nitriding with Screen

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The active screen plasma nitriding (ASPN) is a nitriding method that avoids the edge effects and arcing that occur during the conventional direct current plasma nitriding (DCPN). Furthermore, applying voltage to a sample during the ASPN increases the nitriding rate (S-DCPN). Although steel is the predominant screen material, there are few reports on non-ferrous material screens. Therefore, this study aims to evaluate the effects of a Cr screen and a Ni screen on the S-DCPN. Low

carbon steel S15C was nitrided through the S-DCPN using the Cr and Ni screens. Plasma nitriding was performed at 773 K for 120–240 min in a nitrogen–hydrogen atmosphere with 75 and 25 % of N2 and H2, respectively, under 200 Pa. The nitrided sample was subjected to an X-ray diffraction (XRD) test, glow discharge optical emission spectroscopic analysis (GD-OES), cross-sectional microstructure observation, surface morphology observation, cross-sectional hardness test, and corrosion test. The nitrided layer consisted of a Cr-concentrated layer followed by a nitrogen-diffusion layer for the sample using the Cr screen, whereas it consisted of a Ni-concentrated layer followed by a nitrogen-diffusion layer and Ni-diffusion layer for that using the Ni screen. The surface hardness values of the samples treated using the Cr and Ni screens were approximately 750 HV and 950 HV, respectively. From the surface morphology, fine deposits were observed on both the samples. The corrosion resistances of both the samples were larger than that of the untreated sample.

**Speaker Country**:

Japan

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**Poster** / **22**

## Effect of the Amount of Zr Addition on Microstructure and Mechanical Properties of CoCrFeNi High-Entropy Alloys Prepared by Mechanical Alloying and Spark Plasma Sintering

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A high-entropy alloy (HEA) is a multi-component alloy obtained by blending at least five metals with compositions of 5%˜35%. Generally, HEAs are produced by arc melting and casting. The cast specimens undergo phase segregation and have heterogeneous microstructures. CoCrFeNi is the most investigated high-entropy alloy system. In this study, we used pure Co, Cr, Fe, Ni, and Zr pure powders as raw materials to prepare CoCrFeNiZrx (x = 0, 0.2, and 0.4) alloy powder by mechanical alloying (MA) and subsequent spark plasma sintering (SPS). X-ray diffraction (XRD) is performed on CoCrFeNi powder, which reveals that it has a single-phase face-centered cubic (FCC) structure. Furthermore, the CoCrFeNiZr0.2 alloy completely dissolves into the CoCrFeNi FCC matrix after 50 h of ball milling, and the structure is FCC as well as body-centered cubic (BCC) when the CoCrFeNiZr0.4 alloy is abundant. According to the XRD results of the sintered samples after SPS (1073 K, 50 MPa, 10 min holding), the sintered CoCrFeNi without Zr addition has the single-phase FCC structure. The FCC and BCC solid solution phases are formed in the CoCrFeNiZr0.2 alloy, indicating some amount of Zr is completely dissolved into the CoCrFeNi FCC matrix. The CoCrFeNiZr0.4 alloy sample has two microstructural domains: a single FCC phase without Zr and Zr-rich microstructure consisting of FCC, BCC, and some ω phases. Moreover, a brittle microstructure appears in the sample with the addition of Zr.

**Speaker Country**:

Japan

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**STEEL / 23**

## Influence of the quenching and partitioning heat treatment process on the hydrogen embrittlement resistivity of 20MnSi steel

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This work addresses the influence of the quenching and partitioning (Q&P) heat treatment parameters on the mechanical properties and hydrogen embrittlement (HE) resistivity of 20MnSi wire rod steel. The retained austenite (RA) volume fraction in Q&P heat-treated wires is responsible for the high ductility. However, its influence on hydrogen embrittlement resistivity is still controversial in the literature. The RA volume fractions gained from different Q&P heat treatments and their morphology were determined using different techniques. The hydrogen embrittlement susceptibility was measured using an incremental step load test (ISLT) technique according to standard ASTM F1624-12. The results show that heat treatment parameters do not significantly affect strength ˜ 1300MPa. However, the partitioning time tP has the highest impact on ductility and hydrogen embrittlement index (EI) provided that the relative EI could be improved from 46,7% to 35.5% due to increasing the partitioning time from 420s to 1800s

**Speaker Country**:

Austria

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 25**

## CO2-neutral process heating for carburizing furnaces – Ecological analysis and first experimental results

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The European Green Deal aims at a 90 to 95 % reduction of CO2-emissions within the year 2050 compared to 1990 and identified different solutions to reach these goals. For process heating purposes, direct use of electricity and use of hydrogen produced from renewable energies are mainly discussed. Hydrogen can be used in various applications to substitute fossil energy carriers, especially in high temperature applications. Within steel heat treatment furnaces, natural-gas-fired and electrically heated radiant tubes are industrially well-established. Prominent examples are carburizing furnaces for case-hardening of gear parts.
Case-hardening is a process to harden the surface of parts while the core remains soft. The process includes carburizing of the parts, i.e. infusing carbon atoms into the surface layer, and hardening. The process is controlled by the furnace atmosphere which contains carbon monoxide as the main

carbon carrier. It is therefore essential to separate furnace atmosphere and burner off-gas. In carburizing furnaces like pusher type or chamber furnaces, natural-gas-fired I-type radiant tubes are widely used for process heating. Electrical heating is state of the art in carburizing furnaces but is in many countries economically less feasible. Hydrogen-fired radiant tubes are not industrially implemented and further investigations are needed to examine various mechanisms, e.g. pollutant emission and damage mechanisms.
First results of the experimental investigation of a 40 kW self-recuperative burner fired with hydrogen-air inside an I-type radiant tube are presented and discussed. Within the ecological analysis, different process heating technologies for carburizing furnaces are discussed by a quantitative approach. A state-of-the-art carburizing natural-gas-fired furnace is used as reference case, while electrical and hydrogen heating are the alternatives investigated. Energy balances, primary energy consumption and resulting CO2-emissions are compared for the different cases. For this purpose, different scenarios of the energy mix and CO2-emissions development until 2050 are considered.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 26**

## Technological Shift : from mesh-belt furnaces to a clean, compact and automated production

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Traditionally, the heat treatment of mass production and/or bulk parts is carried out with atmospheric mesh belt furnaces, which allow large volumes of production at a high rate. Faced with the evolution of the industry which wants to be cleaner, safer, while being always more competitive, the suppliers of production equipments develop new technologies to answer these challenges.
ECM Technologies, a global player and pioneer in low pressure carburizing equipment, is responding to this change with an innovation: the ICBP Nano.
In addition to offering the well-known advantages of vacuum heat treatment technologies, the ICBP Nano allows the heat treatment of parts in bulk or in small batches, at very high speed in a very low footprint installation. Its design allows a high level of automation, a gateway to the 4.0 world, but above all a high level of competitiveness while significantly lowering the carbon impact of heat treatment processes.

**Speaker Country**:

France

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**SURFACE ENGINEERING / 27**

## Carbon penetration behavior of Cr-Mo steel specimen in carburizing above eutectic temperature

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Carburizing and quenching are one of the surface modification treatments to impart mechanical properties to materials. Carburizing is a lengthy process, generally performed at approximately 1203 K. Conventional carburizing (gas carburizing or low pressure carburizing) is processed in batches. Consequently, this creates many in-process inventories, which negatively affects the production efficiency. To devise an efficient production process, it is necessary to reduce the carburizing duration. Carburizing is a carbon-diffusion phenomenon, and increasing the temperature accelerates the process. In this study, we investigated the carbon penetrating behavior of a steel specimen by carburization it at temperatures 1473 K to 1573 K, which are above the eutectic temperature of the specimen. A ring specimen- Cr-Mo steel (JIS SCM420) was used in this investigation. Methane and nitrogen gases were used for carburizing. The specimen was rapidly heated by induction heating in a carburized atmosphere and kept for processing at each temperature, followed by quenching. It was observed that the time required to reach the same total carburizing depth was 1/20 times of the treatment at 1203 K compared to that of the treatment at 1523 K. Moreover, the total carburizing depth variations followed the parabolic law, the Harris's empirical formula. It was evident that carbon penetration is proportional to the duration of the carburizing process. The rate of carbon penetration per unit time varied exponentially with the carburizing temperature. The activation energy was calculated from the Arrhenius plot of carbon penetration rate, which was close to that in the decomposition reaction of methane. Thereby, it was verified that the carburizing reaction is rate-controlled by the decomposition reaction of methane.

**Speaker Country**:

Japan

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 28**

# Simultaneous aging and surface treatment of 3D printed maraging steel

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The aim of this work is to investigate the behavior of "as-build" (produced by additive manufacturing, 3D printed) maraging steel in simultaneous surface coating and aging process. In the frame of the study coating experiments on maraging M1 grade steel substrate were carried out. The "as-build" maraging steel parts were produced by selective laser melting (SLM) technology. The "as-build" 3D printed and the reference (Böhler W720, solution treated) specimens were surface coated by the same surface modification technologies. The applied coating heat treatment technology consisted of two steps. First, a nitrided layer was produced on the surface of the specimens. The temperature and the duration of nitriding step were defined on the basis of ageing properties of the maraging steel determined by DSC measurements. In this stage of the heat treatment the diffusion of nitrogen and the precipitation hardening of the maraging steel are the main processes, which happen at the same time, simultaneously. The second, upper layer of the coating was produced at a lower temperature by the physical vapor deposition (PVD) method (DLC, CrN, TiN) in a thickness less than 10 microns. "As-build" and reference material specimens were heat treated under industrial circumstances and

were investigated in a comparative manner from the point of view of surface layer structure and surface hardness.

**Speaker Country**:

Hungary

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 29**

## Influence of the total thermal cycle during wire-based cladding by means of electron beam and subsequent boriding on the microstructure and properties of the Inconel 718 layer

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Inconel 718 has a number of advantageous properties, especially at elevated temperatures and in aggressive corrosion media. Disadvantages are the high price, the difficult formability and machinability and the partly limited wear resistance.
For overcoming the given limitations, the aim of our research activities was to develop a technology for the wire-based (Inconel 718) cladding using electron beam on a cheaper but corrosion-resistant austenitic steel (AISI 347) and subsequent boriding for wear protection. The aim is to demonstrate a low-cost alternative to the current use of components made of Inconel mono material.
The paper focuses on the influence of the different successive thermal cycles, including heating and cooling rates, on the development of the microstructure and properties of the surface composite. In case of Inconel 718, the solidification morphologies of the Ni austenite and the proportions of the various phases have a particular influence on the property level. Special attention is paid to the Laves phase.
In electron beam cladding, relatively high heating and cooling rates are generated, which in principle has a positive effect on the suppression of the Laves phase. Another influencing factor, however, is the Fe/Ni ratio, which changed continuously from single-layer to multi-layer deposition. The associated microstructural changes are discussed on the basis of light optical and scanning electron microscopy images, element depth profiles and hardness measurements. The temperature cycle of the subsequent boriding influences the formation of the boride layer in terms of layer thickness, phase fractions and hardness as well as the age hardening behaviour of the Inconel 718 layer.
On the basis of the knowledge gained, statements are to be made on the general necessity and the parameters of a volume heat treatment in order to set an optimum hardening level for both the layer as well as the base material.

**Speaker Country**:

Deutschland

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**HEAT TREATMENT / 30**

# Application of New Artificial Neural Network model to Predict Heat Transfer Coefficients during Quenching

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In this study, the Heat Transfer Coefficients (HTC) occurring during immersion quenching are predicted using a machine learning regression technique. This paper describes a statistical analysis of HTC by developing an artificial neural network-based machine learning model.

The effects of variation in the quecnhant's temperature, initial temperature and characteristics of measured cooling curves have been analyzed. The ANN has been trained on data acquisited during several types (ie: oil, polymer, spray, etc) and conditions (agitation, temperature, ageing, etc) of liquid quenchants. An Artificial Neural Network (ANN)model is used for regression analysis to predict the HTC in terms of temperature signals recorded, and the results showed high prediction accuracies. The applied ANN model seems to be robust and precise, and could be used by Heat Treatment design engineers for predicting the outputs of hardening processes.

**Speaker Country**:

Magyarország

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 31**

# Born of SmartQuench - In Memoriam of Dr. Soren Segerberg

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Dr. Soren Segerberg played a significant role in development of the ISO 9950 method used for characterisation of quenchants used for hardening processes. Based on these efforts "ivf Quenchometer", the market leader product intended for Heat Treaters and Quenchant producers has been introduced at the late 1980s. The 2nd generation of the instrument became available in 2002 and have been used in 35 countries world wide.
This presentation is highlighting Dr Soren Segerberg's work, results and influence on professional vendors of quenching business

**Speaker Country**:

Magyarország

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**STEEL / 32**

## Fine grained high-interstitial stainless TRIP steel; processing and properties

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High nitrogen austenitic stainless steels (HNAUSS) exhibit excellent corrosion resistance in combination with outstanding mechanical properties that outperform those of conventional austenitic stainless steels [1]. In HNAUSS, the deformation mechanism is primarily planar slip [2]. HNAUSS can be produced by melting in a high-pressure N-containing atmosphere, but higher nitrogen contents can be dissolved directly into the solid-state by high-temperature solution nitriding (HTSN) [3]. In the present work, it is shown that the chemical composition of conventional high C, low Cr martensitic steel grades can be tailored by HTSN to promote particularly high strain-hardening via the TRIP effect. The technological challenge with HTSN is grain growth resulting from the high processing temperature [3,4], which results in relatively large grains and premature failure by intergranular fracture [2]. A method is presented to reduce the grain size after HTSN of the steel. This remedy is reminiscent of the eutectoid decomposition of austenite into pearlite in plain carbon steels. The combined effect of high C and N contents enables a combination of high strength and high ductility.

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4 R. Mohammadzadeh and A. Akbari, Mater. Charact. 93, 119 (2014).

**Speaker Country**:

Denmark

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 33**

## Intelligent Heat Treatment with digital Solutions

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The innovation pressure in the last decay has continued and will even accelerate the transformation for the next ten years. The need for sustainable production profoundly impacts the supplier industry, and it opens new ways to increase manufacturing efficiency. Metallurgy is a crucial part of the supply chain, and alternative production methods have become more popular, not at least because of energy costs, CO2 footprint, and increasing lack of resources. In recent years a dramatic development of high-performance digital solutions allows going alternative ways to produce high-end products in the field of metallurgical processing.

This paper discusses various heat treatment processes and how digital solutions can support a producer to be more innovative and, consequently, more competitive in the long-term view. An example shows how an exemplary control process is designed to modernize an existing heat treatment facility and the role of controlled reactive gases to determine the part quality.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**Poster** / **34**

## Influence of carbon contamination on the gas discharge composition in an active screen nitrocarburizing reactor

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The development of plasma nitrocarburizing processes for steel treatment is important for establishing of an environmentally friendly heat treatment process. One of the strategies is to apply the main discharge power on a so-called active screen (AS). The AS surrounding the workload provides heat and reactive species to the workload. The treatment conditions are controlled by the discharge power and feed gas composition. However, the chemical composition in the reactor is also influenced by the pre-history of the reactor due to undesired surface reactions on the reactor walls that might compromise the process control. The current work reports on the time evolution of $HCN$ production in an active screen plasma nitrocarburizing (ASPN) reactor with a steel AS. Three sets of measurements were performed. Each set starts with a discharge in a $N_2-H_2$ gas mixture with the addition of 10% of $CH_4$ for one hour. In the following three hours, the $CH_4$ flow was replace by 6% or 2% of $O_2$ flow in sets 1 and 2, and in set 3 a pure $N_2-H_2$ gas mixture was used. The concentration of $HCN$ molecules, which are assumed responsible for the nitrocarburizing effect, was determined inside the ASPN reactor by quantum cascade laser absorption spectroscopy. The stabilization of the $HCN$ production was characterized by three time-constants. The fastest time-constant (1-4 min) was associated with the gas residence time in the reactor, the second time-constant (about 20 min) was related to surface reactions on the AS and third one (about 3 hour) most probably reflects the surface reactions on the cold reactor walls. The work indicates the importance of monitoring the gas composition during a plasma nitrocarburizing process to maintain defined treatment conditions.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 35**

## Applying the ANSYS GEKO turbulence model to simulate the heat transfer of impinging jets in continuous heat treatment lines

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Impingement jets are widely applied in industrial cooling and drying processes. In continuous heat treatment lines of aluminium and steel strips impingement jets are used to achieve rapid cooling in the according sections. The heat transfer coefficient depends on the flow but also on the geometric parameters such as nozzle to strip distance and nozzle shape. Various nozzle shapes, slot nozzles, round nozzles or combinations of both are used to design those cooling sections. The key challenge while designing such cooling sections is to determine the performance or the heat transfer coefficient respectively.

Jet cooling sections are challenging to model with either computational fluid dynamics or in an experimental set up. In industrial lines the flow exits the nozzle with velocities up to 160 m/s and the cooling sections can be multiple meters in width and length. After exiting the nozzles, the jets are redirected when impinging the strip and again when meeting each other half-way between the nozzles. Those flow characteristics are challenging to model due to both the high velocities and velocity gradients but also the need to resolve the boundary layer to determine the local heat transfer characteristics.

RANS-turbulence models are a cost-effective way to determine heat transfer coefficients and enable the investigation of bigger scale problems such as the cooling sections to a certain accuracy. In this work the capability of the ANSYS generalized k-omega (GEKO) two equation turbulence model to determine the local and integral heat transfer coefficients of impingement jets is evaluated. The results are contrasted to other turbulence models as well as experimental investigations. The local and integral heat transfer coefficients are investigated in dependence of both the nozzle to strip distances and the nozzle exit velocities.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 37**

## Simulated Strains-Based Approach for Explaining Distortion and Residual Stress in Quenched Steel Cylinder

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Elucidation of the mechanism of distortion and residual stress generation in quenched steel parts has been a longstanding issue. A qualitative explanation on stress distribution changes in quenched rods appeared in the 1930s when residual stress measurements became available for the specimens. In particular, the explanation of stress changes during quenching of pure iron rods has continued to be used in textbooks in this field. At that time, the concepts of thermal and transformation stresses were applied to explain the mechanism of residual stress generation. In the case of a pure iron round bar without phase transformation, the term thermal stress was convincing because the stress originated only from temperature changes. On the other hand, the qualitative discussion of the stress change became more complicated when the term transformation stress due to phase transformations was added. Therefore, the quenching of Fe-Ni alloys, in which only martensitic transformation occurs, was used as a subject for the discussion on its simple behavior in generating residual stress. Theoretical research in this area was established by the realization of heat treatment simulations. This provides not only stress but also strains which are due to thermal, phase transformation, plastic, transformation plastic, and creep phenomena. A method for elucidating the mechanism using simulated strains was devised in the early 2000s and named the simulated strains-based approach. In this paper, the mechanism of quenching residual stress generation in mainly Fe-Ni alloy rods is explained by the classic approach using the thermal and transformation stresses and the simulated strains-based approach for understanding each concept.

**Speaker Country**:

Japan

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 38**

# Induction heating modelling for tempering of low alloy steels

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Induction thermal processing is found in modern production lines as it brings benefits in time and energy savings and allows increased reproducibility and integration in a manufacturing chain. Simulation and experimental studies addressing induction hardening have been widely performed in opposition to induction tempering, which has not been extensively studied. However, applying an optimum tempering treatment is often necessary because of the final mechanical properties it grants to the components before it is in service use. This research aims to develop a fully coupled induction tempering FE simulation model, and a time-efficient induction heating simulation procedure is presented, comparing different approaches in the general-purpose ANSYS software. In addition to thermal results, microstructural evolution calculation models have been implemented in the simulation procedure regarding austenite formation and microstructural grain size. The simulation models have also been employed to analyze the effect of critical material properties, such as the dependence of the electrical resistivity with the microstructure change during the heating phenomena. The numerical results have been experimentally validated in 42CrMo4 low alloy steel cylindrical samples.

**Speaker Country**:

Spain

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 39**

## An Overview of Researches and Standardization Activities on Test Systems for Quenchant Characterization in Japan

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Researches and standardization activities for establishing the quenchant characterization test have been carried out in many countries for a long time. As a result, ISO 9950 using Inconel 600 rod probe was established internationally in 1995. However, there has not been much commentary on the works in Japan, and this paper aims to improve the situation. Past studies on the test systems in Japan are described, which use probes of the Fe-Cr-Ni alloy rod by Sato in the 1930s, the chromel-alumel ball by Tawara in the 1940s, and the silver rod by Tagaya and Tamura in the 1950s. The test devised by Tagaya and Tamura were adopted in JIS K 2526 in 1965 and incorporated into JIS K 2242 for heat treating oils in 1980. On the other hand, the Technical Barriers to Trade Agreement established by the World Trade Organization came into effect in 1995 in order to promote smooth global trade. As part of the response to this, the revised JIS K2242 added a provision on the probe with a thermocouple installed in the center in 2006. When conducting heat treatment simulation, the heat transfer coefficient is needed to specify at surfaces of the heat-treated object model. IFHTSE launched the Liquid Quenchant Database project for obtaining this coefficient in 2010. The activities for the project were carried out in Japan. Since the concept of JIS K 2242 was established a long time ago, there are some absences of provisions such as for the cooling rate curve, the maximum cooling rate and the temperature at which the maximum cooling rate occurs. Resolution of such inconsistencies with ISO 9950 is a future issue.

**Speaker Country**:

Japan

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 40**

## Martensitic Induction hardening of nitrided layers

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The wear and fatigue properties of metallic components can be improved by surface heat treatment. The applied process should be chosen depending on the application, because the processes offer specific advantages and disadvantages. Nitriding is suitable for components sensitive to distortion,

since due to the low treatment temperature no thorough phase transformation takes place. However, the use of nitriding is limited by the achievable nitriding hardening depth. With induction heat treatment, on the other hand, high hardness depths can be achieved in a very short time. However, the maximum hardness increase is limited by the carbon content of the material and the associated hardenability.
The current investigations are concerned with a combination of nitriding and induction hardening, as this is expected not only to result in significant savings in process time and energy, but also to produce surface layer properties that cannot be set with one of the individual processes. In order to achieve optimum surface layer properties careful coordination of the process steps is necessary, as otherwise surface layer damage and undesirable microstructural states such as soft residual austenite can occur. During nitriding, therefore, nitrided layers with low-porosity compound layers and pure diffusion layers were first produced and analyzed on the nitriding and tempering steels EN42CrMo4 and EN31CrMoV9 with a view to the subsequent induction heat treatment. Subsequently, the differently nitrided surface layers were martensitically hardened by means of inductive heat treatment and the microstructure was investigated metallographically and physically. The focus was on the dissolution of the compound layer and its effect on the microstructure formation and the hardness profile. Furthermore, it was investigated how the absence of a compound layer affects the subsequent martensitic transformation. The aim of the experiments was to determine parameters that lead to an optimum surface layer structure by the combination heat treatment.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 41**

## Characterization of Polymer Quenchants - Influence of Agitation

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Polymer quenchants are used extensively to quench a large variety of materials, in a variety of processes. Polymer quenchants can be used for immersion quenching of steel, aluminum, and other alloys, including super alloys. Spray quenching is commonly used for induction hardening. There are predominately four different types of polymer quenchants used in industry today.
To achieve consistent and uniform quenching, the quench rate must be controlled. The quench rate of a polymer is affected by concentration, temperature, and agitation. In this paper, the methods of evaluating the agitation of polymer quenchants will be illustrated and compared.

**Speaker Country**:

USA

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**HEAT TREATMENT / 42**

## Investigation methods for the determination of flow topography on horizontal surfaces in spray nozzle fields

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Quenching is an important process step in the heat treatment of metallic materials in continuous strip lines, as it is crucial to the resulting material properties of the final product. For many modern high-strength materials, the required cooling rates cannot be achieved while using conventional gas cooling systems. Therefore, the material has to be cooled with water. Water can be applied to the strip's surface using a spray nozzle field, which is particularly challenging in regards to temperature homogenei-ty. Furthermore, strips in continuous lines are often run horizontally, which causes water flow on the surface. This flow has a non-negligible influence on the tempera-ture homogeneity during cooling, which in turn determines the quality of the final product. Consequently, a better understanding of spray nozzle fields and the flow on the surface is of interest and, therefore, investigated by the authors.
To examine these phenomena two test rigs have been setup at the Department for Industrial Furnaces and Heat Engineering at RWTH Aachen University. One for in-vestigating water flow on a moving strip and one with a steady horizontal surface. With these test rigs, the influence of several important parameters (e.g. nozzle pres-sure, nozzle-to-surface-distance, strip speed, etc.) on the flow in nozzle fields can be determined in a wide range. This is achieved by a combination of several different measurement methods. Alongside a self-developed measurement methodology, which allows the qualitative and quantitative determination of the flow, the droplet impact on the surface is measured. Additionally, the water impingement density, an important parameter for the description of spray nozzles and nozzle fields, can be measured in one of the test rigs. Finally, the generated data of the used measure-ment methods are correlated for a better understanding of the generated water flow on surfaces and its dependence on the proposed parameters.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**SURFACE ENGINEERING / 43**

## Impact of deep cryogenic treatment on nitridability and properties of nitrided hot work tool steel

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Forming industry is confronted with ever increasing demands on productivity, quality and performance of tools and dies. The main limiting factors are wear and fatigue resistance. Good abrasive wear resistance is obtained by increasing material hardness, which however may hamper toughness and fatigue resistance. Therefore different surface engineering techniques like plasma nitriding are used to form hard surface layers with high wear and corrosion resistance while preserving core toughness. Thickness and properties of the nitride layer depend on the steel composition and nitriding parameters (temperature, time, gas mixture) and is limited to few hundred microns. Deep cryogenic treatment (DCT) is another heat treatment of tool steels gaining attention in recent years. Normally it is combined with the traditional heat treatment, where after quenching material is exposed to cryogenic temperatures below -160 °C, usually by immersion into liquid nitrogen, and then

followed by tempering. DCT facilitates transformation of retained austenite into martensite, induces precipitation of additional carbides and modifies their distribution and size, thus providing improved toughness and fatigue resistance while maintaining high hardness. The aim of our work was to investigate the mutual effect of DCT and plasma nitriding on the formation and properties of the nitrided layer as well as the resulting wear and fatigue resistance of EN 1.2367 Chrome–Molybdenum–Vanadium hot work tool steel. Investigation comprised metallographic analysis, XPS, ToF-SIMS, hardness depth profiling, abrasive wear resistance under dry reciprocating sliding contact (pin-on-disc configuration) and bending fatigue resistance. Results clearly indicate enhancing effect of DCT.
Keywords: plasma nitriding, deep cryogenic treatment, tool steel, wear, fatigue

**Speaker Country**:

Slovenia

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**SURFACE ENGINEERING / 44**

## Lifetime Enhancement of Induction Heating Coils: A Complex Approach Based on Numerical Simulations and 3D-Printing

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Lifetime of an induction heating coil is an important factor directly influencing the economic and environmental attractiveness of an induction heating process. A vast majority of the induction coils are complex electrical devices made of pure copper, carrying extreme electrical currents to generate a strong alternating magnetic field, requiring a water-cooling channel to remove excessive heat loss. The coils are normally subjected to cyclic stress due to large temperature gradients and magnetic forces. A conventional coil's manufacturing method is manual brazing of the copper profiles or machined parts. The method itself introduces a series of design constraints, coils manufactured in this way are often not optimal regarding the mechanical stresses, electrical resistance, and hydraulic resistance of the cooling water channel. In this light, the emerged technology of 3D printing of copper and copper alloys opens new horizons for the design and optimization of induction heating coils. The optimization targeting a lifetime enhancement in the first place requires reliable tools for analysis of the induction coils and the origins of a failure. Among the available analytical, numerical, and experimental methods, tools based on the finite elements method (FEM) are of particular interest, since they can consider all the non-linear coupled phenomena and provide a deep insight into the very root of the causes responsible for a limited lifetime of the induction coils. Besides, FEM can be easily connected to the optimization routines of automatic, semi-automatic, or manual nature. We consider such a case study in this paper. An existing induction coil with an unacceptable lifetime, previously designed for conventional manufacturing, is being analyzed thoroughly, using FEM tools. Multiphysics FEM models, including electromagnetic, thermal, mechanical, and fluid flow, are used to reveal the root causes of the failure. Multiple design modifications are done keeping in mind the great flexibility of the 3D-printing technology. The optimization goal is an elimination of all the factors contributing to the short lifetime of the coil. Design constraints are dictated by a need to preserve an existing heating recipe and electrical impedance of the coil to be able to connect it to an already existing induction heating converter. Numerical and experimental evidence of a significant lifetime improvement of the 3D-printed coil is demonstrated.

**Speaker Country**:

Norge

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**SURFACE ENGINEERING / 45**

## Nitriding on as quenched steel 33CrMoV12-9

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Gaseous nitriding is a thermochemical surface treatment aiming surface strengthening of steels. The diffusion of nitrogen atoms in the ferritic matrix involves the precipitation of nano-scale alloying elements nitrides MN (M = Cr, V, Al…) that leads to secondary phase hardening and the generation of compressive residual stresses. Prior to nitriding, steels are quenched and tempered for industrially practical interests in controlling the machining process, microstructure, and mechanical properties. Nitriding of steels has then been performed at a temperature lower than tempering to avoid core softening during nitriding, especially in case of deep nitriding. Therefore, surface properties depend on the kinetics of nitriding related to as quenched-tempered microstructure.
The present work aims investigating the direct application of nitriding on as quenched steel 33CrMoV12-9. Properties such as the chemical, hardness or residual stresses in-depth profiles will be compared between quenched and quenched-tempered specimens. Optimization of the nitriding process will then be discussed.

**Speaker Country**:

France

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**HEAT TREATMENT / 46**

## The effects of heat treatments on the mechanical properties of secondary aluminium alloys

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As environmental concerns and the law of energy resources become more prevalent around the world, almost all sectors must take action to address these two critical challenges. The production/manufacturing sector also takes precautions regarding these two important issues both in the product life cycles it produces and in the products they supply. Primary ingots, which are used as raw materials in the aluminum casting industry, have significantly higher energy consumption and CO2 emissions than secondary ingots. Thus, secondary aluminum should be used more frequently.

The mechanical properties of secondary aluminum recycling are significantly impacted by impurities, oxides, and boron oils in the structure. The mechanical properties of a material can be dramatically reduced by the presence of oxides and hydrogens. For these decreases not to fall under certain limits, secondary aluminum can be used in certain proportions. Another way to increase mechanical properties above certain limits is heat treatment applications.

In this study, sample casting was carried out by melting secondary aluminums to preserve the high energy used during the production of primary aluminum, which is recycled due to environmental concerns. To increase the possible low mechanical properties of these casted samples, heat treatment was applied. As the heat treatment process, T6 Heat treatment, which is frequently applied in A356 aluminum alloys, was applied. As a result of the study, the change in the mechanical properties of the samples cast from secondary aluminum after the applied heat treatment was investigated.

In conclusion, effect of the heat treatment on metallurgical properties was investigated by an optical microscope. Mechanical properties were obtained by tensile tests. From these tests, elongation, ultimate tensile strength, and yield strength values obtained and comparing with each condition. According to the results, the correlation between elongation, ultimate tensile strength and yield strength under heat treatment conditions are established.

**Speaker Country**:

Turkey

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 47**

## Design of a Quench Ring for Proper Quenching of Small Cylinders – Initial Investigation

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A customer quenches small cylindrical parts using induction hardening, followed by dropping the parts into a quench ring. A polymer quenchant is used to control distortion and residual stresses. In a small percentage of parts, the cylinders would experience soft spots on the cylinder sides. This was usually just a single location, where the hardness could be as much as 20HRC below the targeted minimum. At first, the focus was on the polymer quenchant, and its degradation. The concentration of the polymer was reduced from a nominal 10% to 4%. This improved the situation and reduced the number of soft spots observed. However, reducing the concentration of the polymer quenchant did not eliminate the soft spots occurring.
Investigation of the method of quenching and the resultant microstructure was conducted using CFD and SIMHEAT™.

**Speaker Country**:

USA

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**HEAT TREATMENT / 48**

## Design of a Quench Ring for Proper Quenching of Small Cylinders – Modified Design

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In this paper we examine a modified quench ring for quenching small cylinders. Parts are heated by induction, and then dropped into an immersion quench ring. Previous investigation had indicated that inadequate quenching of the parts was occurring due to poor agitation in the original quench ring. A new design was created, and the agitation was modeled using CFD. The microstructure of the parts was modeled using SIMHEAT™. The new design quench ring was fabricated and implemented. A comparison of the old and new designs shows no soft spots in the new design.

**Speaker Country**:

France

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**HEAT TREATMENT / 49**

## Smart sensors fulfilling the promise of the de-carbonization and IoT

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Many companies being active in heat treatment are facing numerous inefficiencies like non reliable first level sensors and process instrumentation, diverse IT-systems, limited information exchange between sensors and plant units, lack of consistent and standardized data (management). Companies generate high direct and indirect costs through all business processes resulting uneconomic stock/WIP levels, non-essential high lead times and increasing pressure on product margins.
Today mainly talking and reading about hydrogen utilization / de-carbonization and digitalization in the industry supply chain, and very rear about first level sensors and their hydrogen capability and digitalization in the heat treatment.

**Speaker Country**:

Deutschland

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**HEAT TREATMENT / 50**

## Analysis of the stress-relief heat treatment of aluminium alloy wheels

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Aluminum alloys are widely preferred in industrial applications such as automotive, defence and aerospace industries because of their advanced characteristics such as high specific strength, corrosion resistance, and castability. Cast aluminum alloys are frequently heat-treated to change their mechanical properties.

In this study, the effects of stress-relief heat treatment on the microstructural and mechanical properties of aluminum cast alloy were investigated. A356 aluminum cast alloy samples were stresss-relieved for 30 minutes to 3 hours at 200 ℃, 250 ℃, and 300 ℃. The optimal stress-relief heat treatment parameters for an A356 aluminum alloy were identified in this work using the time-temperature relationship.

Hardness values were measured at the end of stress-relief heat treatment and shown. Also, tensile tests were carried out to the samples. In addition, microstructural characteristics were investigated by optical microscopy and the grains were observed after stress-relief heat treatment. The mechanical properties and microstructures of stress-relief heat treated and non-heat treated samples were compared.

The results of appropriate stress-relief heat treatment condition parameters which obtained from this investigation study applied to the aluminum alloy wheels and all mechanical test applied to the product. After the mechanical test, ultimate tensile strength, yield strength and elongation values were compared with non-heat treated and typical T6 heat treated aluminium alloy wheels.

**Speaker Country**:

Turkey

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 51**

## Design of cooling sections for heat treatment based on laboratory measurements of heat transfer coefficient

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Laboratory measurements make it possible to determine the heat transfer coefficient (HTC) depending on the position and surface temperature for different cooling configurations. The HTC evaluation allows to identify the effect of different parameters on cooling. The design and setting of cooling parameters directly affects the microstructure, hardness and mechanical properties of materials. Furthermore, it is possible to use the experimentally obtained dependence of HTC on surface temperature and position both for realistic numerical simulations of cooling processes and for optimize the design of cooling sections.
The article presents examples of designs of cooling sections for heat treatment of long products (plates, rails and tubes) and sections for thin sheets cooled by very high cooling rates (1 000 ℃/s). The implementation of prototypes and plant measurements for long product are presented.

**Speaker Country**:

CZ

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**Poster / 52**

## Solution treatment duration influence on microstructural and mechanical properties of a cold-rolled Ti-Nb-Zr-Ta-Sn-Fe alloy

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The influence of solution treatment duration on microstructural and mechanical properties of a cold-rolled Ti-30Nb-12Zr-5Ta-2Sn-1.25Fe (wt.%) (TNZTSF) alloy was investigated in this study. The TNZTSF alloy was produced by cold-crucible induction in levitation synthesis technique, in argon-controlled atmosphere. After synthesis the alloy was processed by cold-rolling deformation, with a total deformation degree (total applied thickness reduction) of 50%, followed by a solution treatment at 850℃ with a variable treatment duration from 2min to 30min, in 2min increments. Structural characterization was done using X-ray diffraction (XRD) and scanning electron microscopy (SEM). Mechanical properties were evaluated by tensile and hardness testing. The results show that, (1) the TNZTSF alloy contains single-phase β-Ti phase microstructure in all cold-deformed and solution treated conditions, (2) the microstructure of solution treated conditions shows an increasing in average grain-size and decreasing in internal average micro-strain with solution treatment duration increasing, (3) a suitable combination of high strength – high ductility properties could be obtained due to stability of the β phase.

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**Speaker Country**:

Romania

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**HEAT TREATMENT / 53**

## Climate change and loss of biodiversity raise new provocations on the materials science and surface engineering

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The materials science, including surface engineering has to be seen in a new approach as well. Learning from the mother nature it may- and has- to contribute to the sustainability of the development on the Earth, to the decrease of the deleterious effects of the technical development on environment, to help to prevent the uncontrolled climate change and the loss of biodiversity on Earth.
The paper presents a few negative effects of the technical and industrial development on the sustainability of the planet Earth and -certainly- on the human life on our planet. All the developments, scientific research have to consider the environmental aspects as well and have to act in the direction of sustainability of the natural world. We have to learn to reduce the trash and to develop reusable materials and without deleterious effect on the nature -and at the end of the day- at the human life on Earth. The new orientation should also be considered in the activities of IFHTSE as a world organization dealing with specific aspects of materials science with specific orientation on heat treatment and surface engineering.

**Speaker Country**:

Romania

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**STEEL / 54**

## Investigations on the effect of cooling rate on quenching & partitioning (Q&P) in martensitic stainless steels

**Author:** Simona KRESSER[1]

**Co-authors:** Reinhold SCHNEIDER [2]; Horst ZUNKO [3]; Christof SOMMITSCH [4]

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Quenching and partitioning (Q&P) is a heat treatment used to adjust the retained austenite content in the microstructure. The heat treatment consists of a hardening step followed by rapid cooling to a certain quenching temperature between martensite start and martensite finish temperature and subsequent partitioning, i.e. heating and then holding at temperature. During partitioning, the formed martensite is tempered and the austenite is stabilised by diffusion of carbon atoms from the martensite into the austenite. This type of heat treatment is mainly used for low-alloyed steels. However, the partitioning effect has also an influence on higher alloyed steels, such as martensitic stainless steels. The typical heat treatment for these steels is quenching and tempering (Q&T). For large-scale tools, it happens that the centre region of the tool is not cooled down to room temperature before the tempering step takes place, resulting in a Q&P instead of a Q&T treatment. This can lead to higher retained austenite content or even fresh martensite in the microstructure after heat treatment.

Q&P depends on the dissolved alloy content in the matrix before quenching, which is controlled by the material composition and the austenitizing temperature. Important factors are also the quenching and partitioning temperatures and the cooling rate. Especially with larger components the cooling rate in the inner area is lower than in the peripheral area. Therefore, the influence of the Q&P on martensitic stainless steels at fast and slow cooling rates was investigated in this work. Heat treatments with different parameters were carried out on a dilatometer. Subsequently hardness and retained austenite content of the samples were determined in order to compare the properties. It will be shown that the alloy content and the cooling rate have an influence on the retained austenite content of the finale microstructure and also the hardness.

**Speaker Country**:

Austria

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 55**

## Experimental and numerical investigation of heterogenous gas quenching for determining optimal heat treatment parameters

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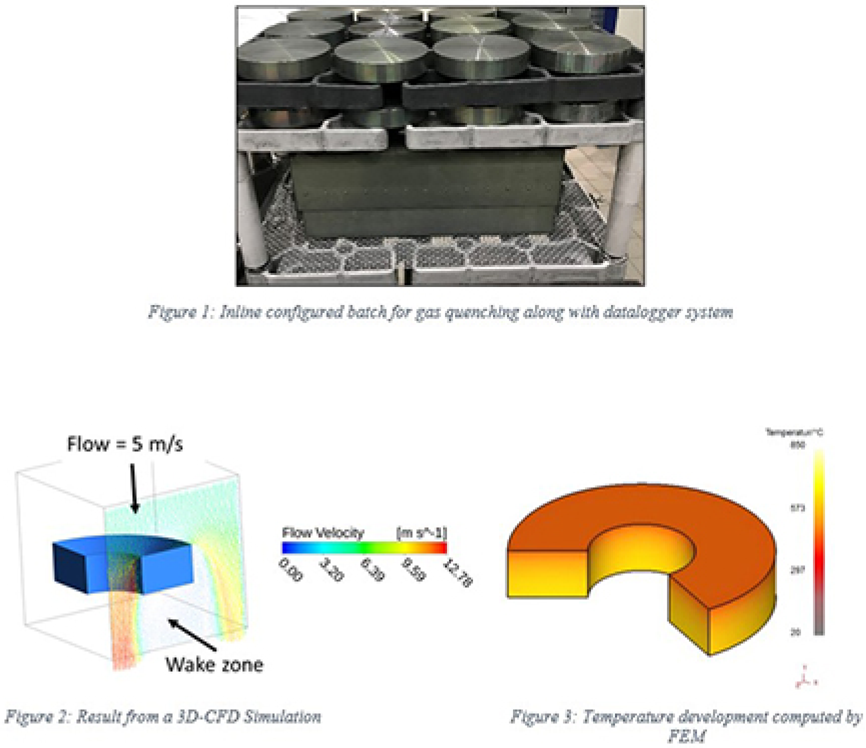
**Abstract**

For several technical engineering applications, steels are of great emphasis. Heat treatment of steels intents to attain the pre-determined material properties. After austenitisation in vacuum, gas quenching is a widely preferred heat treatment process, since in contrast to quenching by fluids, it is cleaner and more environment friendly process. In addition, gas quenching does not show the Leidenfrost effect, so that uniform cooling is possible. However, challenges reside with the selection of suitable heat treatment parameters, which are highly depending on different criteria such as sample geometry, material composition, batch properties etc. The current study superiorly focusses to develop a prediction tool based on ANN (Artificial Neural Network). The ANN is trained with the experimental and simulation results to predict the optimum heat treatment parameters in order to achieve a homogeneous quenching process under consideration of the components geometry and material as well as energy efficiency. In order to accomplish this target, the heat treatment and flow conditions during gas-based cooling as well as the development of the treated material's microstructure and hardness are investigated in detail. To obtain a stochastic parameter field for the ANN training, different sets of samples are produced with varied process parameters including gas flow velocity, gas pressure, treatment temperature of the sample, sample geometry and sample batch. To obtain the input parameters for attendant simulation, HTC (heat transfer coefficient) and temperature curve at several sample spatial locations within the sample volume are measured by means of film probes (Glue-on-Film) glued to the probe surface and thermo-elements respectively. The investigation of the flow character is accomplished in gas quenching setup by means of CTA (Constant temperature anemometry) system and Pitot tube. After the heat treatment, the microstructure of the sample is analysed at several spatial positions by light and scanning electron microscopy to evaluate calculated local cooling curves. Hardness measurements additionally determine the microstructure constitution. Furthermore, the CFD and FEM Simulation models are developed and validated respectively by means of the experimental results achieved from this study. The validated models serve to numerically investigate the influence of quenching parameters (gas pressure, flow velocity etc.), geometry and batch dependent heat transfer between gas and treated component as well as the material properties and that provides sufficient data to introduce the ANN-based forecast tool addressed above.

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**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**SURFACE ENGINEERING / 56**

## On plasma processed aluminide coatings on ferrous and non-ferrous substrates: effect on microstructure and mechanical properties

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Plasma assisted diffusion heat treatment has been wellknown for interstitial diffusion processes such as carburizing, nitriding etc. However, such glow discharge plasma assisted diffusion treatment has been scarcely reported for substitutional processes like aluminizing. This work presents an overview of the plasma based aluminide diffusion treatment on 9Cr steels and Ti substrates. This paper will elaborate on the changes in microstructure and mechanical properties of plasma processed iron aluminide and titanium aluminide coated substrates. The processed samples have been characterized using SEM-EDS, X-ray diffraction, vicker's microhardness and tensile test data. The plasma has been found to promote stable alpha-alumina phase after heat treatment and is also found to create

nanocrystalline aluminide structure in the diffusion coating as found from XRD data. This is also supported by vicker's hardness measurements. The tensile tests showed marginal change in the tensile strength of substrates as compared to uncoated samples. The high temperature oxidation resistance of the plasma substrates was significantly better than the conventionally treated samples.

**Speaker Country**:

India

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 57**

## The ISO 20431 standard: a new quality standard for heat treatment workshops

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The ISO 20431 standard is currently being finalized and will be available soon. Experts from 7 countries (Canada, Austria, Germany, Italy, Japan, China and France) have been working on this project for several years. This standard is designed to be flexible and can be used worldwide in different industrial sectors (automotive, aerospace, civil engineering, energy, fasteners, etc.). The standard compiles requirements and recommendations. It allows the organization and the controls performed to be evaluated according to the customer's objectives and the supplier's capabilities, which vary from sector to sector. An evaluation of non-binary criteria, in the case of recommendations, produces a result with a success percentage. In this way, continuous improvement is achieved. Once implemented, the ISO 20431 standard will be an effective tool to improve the quality level of heat treatment workshops worldwide.

**Speaker Country**:

France

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 58**

## 'Ultra-low' temperature nitriding of martensitic stainless steels

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**Co-authors:** Matteo VILLA [1]; Thomas CHRISTIANSEN [2]; Marcel SOMERS [1]

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In the present work a new process route for martensitic stainless steel X30Cr13 (AISI 420) is pursued. Conventional austenitization or high temperature solution nitriding is followed by unconventional

tempering and 'ultra-low' temperature gaseous nitriding. Tempering is performed in high vacuum and at higher temperatures than the recommended ones for X30Cr13. The relatively high tempering temperature impairs the corrosion resistance, but is restored by an additional gas nitriding step at temperatures below 380℃, which is considered the lower limit for low temperature surface hardening. Surface hardness values of around 1400-1500 HV were achieved for the surface hardened zone, which neither shows cracks nor spallation. Despite the low temperature, the hardened case has an unprecedented depth of 15-20 m for the adopted temperature range. The microstructural evolution was investigated with reflected light microscopy and X-ray diffraction analysis. Micro-hardness Vickers indentation provides information on the depth dependence of the hardness. Electrochemical polarization is performed by potentiodynamic and potentiostatic tests in order to evaluate the passivity of the material and its resistance to localized corrosion (pitting) and, hence, the overall performance after the full treatment cycle.

**Speaker Country**:

Denmark

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**Poster** / **60**

## Synthesis and characterisation of MAX phase Ti3AlC2by pressureless sintering

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**Co-authors:** Arunsinh ZALA [2]; Aroh SRIVASTAVA [3]; Surojit GUPTA [4]; Nirav JAMNAPARA [1]

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MAX phases materials have the potential to bridge the gap between metallic and ceramic materials owing to their excellent properties like good machinability, thermal conductivity, high temperature oxidation and corrosion resistant, low density, low thermal expansion coefficient etc. [1,2]. The present study emphasises the synthesis of layered ternary carbide Ti3AlC2 by mixing the TiH2, Al and TiC powders in a planetary ball mill followed by pressureless sintering in flowing Argon (Ar) atmosphere. The sintering process is carried out in two steps; i) decomposition of TiH2 to Ti which leads to solid – liquid reaction of Ti and molten Al. ii) Ti-Al compounds formed by step 1 react with TiC to synthesis MAX phase Ti3AlC2 [3]. The mixed precursor powders were cold pressed and annealed at 750℃ for 2 hours at a ramp rate of 10℃/minute in step 1. Step 2 includes the heat treatment of annealed samples at a ramp rate of 10℃/minute to 1250℃ for 5 hours in a tube furnace under flowing Ar. The processed Ti3AlC2 samples were analysed by X-ray diffraction (XRD), Raman Spectroscopy for phase identification followed by Scanning electron microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDS) to investigate the morphology and quantify different phase constituents present. Differential Scanning Calorimetry (DSC) was performed to study the thermal analysis of Ti3AlC2 phase upto 1400oC in Ar atmosphere. The results indicated that the synthesised Ti3AlC2 have high purity along with TiC as a minimal impurity. DSC results revealed that Ti3AlC2 phase does not undergo decomposition upto 1400oC in Ar atmosphere. Thus, this study provides a beneficial approach to low temperature synthesis of high-purity Ti3AlC2 materials and understanding the thermal behaviour of Ti3AlC2 for high temperature applications.

**Speaker Country**:

India

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 61**

## Recent advances in heat treatment and surface engineering within metal additive manufacturing

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Metal additive manufacturing (MAM) is maturing as a production route and is gaining a strong foothold within industry. MAM covers several different methods including laser powder bed fusion (LPBF) and binder jetting. A common feature of the MAM methods, such as LPBF, is the unorthodox microstructure resulting from the very rapid solidification, inherent to the process. This provides new opportunities as well as challenges with respect to heat treatment and surface engineering. Heat and surface treatment methods developed for conventionally manufactured materials with perhaps the same composition but a very different microstructure, are generally inapt or can even be detrimental for MAM parts. On the other side, the unorthodox microstructures can provide an opportunity to achieve properties that are not obtainable through heat/surface treatment of conventionally manufactured metals.

The present contribution provides an overview of how to exploit the unorthodox microstructure resulting from printing. How can we design new heat treatments and surface engineering processes for exploiting and optimizing the unique "features" associated with MAM? Focus is on research from the authors' own laboratory and will address different metals, including titanium alloys and steels.

**Speaker Country**:

Denmark

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**SURFACE ENGINEERING / 62**

## Advances in thermochemical surface engineering and heat treatment of titanium and titanium alloys

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Titanium is a lightweight highly corrosion resistant material used in industrial applications as diverse as aerospace, biomedical, military and chemical processing. Titanium's excellent biocompatibility makes it one of the materials of choice for implants and medical devices. Furthermore, titanium is widely used in 3D metal printed applications, which is becoming increasingly popular. However, titanium and titanium alloys suffer from poor tribological properties, including poor wear resistance. Hence, targeted improvement of the wear resistance of titanium surfaces could importantly contribute to their applicability.

Thermochemical surface hardening is the classical way to improve the wear performance of materials, most notably steels. For titanium, thermochemical treatment is challenged by the very strong affinity of titanium to light, interstitially dissolvable elements. In addition, the heat treatment condition (and thus microstructure!) of titanium alloys is an important parameter in thermochemical surface treatment as it has a significant influence on the hardening response. Potentially, the bulk microstructure is affected negatively by the thermal impact of the thermochemical surface treatment. Hence, heat treatment and thermochemical surface treatment are highly interlinked.

The present contribution addresses thermochemical surface treatment and heat treatment of titanium and its alloys. It is shown that relatively deep and hard diffusion zones consisting of interstitials in solid solution can be obtained by gaseous methods. Also, hard compound layers based on one or more interstitials can be obtained. Surface modification by thermochemical treatment to obtain robust white surfaces is also possible; here examples relating to dental applications are showcased. Lastly, titanium additively manufactured by laser powder bed fusion is addressed. The role of heat treatment and thermochemical surface treatment as important post-processing treatments is emphasized.

**Speaker Country**:

Denmark

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**SURFACE ENGINEERING / 63**

## Influence of cold rolling and post annealing on low-temperature gaseous nitriding of meta-stable and nitrogen-stabilized 304 austenitic stainless steel

**Authors:** Bo WANG[1]; Konstantin V. WERNER[2]; Matteo VILLA[2]; Thomas CHRISTIANSEN[3]; Marcel SOMERS[2]

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AISI 304 austenitic stainless steel plates were austenitized in Ar or solution nitrided in 0.5 bar N2 gas at 1150 °C for 2 h. Both austenitized and solution nitrided conditions were cold rolled to different engineering strains by 10–70 % thickness reduction. The most heavily deformed coupons were subsequently annealed at various temperatures for up to 1 hour. Gaseous nitriding of the deformed and the annealed steels was performed in ammonia/hydrogen gas mixtures at atmospheric pressure at different temperatures: 430 °C and 460 °C. The nitrided case was characterized with X-ray diffraction analysis, reflected light microscopy, electron microscopy and hardness testing. The influence of microstructural features as grain size and the deformation mode by martensite/twin formation and/or dislocation generation and dislocation glide, on the development of the nitrided case and microstructure of the expanded austenite zone is discussed.

**Speaker Country**:

Denmark

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**STEEL / 64**

## Continuous Annealing Digital Twin Implementation and Calibration

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Together with Ebner Industrieofenbau, ENRAG developed a fully transient plant model for continuous annealing lines. The model is directly connected to the plants automation system. It takes inputs like fuel flow and blower speeds and calculates the temperature distribution in the annealing line including the temperature of the steel strip in each point of the line. This information is then returned to the automation system and delivers this information to the operators desk. Based on new developed algorithms the digital twin optimizes the transition phase between different strips and delivers immediate instructions to the operator in case of partial plant failure (e.g. heating zone failure) to optimize strip quality in every phase of operation.

**Speaker Country**:

Austria

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**HEAT TREATMENT / 65**

## Investigations into the process- and heat treatment-related design of wire-based additive manufacturing of Al materials using electron beam

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The future development of components is aimed at optimising lightweight construction and service life while at the same time ensuring sufficiently high specific strength of the component, for which age-hardenable aluminium alloys are particularly suitable. Additive manufacturing processes (AM) create new innovation opportunities in terms of design freedom and the customizability of microstructure/property relations, among other things. In the field of powder-based AM of Al alloys, the laser beam has already become well established, whereas the advantages of wire-based AM, such as high building rates, are currently not effective due to poor energy absorption. An excellent alternative is the electron beam (EB) with its almost surface-independent energy input.
The article deals on the one hand with the technological parameters influencing the geometry and quality of single- and multilayer wire-based AM using electron beam. The effects of the EB parameters (sample feed rate, beam current, power density, etc.) as well as wire feeding options (deposition strategy, wire positioning, etc.) and the associated parameters on both the layer geometry, defect and pore formation as well as surface deformation are in focus of the investigations.

Another focus was on the influence of the process-related thermal regime (melt pool size, pre- and post-heat effects, etc.) and/or vacuum on the microstructure formation and the heat treatment regime of the Al materials. An important aspect was the question of evaporation of heat treatment-relevant alloying elements, such as Mg. External annealing tests with T-t regimes relevant to age hardening were carried out for this complex. For comparative evaluations, conventional and SLM-produced Al samples were also included in the investigations. These were analysed using light and scanning electron microscopy, XRD analyses and hardness measurements, and conclusions were drawn for an optimised process design.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**STEEL / 66**

## Practice and Discussion of Intelligent Continuous Annealing Furnace Based on Big Data Analysis Technology

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With the rapid development of China's automobile industry, the prospect of automobile plate market is very broad. Continuous annealing furnace is the main core equipment of automobile plate production line, and the process parameters and equipment status related to annealing furnace directly affect the product quality. This paper introduces the establishment of industrial furnace big data platform by using big data analysis method, and introduces the main process of annealing furnace process, operation, equipment and so on Parameters and various manufacturing resources should be connected together to form a unified resource pool, and intelligent response should be made under the joint decision of human, machine and material, so as to realize remote diagnosis and intelligent early warning for abnormal trend data. Prevent the occurrence of major quality accidents or equipment failures.

**Speaker Country**:

china

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**STEEL / 67**

## Energy efficient manufacturing chain for advanced bainitic steels based on thermo-mechanical processing

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**Energy efficient manufacturing chain for advanced bainitic steels based on thermo-mechanical processing**

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Keywords: thermo-mechanical treatment; synchrotron diffraction; bainitic steels; continuous cooling; carbide-free bainite

The development of new strategies in the manufacturing chain of mechanical components is one promising way to achieve energy efficiency in the production of machine and automotive components. The development of advanced high strength steels by exploration of metallurgical processes is one of the key objectives in this regard. On this occasion, continuous-cooling-bainitic-forging-steels offer an extraordinary path for accomplishing this goal, since they allow achieving their final microstructure directly after hot forging followed by controlled cooling, simultaneously attaining suitable mechanical properties. Considerable reduction of energy consumption is achievable thanks to the suppression of conventionally used energy-intensive additional heat treatments. In the present project, different concepts for a manufacturing chain with thermo-mechanical processing and subsequent surface engineering have been thoroughly investigated by means of advanced *in-situ* methods such as the High Energy X-Ray diffraction and the use of Eddy-Current Sensor. Furthermore, Finite Element Method Simulation was employed to identify suitable processing windows regarding the parameters of the thermo-mechanical treatment. The knowledge delivered by these experimental and numerical investigations was then transferred to on-site industrial and laboratorial forgings to achieve tailored properties of treated parts. Different surface treatments based on plasma nitriding, deep rolling and induction hardening were then employed to further improve the surface-near properties for application of highly loaded components. In the present contribution, an overview about the overall project and of the main results will be presented and discussed.

**Speaker Country**:

Brazil

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**SURFACE ENGINEERING / 68**

## Impact of process parameters during multi-step carbo-austempering on the hardness and microstructure morphology

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Highly stressed components such as gears are usually case-hardened according to the current state of the art in order to adjust the specific stressability at the tooth flank and root. The heat treatment process typically involves carburization followed by quenching to room temperature in gaseous or liquid media. In most cases, the result is a predominantly martensitic structure with finely distributed retained austenite.
In particular, an isothermal transformation of the carburized component into lower bainite promises advantages for the mechanical properties of components treated in this way due to the increased toughness of the bainite compared to the high-carbon tempered martensite. In addition, further changes in the process regarding the quenching technology for hot bath treatment due to the bainitic transformation are necessary. For example, the transformation temperature and duration must be adjusted depending on the previous carburization and the surface carbon content set in this process.
The results of the first project carried out for this purpose have already produced very promising results that have shown great potential for technical application. Open questions have arisen regarding the process duration and achievable hardness or the mechanical properties, which are currently investigated in a follow-up project, particularly with regard to a multi-stage isothermal transformation into lower bainite. In this context, extensive dilatometric and metallographic investigations were carried out to characterize the transformation kinetics and resulting phase fractions as well as their morphology.
The process and material engineering of carburization with subsequent multi-stage bainitic transformation as well as the resulting mechanical characteristic were systematically investigated and will be presented and discussed in the context of the talk.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**STEEL / 69**

## Replacement of Si by Al in Q&P-steels and its effect on the tempering behavior of martensite

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With the quenching and partitioning (Q&P) process, high-strength and crash-resistant steels for body in white applications with a good combination of local and global formability can be produced in continuous heat treatment lines. This is attributed to a fine-grained and homogeneous microstructure of tempered martensite and substantial amounts of stabilized retained austenite. This retained austenite transforms into martensite during plastic deformation, by increasing the work hardening behavior. To adjust these required fractions of stable retained austenite, carbide precipitation during heat treatment needs to be suppressed. This is primarily ensured with the alloying element Si. Since higher contents of Si cause problems with regard to hot-dip galvanizing and subsequent welding, this element is increasingly being replaced by the element Al. But it is known that Al exhibits a different, less favorable behavior with regard to carbide precipitation, especially in tempered martensite. Therefore, the tempering behavior of pure Si- and Al-steels, but also combined Si-Al-steels, were investigated by state of the art investigation methods.
Using a combination of dilatometry and differential scanning calorimetry, the tempering behavior in martensite during continuous heating was investigated on lab-scaled produced steels with different Si:Al ratios. Additional investigation methods such as high-resolution scanning electron microscope and X-ray diffraction were used to characterize the microstructure after tempering in more

detail. With these findings, it was possible to describe the differences in the tempering and retained austenite-stabilizing effect of Si and Al during the Q&P process.
The investigations show a clear influence of the alloying elements Si and Al on the tempering behavior in martensite. As Al alloyed steels show a more pronounced carbide precipitation than Si alloyed grades at the early stage of tempering, lower amounts of retained austenite could be stabilized during Q&P. However, a significant reduction in Si is achieved by adding balanced amounts of Al to stabilize high contents of stable retained austenite during successive Q&P.

**Speaker Country**:

Österreich

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**SURFACE ENGINEERING / 70**

## Microstructure and mechanical property assessment of plasma tempered aluminized Indian RAFM steels

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**Co-authors:** Rakesh TUNK [2]; N. I. JAMNAPARA [1]; C. S. SASMAL [3]; P. CHAUNDHURI [1]; J. MUKHOPADHYAY [2]; Amit ARORA [2]

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Indian Reduced Activated Ferritic Martensitic (IN-RAFM) steels are structural material of the blanket module for nuclear fusion application. Critical issues such as liquid metal corrosion of RAFM steel, tritium permeation and magneto hydrodynamic drag generation due to flowing Pb−17Li is already reported for the test blanket module. To mitigate the same, aluminized coatings (FeAl +
α-Al2O3) with novel plasma assisted heat treatments are widely reported for the surrogate material 9Cr-1Mo steel. However, the coatings on RAFM steel and its effects on microstructure and mechanical properties are scarcely reported.

In order to investigate the same, aluminizing process of RAFM steel followed by tensile tests were carried out in this study. In-RAFM steel (9Cr-1.4W-0.06Ta) samples were hot dipped in a molten bath of 93%Al & 7%Si at 730 ℃. These samples were then subjected to heat treatments in air and plasma environment (100% O2) to study the transformation of θ-Al2O3 to α-Al2O3. The coated samples were characterized with X-ray diffraction and scanning electron microscopy (SEM) to correlate the phase transformation in microstructure. Subsequently, tensile tests of coated samples at room temperature and 550℃, and a comparatively analysis of both is done with respect to substrate steel. At room temperature, mechanical tests revealed a higher strength in case of thermally tempered specimens with around ˜720 MPa, 25% elongation; whereas plasma tempered and substrate steel strength was found around ˜550 MPa, 25% elongation and ˜600 MPa, 28% elongation respectively. Similar trend was observed at high temperature (550 ℃ ). The
outcomes are promising as the effect of coating is minimal on tensile strength in case of plasma tempering. In addition, it also motivates the scientific community to conduct extensive research for the implication of coatings for fusion applications.

**Speaker Country**:

India

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**SURFACE ENGINEERING / 71**

## Influence of nitrogen enrichment on microstructure and mechanical properties of a carbonidrided low steel alloy

**Authors:** Maria Rita CHINI[1]; Corentin DIDES[1]; Jacky DULCY[1]; Julien VALETTE[1]; Mathieu BILLET[2]; André GALTIER[2]; Marc COURTEAUX[3]; Benoît GIRARD[1]; Pascal LASMESLE[None]

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In some applications, carbonitriding treatment is used to replace the carburizing treatment thanks to its ability to improve mechanical properties.

The aim of this study is to better understand the role of nitrogen on mechanical properties and microstructure. For this we studied the response of the 27MnCr5 steel to different carbonitriding treatments which target specific carbon and nitrogen composition profiles. These specific compositions profiles were chosen to generate equivalent hardness profiles to the carburized reference.

The results confirm the positive effect of nitrogen on the mechanical properties. The performance of carbonitrided steels with high nitrogen content (> 0.3%N) are improved. Additionally, tempering at an intermediate temperature (160℃) further improves the mechanical resistance thanks to the precipitation of nanometric $Fe_{16}N_2$ nitrides. Moreover, a new carbonitriding treatment was developed to obtain greater nitrogen enrichment leading to superficial nitrogen mass fraction of 0.5%.

**Speaker Country**:

France

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**SURFACE ENGINEERING / 72**

## Influence of shot peening on carbonitrided low alloy steel

**Authors:** Maria Rita CHINI[1]; Benoit GIRARD[1]; Corentin DIDES[1]; Jacky DULCY[1]; Julien VALETTE[1]; Mathieu BILLET[2]; André GALTIER[2]; Marc COURTEAUX[3]

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In industry, thermochemical carbonitriding treatment is often followed by shot peening. Each of these processes generates surface microstructural modifications and residual compressive stresses

which have a direct effect on the fatigue resistance. In the literature, these processes are often studied separately and therefore optimized independently.

This study focuses on these two processes, carbonitriding and shot peening, combined to better understand how they interact. For this, a complete analysis of different configurations was carried out, which includes the metallurgical characterization (microstructure, residual austenite level, residual stresses, microhardness) and the mechanical response through a campaign of mechanical tests.

Various analyzes have shown that the shot-peening of carbonitrided parts causes an increase in surface hardness, a transformation of the residual austenite and generates residual compressive stresses which depend on the level of residual austenite after carbonitriding. The test campaign has shown that shot peeing improves the mechanical properties of carbonitrided parts if a tempering step is carried out after thermochemical treatment.

**Speaker Country**:

France

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**HEAT TREATMENT / 73**

## Development of an individually adjustable nozzle cooling system for optimization of the strip flatness for ultra-thin precision strips: state of the art and evaluation of the solution approaches

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**Co-authors:** Dominik BÜSCHGENS [2]; Moritz EICKHOFF [1]; Herbert PFEIFFER [3]

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The optimal strip flatness of stainless martensitic steels is a mandatory requirement for many components in microelectronics or medical technology in order to fulfil the function or manufacture of the products. In the context of energy efficiency, there are increasing demands for thinner materials, e.g. for valves in compressors.
In modern plants, stainless steel strips are quenched using various cooling methods. The temperature is not measured and controlled across the width of the strip but gradients have a significant influence on the flatness. A lack of temperature measurement and control forces manufacturers to produce in larger widths and then cut the strips into narrower ones. Depending on the flatness of the manufactured strips, the belt is sold or scrapped. Above a strip thickness of 0.25 mm the required flatness is achieved and the scrap is quite low. However, the output of strips with the desired flatness decreases the thinner and the wider they are. The rejection rate is up to 99 %.
Familiar plants for the quenching and tempering of the thinnest stainless martensitic strips cool the material in the final quenching and tempering phase via a mechani-cal quench. An exact adjustment of the temperature over the strip width is impossi-ble. Therefore, for the first time in this project, a system is to be developed whose nozzle cooling makes the cooling capacity individually adjustable over the strip width. This forms the basis for controlling the flatness of the strip over its width, since the cooling capacity is defined locally for each width.
With the aim of finding the best possible cooling concept using nozzles to optimize strip flatness, a basic study of the state of the art was executed. The various cooling concepts with different nozzle arrays are presented and evaluated regarding their application to the project objective.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**SURFACE ENGINEERING / 74**

## High temperature solution nitriding and heat treatment of martensitic stainless steels for bearing applications

**Authors:** Matteo VILLA[1]; Marcel SOMERS[1]; Thomas CHRISTIANSEN[2]

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High temperature solution nitriding (HTSN) of stainless steel was originally introduced in the early 1990s and is in many aspects the "stainless" analogue to carburizing of steels. Instead of introducing carbon to the surface, nitrogen is used. The process is normally carried out at temperatures above, say, 1050°C, using an atmosphere of molecular nitrogen at a fixed pressure in order to control how much nitrogen is introduced. Austenitic, ferritic, duplex and martensitic stainless steels can all be high temperature solution nitrided but the strategies to obtain optimal properties can be quite different. For martensitic (and ferritic) stainless steel the concept is to obtain a nitrogen containing martensitic case for improved wear, fatigue and corrosion performance. Hitherto, the HTSN process has been somewhat niche in industry owing, in part, to the high temperatures involved and in particular to the inherent challenges associated with the process and the resulting microstructures. The present contribution will provide an overview of the state-of-the-art of HTSN treatment of martensitic stainless steel - including the different challenges associated with HTSN. New developments in the optimization of the HTSN process and the resulting microstructures will be presented. For HTSN treatment of martensitic stainless steels, special heat treatment processes are required in order to exploit the full potential of HTSN. It will be shown that microstructures and properties equivalent to the expensive nitrogen containing "Cronidur30" type martensitic stainless steel can be achieved in conventional martensitic stainless steel grades via HTSN and specialized heat treatment. Such materials are highly effective in combatting failures relating to "white etching cracks" (WEC) – a widely known challenge in many bearing applications.

**Speaker Country**:

Denmark

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**STEEL / 75**

## Austenite aging of 17-4 PH martensitic stainless steel: phenomena, effects and implications

**Authors:** Matteo VILLA[1]; Frank NIESSEN[1]; Flemming GRUMSEN[1]; Thomas DAHMEN[1]; Marcel SOMERS[1]

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Precipitation hardening martensitic stainless steel 17-4 PH is a classic grade that receives renewed attention because of its suitability for metal additive manufacturing (MAM). Conventionally, 17-4 PH is subjected to austenitizing before it transforms into martensite during cooling. Subsequently, an aging treatment is performed to achieve strengthening by precipitation of copper particles. It is generally believed that no precipitation reaction is possible while the material is austenitic. This would make it robust to variations in the treatment process and thus avoid precipitation during MAM. In the present study we demonstrate that this belief is unjustified and that austenite does age. Accordingly, martensite formation is affected as well as martensite's aging response. It is demonstrated that the aging phenomena occurring in austenite can affect the properties of the steel at the end of the thermal cycle, and hence its performance in service. The implications and the potential exploitation of the revealed phenomena are discussed.

**Speaker Country**:

Denmark

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**Poster** / **77**

## Influence of isothermal heat treatment on the metallurgical characteristics of the IN625 alloy

**Authors:** Luis Henrique PIZETTA ZORDAO[1]; Davide PANZERI[1]; Riccardo GEROSA[1]; Barbara RIVOLTA[1]

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The nickel super alloy 625 can be used for mechanical applications on the solid solution state but has its applicability in aeronautic, aerospace, marine, chemical and petrochemical industries when improvement on mechanical resistance by age-hardening treatments are performed. In this study the grain growth, precipitation and phase transformation were evaluated in a commercial superalloy 625. Grain growth at different temperatures and the correspondent phase transformation were evaluated during the solution . A comparison between single aging at different temperatures and an innovative double aging heat treatments combination were investigated by SEM, hardness test and tensile tests. As a consequence of heat treatment in nickel alloys the high temperature can influence negatively reducing the corrosion resistance, an important characteristic for this group of alloy that was evaluated according the ASTM G28 method A.

**Speaker Country**:

Brazil

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT** / **78**

## Comparison of high-severity quenchants for low-carbon steels

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High hardenability of steels is related to the presence of alloying elements, which enable quenching in less severe media, which are characterized by low cooling rates. However, such alloying elements increase the cost of steel. Considering the possibility of developing quenching heat treatments with lower cost steels and achieving hardness values close to those of alloyed steels, this article aims to compare quenchants for low-carbon steels (SAE 1020 and SAE 8620), from different criteria. Among the cooling media, an aqueous cooling fluid formulated with surfactants and ionic additives, which is called Fastquench, was studied. In addition, brine, a solution of silica nanofluid, water and oils were used. The evaluation of the media was performed by analyzing the hardness profile in the steels after quenching, cooling curves and Grossman quench severity factor. The results show that among the evaluated media, brine had the highest severity, followed by Fastquench solution. Thus, the Fastquench solution formulated for this research has not been identified as an advantageous additive for quenching low carbon steels under the experimental conditions adopted since it did not reach results equal or superior to those of brine.

**Speaker Country**:

Brazil

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**HEAT TREATMENT / 79**

## Quenching for the future - In memoriam of Sören Segerberg

**Author:** Eva TROELL[1]

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Sören Segerberg passed away July 27 at age 78. Born in 1943 he graduated from Materials Science and Engineering at KTH Royal Institute of Technology in Stockholm, Sweden, 1968 with a degree in metallurgical science. Sören Segerberg was a leading expert in the quenching area. From 1979 and the next 25 years he worked in research and development at the Institute for Engineering Technology Research (IVF, today RISE) in Gothenburg, Sweden. He was one of the initiators of the development and sale of IVF's Quenchotest/ivf SmartQuench, an equipment for quality control of cooling curve measurement. He was also a contributor in the development of ASTM D6200 and ISO 9950.

During his time at RISE, many projects in the field of quenching were carried out involving cooling characteristics of quenchants, classification of quench oils and polymers as well as correlation between quenching characteristics of quenching media and hardness. In the early 90s one focus were environmental adapted quenchants and methods. The work included spray-quenching with e.g. water/air-mixtures, fluidized bed and, of course, cooling in gas. Where the latter was an extensive part of the work also including an equipment with an atmospheric furnace connected to a cold high-pressure gas cooling chamber. Pressures up to 40 bar helium and up to 10 bar with nitrogen could be used. The aim was to study whether gas cooling could be used as an environmental adapted replacement for oil or salt cooling. Today cooling in gas has increased and has proven to be a sustainable alternative to liquid quenching, especially oils.

**Speaker Country**:

Sweden

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**Poster / 80**

## Surface alloying of austenitic stainless steel with nitrogen and carbon for improved hardness through low-temperature nitrocarburizing using pulsed DC N2-H2-C2H2 plasma

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Austenitic stainless steels are widely surface hardened by alloying with nitrogen and carbon through nitrocarburizing process1, 2. The process results in the formation of a hard case consisting of nitrides or both nitrides and carbides of Fe and Cr which are responsible for the increased surface hardness. But the formation of nitrides and carbides of Cr degrade the corrosion resistance property of stainless steels2. The nitrides and carbides of Cr can be avoided by carrying out nitrocarburizing process through low-temperature plasma nitrocarburizing which forms a hard case consisting of a solid-solution of nitrogen and carbon occupying interstitial sites in "expanded" austenite phase2, 3. The expanded austenite is further characterized as nitrogen-expanded austenite (γN) and carbon-expanded austenite (γC) 2, 3. In addition to γN and γC the hard case can also consist of a γ'-Fe4N-like (γ'N) and □'-Fe2-3N-like (□'N) phase3-5. In the present work austenitic stainless steel AISI 304 samples processed by a series of low-temperature plasma nitrocarburizing treatments were characterized by means of X-Ray diffractometry, Vicker's microhardness testing, and potentiodynamic polarization testing to study the surface property of the hard case in terms of constituent phases, surface hardness, and corrosion resistance property. From the X-Ray diffractograms the γ'-Fe4N-like and □'-Fe2-3N-like phases were confirmed and were only seen after 5-hour LTPNC process time. By Glancing incidence X-Ray diffractometry it was found that the surface of the hard case is rich in γ'-Fe4N, and γN was only seen in the sub-surface below the γ'N. Surface hardness significantly improved after the pulsed DC plasma nitrocarburizing treatments and corrosion resistance did not deteriorate as the hard cases were free from nitrides and carbides of Cr which are elucidated from the X-Ray diffractograms.

**Speaker Country**:

India

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 82**

## Control of quench severity by applying an electric potential during heat treatment of aluminium alloys

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Since quenching in cold water usually leads to distortions of the quenched component, it is obvious to either increase the temperature of the quenching bath (if necessary to near boiling point) or to

use a different quenching medium, e.g. polymer solutions and gaseous media, respectively. In all cases, this is usually associated with higher investments and/or operating costs.

It would be more elegant, however, to achieve this with one and the same medium. This could be done by applying an electric field between the component to be quenched and a counter-electrode, which is immersed in the quenching medium. The latter must be a salt solution, an acid or lye, as the quenching medium must have at least a certain electrical conductivity. As already reported at the ECHT/QDE Conference 2021, the arrangement described above was able to stabilize the film boiling period for several additional seconds before nucleate boiling and rewetting of the component took place. This process can be controlled within certain limits by selecting the current density or the duration of the current flow. The component was connected as a cathode. Reversing the polarity, however, did not lead to a change in the quenching process.

In this paper, the influence of further variations of current density and electric potential, as well as the importance of an optimized design of the counter-electrode in terms of geometry and material, and the influence of the surface structure of the component to be quenched are to be demonstrated. If one interprets the arrangement casually as a capacitor or as a series of capacitors connected in series, a vivid explanation of the observed phenomenon emerges. This model can be used for further, targeted optimizations.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**STEEL / 83**

## Innovative heat treatment leading to formation of nanocrystalline multiphase microstructure in high-alloy tool steel

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Nanostructurization by bainitic phase transformation is a revolutionary method of improving mechanical properties of a wide range of steels. It can be applied as a single process or as a part of the innovative multistage heat treatment. While implementing the latter to the tool steel it allows obtaining a new type of complex microstructure consisting of very hard carbides in tough, nanocrystalline matrix comprising bainitic ferrite, martensite and retained austenite. In the present work the influence of process parameters on multiphase microstructure evolution was investigated in high carbon steel, containing enhanced concentration of silicon and carbide forming elements. By controlling the amount of particular components in the microstructure it is possible to change mechanical and service properties of steel.

The kinetics of phase transformations that occurred during the process was analyzed using dilatometric tests. The phase composition and morphology of phase constituents were determined by observations with the scanning electron microscope (SEM) and transmission electron microscope (TEM), accompanied by the XRD and magnetic measurements. The study was completed with mechanical tests, including hardness measurements, uniaxial compression tests, impact and fracture toughness tests.
This research is funded by the National Centre for Research and Development under the LIDER IX program, project NanoCarbain (contract no. LIDER/12/0040/L-9/17/NCBR/2018).

**Speaker Country**:

Poland

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**SURFACE ENGINEERING / 84**

## Modification of boride layers on alloy steel by impulse electron beam

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The development and implementation of new coatings and layers with a specific complex of physicochemical, mechanical, and functional properties are of significant fundamental and applied importance for expanding the performance characteristics of machine parts and tools and increasing their service life. The excellent resistance of boron-based diffusion layers and coatings to abrasive, corrosive, and erosive wear is the reason for their widespread use as protective coatings on parts of high-tech products of power and unique mechanical engineering and in the production of critical technological equipment. Despite the benefits, such coatings and layers have several serious disadvantages, such as high fragility, a small thickness of the modified layer, insufficient quality of the surface morphology, which often requires subsequent mechanical processing. Nowadays, the technological possibilities of creating new materials by common thermal-chemical treatment are practically exhausted. The use of concentrated energy sources, such as intense pulsed electron beams, to modify the surface properties of machine parts and tools allows flexible regulation of the structural-phase state of materials in a wide range.
The current research aims to create functional layers on the surface of alloy steels by subsequent processing of diffusion boride layers by an intense pulsed electron beam of a megawatt power level. A modernized electron source with a plasma cathode allows generating an electron beam of millisecond duration, where its power and the temperature of the irradiated surface can be controlled during a single pulse.

**Speaker Country**:

Russia

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 85**

## Solution nitriding of a Fe-0.13%C-1.2%ni-13%Cr grade steel: a theoretical and experimental study

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Solution nitriding is a high temperature nitriding process carried out in a gaseous atmosphere composed of pure nitrogen under various pressure. It is notably used to reinforced stainless martensitic steels while limiting loss of stainless properties due to chromium precipitation. The aim of the study is to propose an approach based on thermodynamics considerations for identifying adequate treating parameters for a given steel grade. Therefore, a theoretical study has been conducted considering a Fe-0.13%C-1.2%Ni-13%Cr steel. The use of thermodynamics calculation software permits on one hand, to determine the nitrogen solubility limit in the austenitic region before precipitating chromium nitrides for the considered steel and on the other the hand, to estimate the maximum nitrogen content that it is possible to introduce in steel with respect to the treatment pressure. Nitrogen profile could then be estimated thanks to use of diffusion modelling software. To confront the theoretical approach with experimental results, samples were treated on laboratory equipment under N2 and N2-NH3 atmospheres at temperatures comprised between 1000 ℃ and 1100 ℃. Nitrided layers were investigated using light optical microscopy, hardness measurements and glow discharge optical emission spectroscopy (GDOES). Degradation of stainless properties was evaluated using voltammetry method. The thermochemical approach of the solution nitriding process developed in this study, based on the coupling between thermodynamics et kinetics, appears to be a reliable support for the identification of conditions allowing minimization of stainless properties loss for nitrided stainless martensitic steel.

**Speaker Country**:

France

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 86**

## Contact fatigue in carbonitrided steels and the influence of retained austenite

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Carbonitriding has shown great potential to further increase service life of components exposed to contact fatigue. In this project, the rolling contact fatigue properties of case hardened and carbonitrided 18CrNiMo7-6 were investigated. The aim was to qualitatively assess the impact of retained austenite on micropitting damage to further understand the underlying mechanisms of the carbonitriding process. In regular case hardening, it was found that high retained austenite reduces the degree of micropitting damages significantly, due to the mechanical-induced transformation of austenite into martensite. This was also found in in carbonitrided samples, but the results were further influenced by precipitation of chromium carbonitrides. These precipitate as nitrogen disassociates from the ammonia in the carbonitriding atmosphere into the steel. Indication were found that the size of these precipitates controls the impact they have on the resulting fatigue properties. The resulting hypothesis is that for lower ammonia content, <3%, the precipitates remain small (<10 µm) and provide a dispersion hardening effect with excellent enhancement of performance. On the other hand, at higher ammonia atmosphere contents, >5%, more of these precipitates grow large (>100 µm), thus providing sources for crack initiation and slightly reduce the fatigue strength compared to if they remained small.

**Speaker Country**:

Sverige

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 87**

## Improving the properties of K490MC tool steel after hardening accompanied with deep cryogenic treatment and plasma nitriding

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The Böhler K490 MicroClean tool steel was developed for hardening and tempering applications with the possibility of additional nitriding in plasma, gas or salt bath. Its application includes cold working tools and polymer processing tools. The paper analyses the influence of the choice of austenitization temperature, deep cryogenic treatment (DCT), tempering temperature and plasma nitriding on the hardness and microstructure of K490MC steel. The obtained results of the surface hardness and effective nitriding depth was compared on specimens exposed to the DCT process after quenching and then plasma nitrided in the Rübig direct current (DC) micropuls plasma furnace PC 70/90 in relation to the specimens which were hardened and tempered without DCT and plasma nitrided or nitrided in salth bath Tenifer. Conducted tests of surface layer hardness and microstructure analysis showed combinations in the choice of austenitization temperature, application of DCT and nitriding process which can achieve high surface hardness, good tempering resistance and increased depth of nitriding in the DC micropuls plasma or salth bath Tenifer.

**Speaker Country**:

Croatia

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**Poster / 88**

## Increasing the wear resistance of high-alloy tool steels for cold work with multilayer coatings TiN/TiCN and TiN/Ti-B-N applied by the PACVD process

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The paper compares the abrasion and erosion resistance of two high-alloy tool steels, EN X153CrMoV12 and Böhler K390 MICROCLEAN, coated with multilayer coatings TiN / TiCN and TiN / Ti-B-N. Multilayer coatings were applied to hardened and tempered samples by pulsed direct current (DC)

plasma-assisted chemical-vapour deposition (PACVD) process in the Rübig PC 70/90 industrial vacuum oven. The mechanical properties of the coating were tested by calotest, Rockwell-C indentation test and the test of fracture toughness and microhardness. Abrasion resistance was tested by the “”Dry Sand/Rubber Wheel” method. Erosion resistance was tested by exposing the surface of the samples to a jet of fine sand particles at an angle of incidence of 90 degrees for 60 min. Worn surfaces were analyzed with a light and scanning electron microscope. It was found that increased resistance to abrasion and erosion wear is achieved on samples with higher substrate hardness and higher hardness, fracture toughness and better adhesion of the coating. Based on the test results, a mathematical model for predicting the loss of coating mass after sand blast erosion was proposed.

**Speaker Country**:

Croatia

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**SURFACE ENGINEERING / 89**

## Surface treatment of metallic materials by electron-beam-plasma methods

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**Abstract.** The development and implementation of new coatings and layers with a certain set of physicochemical, mechanical and functional properties is of great fundamental and applied importance for expanding the performance characteristics of machine parts and tools and, in particular, increasing their service life. One of the promising combined methods that are of interest to scientific researchers is the deposition of a coating followed by electron-beam processing of the “coating/substrate” system, which makes it possible to obtain surface alloys of various compositions with a thickness of ˜ 0.1–100 μm with unique properties.
The study in this paper is aimed at developing scientific and methodological approaches of pulsed electron-beam mixing to create functionally graded coatings on the surface of structural steel, on the surface of which a layer of niobium is deposited. For coating, the method of vacuum-arc deposition with plasma assistance was used. Coating was carried out on a unique experimental setup “QUINTA”. For electron-beam processing, a “SOLO” electron source with a plasma cathode based on a low-pressure arc was used. This source makes it possible to generate an electron beam of submillisecond duration, the power of which can be controlled in the course of a pulse. This makes it possible to control structural and phase transformations in diffusion coatings on the surface of metals by maintaining the temperature of the irradiated surface.
The use of the unique capabilities of electron-ion-plasma equipment made it possible to demonstrate a multiple increase in the microhardness and wear resistance of the surface under study. The change in the phase and elemental composition of the near-surface layer, observed using X-ray diagnostics and scanning electron microscopy, as well as the assessment of the dynamics of the melt and cooling of this layer, made it possible to establish the main mechanisms for hardening the surface under study, which opens up new possibilities for using combined electron-beam-plasma technologies for surface modification of various metal materials and products.
**Keywords**: vacuum-arc plasma-assisted deposition, pulsed electron beam, surface modification, surface layer, hardening, layer structure.

**Speaker Country**:

Russian Federation

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 90**

## Current Investigations at Quenching Research Centre

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Quenching Research Centre (QRC) has been established at the beginning of 2010 by the financial support for excellence of the Ministry of Science Education and Sport, of the Republic of Croatia. The main investigation and research possibilities and potentials of the QRC are: quenching in liquids or in a salt bath and cooling by high pressure gases. As a result of long term research the Temperature Gradient System has been designed, together with a unique cylindrical probe of 50 mm Dia. × 200 mm instrumented with three thermocouples. Another device used at the Centre is IVFSmartQuench system according to ISO 9950 standard, using a quenching device with agitation according to ASTM D 6482 standard. That equipment is used to investigate liquid quenchants and process parameters, including development of new quenchants: water, oil and polymer based nanofluids agitated by ultrasonic vibrations, as a novel technology. QRC is also equipped with a unique high pressure gas quenching facilities providing the hardware for controllable heat extraction. The aim of using that equipment is to develop the method for measuring hardenability of high-alloyed steels when they are gas quenched, where Jominy test is not applicable. QRC is also one of initiators and an active participant in the project Global database on cooling intensities of liquid quenchants which is coordinated and conducted by International Federation for Heat Treatment and Surface Engineering (IFHTSE).

**Speaker Country**:

Croatia

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 91**

## PACVD- and nitriding processes as surface treatments to enhance corrosion- and wear resistance of piston rods for the hydraulic industry

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Hydraulic cylinders are one of the main products in the fluid power industry. During their service life, piston rods are exposed to corrosive environments and wear stresses. Thus, a suitable surface treatment for enhancement of corrosion- and wear resistance is of high importance to guarantee a long lifetime of the parts. The main requirements to piston rod coatings include high surface hardness as well as a low and evenly distributed surface roughness to minimize wear of sealing and coating.
During the gas- or plasma nitriding process, atomic nitrogen diffuses into steels and leads to hardening of the surface and edge zone, where formation of nitrides with alloying elements such as Cr, Al and V represents the biggest contribution to hardness increase. Due to its ceramic character, the compound layer consisting of iron-nitrides, leads to an increased corrosion- and wear resistance. To reach a further increase in corrosion resistance, an oxidation step can be added after nitriding in the same process. Moreover, the slightly softer oxide layer can serve as a run-in layer to reduce sealing wear and the small pores act as a lubricant reservoir.
The PACVD technology can be used to deposit Si-doped amorphous carbon coatings (a-C:H:Si, "Diamond Like Carbon" - DLC). The Duplex DLC Xtended® process is a combination of plasma nitriding with subsequent DLC coating, enabling edge-zone hardening and coating in a single process.
Treatment of steels with RÜBIG technologies GASOX® or PLASOX® meet the requirements of 24-120h in the neutral salt spray test (NSS, ISO 9227). The Duplex DLC Xtended® thick coatings withstand more than 500h in the NSS test.
A comprehensive characterization of RÜBIG technologies in comparison with commercially available Cr- and Ni-Cr coatings including corrosion- and tribological testing with sealings as counterbody showed the applicability of of GASOX® and PLASOX® as alternatives for one layer Cr- coatings. For higher corrosion-requirements, Duplex DLC Xtended® coatings may be used.

**Speaker Country**:

Austria

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 92**

## Advanced developments in the field of liquid quenchants State of technique - New Requirements – Technical Perspectives

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The quenching process and the quenching media in use are of great importance for the suc-cess of the heat treatment process. The quenchant and its heat transfer properties significant-ly influences the resulting mechanical properties and the dimensional change and intensity of distortion.

All current considerations in the field of quenchants are conducted with the objective of opti-mizing the overall costs for the heat treatment process and minimizing rework and scrap. Therefore, new requirements are being formulated for the quenchants in use with regard to a better uniformity of the quenchant properties.

In addition the technological change and the requirements of the legislation as well as increas-ing efforts to reduce environmental pollutants and CO2 - emissions in the manufacturing pro-cess of parts and components leads to numerous efforts to establish production processes in a more energetically and environmentally friendly way.

The introduction of new materials for the parts, their reduction of weight and the increase of functionality in components becomes more relevant - resulting in parts of more sophisticated design and higher sensitivity to distortion.

This development also leads to increased requirements to the properties and quality of quenchants.

This presentation describes the liquid quenchants currently in use and shows up the new re-quirements and furthermore approaches in regard to the development of quenchants which are targeted to achieve these technical and environmental objectives.

**Speaker Country**:

Deutschland

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**Poster / 93**

## Abnormal plate type iron-carbonitrides development during salt bath nitrocarburizing of Fe-4wt.%V alloy

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A precise understanding of compound layer growth on nitrocarburized steels requires fundamental investigations on nitrocarburizing of iron-based binary and ternary alloys. Such studies were extensively carried out for the case of nitriding. To this end, this study is devoted to understanding the role of V on the structure and morphology of iron-carbonitrides developed during salt bath nitrocarburizing of pure Fe and Fe-4 wt.% V alloy. Salt bath nitrocarburizing is carried out in a cyanate-based bath at 500oC and 560oC for nitriding times of 4h and 10h. Treated specimens were characterized using light and scanning electron microscopes, X-ray and Electron Back Scattered diffraction techniques, and microhardness measurements.
An unusual plate-type morphology of γ' and ε phases growing into ferrite matrix was evidenced in the case of Fe-V alloy and usual layer type growth of compound layer occurred in a pure iron specimen. Interestingly, the ε nitride phase was developed first (i.e., present at larger depths from the specimen surface) followed by the γ' which has been attributed to the role of C in stabilizing the ε phase and C is known to enrich at subsurface regions during nitrocarburizing. Developed nitrides and carbonitrides maintained a specific crystallographic orientation relationship with the ferrite matrix. XRD and hardness measurements indicated the development of VN precipitates in the ferrite matrix before the plate-type growth of iron nitrides and iron-carbonitrides. Such plate-type morphology of iron-nitrides developed in nitride Fe-Al, Fe-Si, and Fe-Mo was attributed to the difficulty in alloying element partitioning required for the development of nitrides. In the current work where iron-carbonitrides were growing into a ferrite matrix in which all V has already precipitated as nitride suggests the role of developed VN and associated interfacial and misfit strain fields could be responsible for the unusual plate-type morphology. Thermo-Calc software and steels thermodynamic property database (TCFE9) were utilized to predict the phase constitution expected and were utilized to explain the observed phase formation sequence.

**Speaker Country**:

India

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**HEAT TREATMENT / 94**

## CO2-Reduction by enhanced energy efficiency in LPC-heat treating plants

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One measure to achieve the demanding future climate targets with regard to CO2 reduction is to reduce the energy consumption of thermal process plants. In the field of case hardening of transmission components, low-pressure carburizing systems with high-pressure gas quenching are often used in the automotive and supplier industries. Components treated with this technology are clean, free of intergranular oxidation and low in distortion, i.e. they require only minimal post-processing, which saves costs and energy.
Due to the vacuum technology, the consumption of process gases during carburizing is minimal. During quenching, the consumption of inert gas is minimized by gas recycling. The main energy source of this technology is electrical energy, as the equipment is heated electrically without exception. Quenching, in turn, is carried out by means of highly compressed inert gases. The necessary rapid circulation of the quench gases is in turn achieved by means of electric blower motors.
The paper presents various measures for reducing the consumption of electrical energy during the heating and carburizing phase as well as during the quenching phase by means of improved process control and optimization of the plant technology. For exploiting this potential, modern material systems in conjunction with appropriate component specifications from the gearbox manufacturers are suitable starting points. The paper compares the effect of different measures in the area of process, plant and component material and quantifies the impact on electrical energy consumption and thus the CO2 footprint.

**Speaker Country**:

Deutschland

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**Poster / 95**

## Cyclic application of ultrasonic shot peening and low-temperature liquid nitriding on 316 stainless steel

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Prior severe surface plastic deformation (SSPD) treatments have proven beneficial to low-temperature nitriding to achieve a thicker nitride layer, improved hardness, and wear resistance. Although extensive work has been reported on SSPD followed by nitriding; however, cyclic treatment of SSPD and low-temperature nitriding on austenitic steels (ASS) is not reported. Also, the role of deformation on nitridation kinetics was not well understood.

In the present work, at first, ultra-sonic shot peening (USP) and low-temperature liquid nitriding (LN) are performed in cycles on 316 ASS. Comparison is made among cyclic treated, liquid nitrided, and one-time shot-peened and nitrided sample conditions.

From the results of this study (optical, electron microscopy and hardness depth profile at the cross-section, XRD depth profiling by sequential removal of layers from the treated surface to the core to know the phases formed with depth), we have extended our research to know the role of deformation on the kinetics of nitridation for various ASS.

The ASS are subjected to LN at 425 ℃ for 4 hours before and after the deformation (USP and cryo-rolling). The treated sample surfaces and cross-sections are characterized using X-ray diffraction and scanning electron microscopy, respectively.

It is observed that the role of deformation in enhancing the nitrided layer thickness is dependent on the material chemistry along with the phases present in it. All the possible causes are analyzed and discussed.

Further, to establish links between the deformation and nitriding kinetics for various phases with the same chemistry, the experimental tests are followed by Thermo-Calc studies.

**Speaker Country**:

India

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**Poster** / **96**

## Usage of continuous cooling transformation (CCT) diagrams for laser and small-scale induction hardening

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Hardness of hardened steel material is mostly determined from its CCT, according to the corresponding curve of cooling. These diagrams are based on experiments when the samples of dimensions at the level of centimetres are heated under prescribed conditions in special furnaces and then cooled at different rates. However, hardening based on laser or small-scale induction heating concerns only small volumes of material (usually several mm3). Unlike convection which typically prevails at cooling larger samples (reaching rates on the level of tens degrees of Celsius per second), cooling of small volumes is characterised mostly by conduction of heat to the interior of material and rates of many hundreds degrees of Celsius per second. That is why the work with standard CCT diagrams (in full version) should properly be modified in this case in order to get correct results.
Moreover, the structural variations in materials for that high velocity of cooling are substantially different (chemical changes, carbidization or formation of levels such as pearlite, ferrite or bainite) and these changes cannot be correctly derived (approximated) from the standard CCT diagram.
The solution to the problem is based on both theoretical and experimental approaches. The sample of material is heated by laser beam with variable heating power, but anyway, the temperature of the irradiated spot must exceed the value Ac3. After cooling, its hardness is measured by the fully automated micro-hardness tester Falcon 600. Then, laser beams of different trace areas, are used, but of the same power per unit area delivered to the spot. The goal of these experiments is to find the dependence of resultant hardness on the area of hardened surface and rate of subsequent cooling.
Next step is to build a full model of the process and calibrate it (because the heat delivered to the irradiated spot is not known quite accurately) using optimization techniques and results of all experiments. This data is expected to provide information enough for building a surrogate model that would be able to estimate the parameters for subsequent computation of hardness taking into account all important structural changes in the material and also speed of the laser beam in case of continuous hardening. The surrogate model is supposed to consist of a combination of polynomial and exponential functions whose coefficients will be determined by the Gaussian process and eventually modified by training on a sufficient amount of further experimental data.

**Speaker Country**:

Czech Republic

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 98**

## Numerical simulation for advanced designing of induction heat treatment systems with magnetic flux concentrators

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Only limited variety of induction heat treatment processes could be realized by induction coils without applying of so called magnetic flux concentrators (MFC). An advantage solution is to apply so called composite magnetic materials. Nevertheless, there are several difficulties because of significant internal losses at high frequency, limited thermal conductivity in combination with pronounced anisotropy of the material properties.
Nowadays induction coils with MFC are included into coupled electromagnetic-thermal numerical models as electromagnetic active element while the thermal analysis is carried out for the workpiece only. This way leads not only to significant reduction of simulation accuracy but to overheating of the coils with MFC up to loss of their working capacity. The proposed approach of numerical simulation for advanced designing of induction heat treatment systems with MFC includes precise analysis of thermal processes in the coil and MFC as well. The approach has been successfully tested on one example of line induction coil with MFC for heating of the workpiece surface.
The most difficult problem is to know electro- and thermo-physical properties of MFC materials including self losses, especially in anisotropic version. That is why the authors were forced to create a method to extract the needed data. Anisotropic relative magnetic permeability, thermal conductivity and self losses were still to be defined. For this purpose an experimental set-up including 100 kW high frequency generator and a line induction coil with MFC has been build. Mounting the MFC in various direction orientations one can investigate the process in three dimensions separately. Frequency, the coil current and the surface temperature of MFC as well as the cooling water temperature inside the coil profile are measured till reaching thermal steady-state mode.
At the same time, a three-dimensional coupled electromagnetic-thermal numerical model has been developed as a digital twin of the experimental set-up. Identification of MFC properties is realized as optimization of the properties values in the model to reach the same temperature dynamics in the model as in the experiment.
Identification of thermal conductivity of MFC material gives very stable solution independent on assumed values of relative magnetic permeability and self losses. One example of such identification will be presented in the paper. The self losses are identified also, but they depend on the assumed relative magnetic permeability. The measured and identified material data have been implemented into new generation of numerical models which provide advanced designing of induction coils with MFC.

**Speaker Country**:

Germany

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**SURFACE ENGINEERING / 99**

# Surface nitriding of aluminum using barrel and its applications

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A passivation layer is present on the aluminum surface, and Al has a better affinity for oxygen than nitrogen so generation of aluminum oxide is easier than with aluminum nitride (AlN). Therefore, it is difficult to form the AlN on aluminum surface below the melting point. However, gas nitriding of aluminum is possible by using the barrel nitriding in which the oxygen partial pressure in the atmosphere is reduced and the passivation layer on the surface is polished with heating in nitrogen atmosphere. Scanning electron microscopy (SEM) is used for thickness measurement and structure observations of the modified layer. X-ray diffraction analysis (XRD) is carried out to characterize the constituents of the modified layers. The distribution of nitrogen, oxygen Al and magnesium in the modified layer is analyzed by electron probe micro analyzer (EPMA).
A nitrided layer of several hundred micrometers can be formed on the aluminum substrate by using the barrel nitriding, and its hardness is about 600 HV. The chemical composition of the aluminum alloy affects the formation of the nitrided layer. Magnesium promotes the formation of a nitride layer, and silicon prevents the formation of a nitride layer.
This method is also applicable to aluminum powder, and aluminum powder with a diameter from 75 to 125 micrometers can be nitrided uniformly. By mixing AlN powder nitrided by the barrel method with the resin, the thermal conductivity of the resin can be improved.

**Speaker Country**:

Japan

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 100**

# Calibration of model for hardening gear wheels

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The paper focuses on the calibration of a model of induction hardening of gear wheels. This process requires high precision and cannot be realized without an application of a good mathematical model to adjust the input parameters of heating and subsequent cooling to achieve the desired results, mainly the prescribed distribution of hardness and microstructure in surface layers of the tooth. Calibration itself is an absolutely necessary step for subsequent optimization procedures or building a digital twin of the process as larger experiments in this domain are demanding and expensive.
From the mathematical viewpoint, induction hardening represents a 3D coupled task characterized by a strongly non-linear interaction of magnetic and temperature fields, which is accompanied by

metallurgical and chemical changes in the structure of the processed material. For practical computations, this full model has to be suitably simplified. Now a question arises as to how accurate and reliable the results thus obtained are. For this purpose,the simplified model has to be calibrated so that these results obtained are within the tolerance band with the experiment.
The simplified model that we use does not take into account the following items: the austenization temperature Ac3 is supposed not to be a function of the rate of heating and the continuous cooling transform (CCT) diagram does not depend on it either. The description of chemical changes in the material structure and production of levels like pearlite, ferrite, bainite, and martensite is only qualitative. The procedure of cooling of the heated teeth that is realized by spraying a suitable quenchant is described using a constant or linearly dependent coefficient of convection that has to correspond to the real time of cooling.
The calibration itself is performed automatically using suitable optimization techniques. The key parameters of the model are selected using the sensitivity analysis. We consider the material characteristics of the gear to be sufficiently known and accurate, so the focus is mainly on the convective coefficients in the course of heating and cooling. In more detail: we consider the convective coefficient given by a linear decreasing function, whose starting point and slope are optimized. As the dimensions of the inductor are known, the items to be optimized are the amplitude and frequency of the field current. But as the frequency of the converter can vary only in a rather narrow range, it is often sufficient to optimize its amplitude.

**Speaker Country**:

Poland, Czech Republic

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**SURFACE ENGINEERING / 101**

## Neural Metamodels for the Identification of Driving Parameters of an Induction Heating Process

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In the paper, authors explore the possibility of applying convolutional Neural Network (CNN) to the solution of coupled electromagnetic and thermal problem, i.e. the classical modeling of induction heating systems, traditionally solved by resorting to Finite Element Models. In fact, finite Element modeling is widely used for the design of induction heating systems also in industrial production, even if the solution of a coupled nonlinear problem, that usually arises for the design of induction heating devices, is still expensive in terms of computational time and hardware resources, notably in 3D analysis.
CNN is a learning model selected for its excellent ability of convergence, also when trained with a limited dataset. CNNs are able to treat images as input and they are here used as follows: given a temperature map, identify the corresponding vector of current, frequency and process heating time; this mapping is a model of the inverse induction heating problem. Specifically, we consider as an example a classical problem, i.e. the induction heating of a cylindrical steel billet, made of C45 steel, placed in a solenoidal inductor coil exhibiting the same axial length. The thermal process is usually applied before hot working of the billet, like in extrusion processes, but this methodology can be applied also in the design of induction hardening processes.
Two different neural networks, a CNN trained from scratch and GoogleNet, i.e. a Deep Convolutional Neural Network able to classify images, have been trained by means of a dataset of FE solutions of coupled Electromagnetic and Thermal problems. The training dataset has been built by solving a linearized weakly coupled model, namely a low fidelity modelling. When the training dataset contains a limited number of samples, only GoogleNet shows a good accuracy in predicting the

process parameters, while in the case of high number of samples in the training set, namely more than e.g. 1500, both CNNs show a good accuracy in the result.

**Speaker Country**:

Italy

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**SURFACE ENGINEERING / 102**

## Multi-physics finite element simulations for induction brazing

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Electrothermal technologies, in particular induction heating, can play an important role on improving performance and quality in brazing and soldering metal joints. Induction heating, in comparison to other industrial heat treatments for brazing processes that are traditionally based on open flames, allows to induce heat directly inside the workpiece, reducing process time and costs, with fully controllable and repeatable processes. The development and design of induction heating processes for brazing homogeneous or heterogeneous metal joints can be carried out by means of finite elements models and simulations. Numerical methods allow for an optimal design of the process in order to fulfil the technical requirements of brazing alloys by setting process recipes, inductor shapes and power requirements, taking into account all the constraints related to the integration of the induction heating system on production lines. In this paper, some applications of induction brazing technology, considering different joint geometries, base metals and brazing alloys, will be described with an in depth focus on inductor design and process fine tuning by means of multi-physics finite element modelling and simulations. The whole process of finite element simulation will be described, starting from geometry definition, models of relevant properties of joint materials and brazing alloys, by resorting to electromagnetic steady state sinusoidal solutions coupled with time dependant thermal model. Simulation results will be compared with experimental data obtained from field tests conducted on metal joints brazed using induction heating technologies and the same inductors and process recipes defined during the simulation stage.

**Speaker Country**:

Italia

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 103**

## Decarbonization plan for conventional heat-treatment facilities : CO2 contributors assessment, neutrality targets, levers and actions plan

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Keyword : decarbonization, Heat-treatment, CO2 calculation, CO2 reduction, energy saving

Forvia is the new entity gathering the French automotive supplier Faurecia and German Hella, involved in an ambitious plan to reach carbon neutrality : 2025 for internal operations and 2050 for all operations. Heat-treatment facilities are one major contributor to CO2 exhaustion in a classical plant, gathering all operation from raw material to final product, like cutting, welding, assembling… Actually, most process are based on the cracking of an alcohol, providing chemical reactions among molecules of CO, CO2, H2, O2 …. Resulting CO2 exhausting can be calculated from the chemical reactive equilibrium, details about calculation are given. Resulting CO2 footprint is given either for one furnace or one part, per kilogram.
Comparison with the last generation of low pressure heat-treatment is made on the same level of heat-treatment parameters. Beside process change, levers to reduce CO2 exhaustion is possible to a certain extent by modifying some technical points on the furnace. The balance between CO2 exhaustion resulting on one hand from the gas reaction supplying the furnace atmospher and the other hand from electricity consumed for the heating, is depending on the electricity production source. Each country can't act the same way. All over Europe, the situation is to be approached according to local situation.
As a conclusion, the different alternates to reduce CO2 can be correlated to the cost of energy on one side, and the forecasted cost of one ton of CO2, in the years coming. Scenarios may vary according to the weighting of both insights.

**Speaker Country**:

France

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**STEEL / 104**

## Effect of Zr, Ti and Al addition on dispersoid formation, microstructural and mechanical properties in Y2O3 added invar alloy followed by SPS + Annealing route

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In the present study mechanical properties and thermal stability was studied on three different composition Fe-42Ni-2Y2O3-2Zr, Fe-42Ni-2Y2O3-2Ti and Fe-42Ni-2Y2O3-2Ti-2Al respectively. All the three compositions were prepared using mechanical alloying via high energy ball mill and consolidated through spark plasma sintering at 1100 °C, with an applied load of 60 MPa. All the sintered sample were mirror polished using colloidal silica EBSD (Electron Backscatter Diffraction) scan was conducted to understand the microstructural features along with micro-strain using KAM (Karnel Average Misorientation) and texture formation. Microstructure features were correlated with mechanical properties using Vickers hardness. XRD was conducted to understand the phase formation. Diffusional annealing was conducted on sintered sample at a temperature of 1200 °C under argon atmosphere to understand the grain growth mechanism and thermal stability. Annealed sample were compared with sintered sample on the basis of mechanical properties and micrographic feature and phase formation. Orowan strengthening and Zenner pinning played vital role in high temperature thermal stability and grain refining.

**Speaker Country**:

India

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**Poster / 105**

## Formulae for Safe Design Against Fatigue Failures, Part-II

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Through this third paper of the three-paper series, two formulae, called Nori Fatigue Formulae, are presented for calculation of maximum allowable fatigue stress for components and structures with significant stress-raisers. Further, this paper provides formulae required for several other mechanical design applications. These formulae will eliminate the usage of code-sensitive safety factors along with other factored values from the entire mechanical design engineering work ranging from a safety-pin to spacecraft. The first formula gives the maximum allowable fatigue stress in tension, and the second formula gives the maximum allowable fatigue stress in shear. These formulae are developed through deployment of all the fundamental mechanical properties of steel like ultimate tensile strength (T), yield strength (Y), reduction of area (R) and elongation (E) that are commonly obtained from the engineering stress-strain curve resulting from the globally standardized tensile test. Thus, the vast amount of data, reduction of area and elongation, currently available with the world is put to effective use for calculation of maximum allowable fatigue stress of a given material in the given condition for the given application. As a result, application of Nori Fatigue Formulae does not call for generation of additional data that often calls for huge investment of time and money. Work in this direction, hitherto unavailable, is found essential since different international design codes, standards and handbooks have been adopting different design philosophies and different design factors that are different at different times for arriving at the maximum allowable fatigue stress.

**Speaker Country**:

India

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**HEAT TREATMENT / 106**

## Analysis of shots flight inside and outside of peening nozzle

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Introduction
Fine Particle Peening (FPP) is one of the cold working process to improve fatigue strength. FPP is used in a wide range of industries such as automobiles and aircraft. FPP is a process which shots collide with specimen. Work hardening increases the hardness of the specimen surface and improves the fatigue strength of the specimen. In FPP, the shots are released from the nozzle by the airflow. Outside of the nozzle, depending on the spread of the airflow, there is also a spread in shots flight. After shots bounce off the specimen, the bounced shots collide with flying shots. However, there are few studies that have described the spread and bounce of the shots.

Objectives
Herein, the purpose of this research is to optimize the conditions of FPP process by analyzing the series of shot flight by simulation. By simulating the spread of shots and the bounce of shots, we can optimize the FPP processing conditions, such as the processing speed.

Methodology
Moving Particle Simulation Method (MPS) was used to simulate the spread and bounce of the shots during processing. For the airflow, the velocity data obtained from the finite element simulation was transferred to the particle method software, and we analyze the flight of the shot under the airflow inside and outside the nozzle. The parameters used in the analysis were the nozzle outlet diameter, nozzle inlet pressure, and the distance between the nozzle outlet and the specimen.

Results
We investigated airflow velocity inside and outside the nozzle. As the inlet pressure of the nozzle increased and the nozzle outlet diameter decreased, the velocity of the airflow near the nozzle outlet increased, and the region of high velocity also increased. We also investigated the flight of shot in the airflow. As the diameter of the shot decreased, the velocity of the shot increased. In front of the specimen, the bounce of the airflow off the specimen decreased the velocity of the shot.

**Speaker Country**:

Japan

**Register for the Tom Bell Young Author Award (TBYAA)?**:

Yes

**Poster** / **107**

## Salt Bath Quenching after Nitriding in AISI H13 Tool

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AISI H13 tool steel presents a good combination of mechanical strength and toughness, with this, they are used, as examples, in the manufacture of aluminum extrusion dies, hot forging dies and injection molds of non-ferrous materials and polymers. These tools, in practice, are subjected to tensile and compression stresses during the heating and cooling process, which lead to thermal fatigue and also to wear. To extend the life span of these tools, new surface treatments are being researched. In the present work, the influence of quenching treatment on the surface properties of nitrided AISI H13 steel was studied. First, gas nitriding was carried out at a temperature of 540ºC with time durations of 84 hours. Then, nitrided steels were subjected to salt bath quenching at a temperature of 1030ºC with time durations of 50 minutes. The salt bath quenching treatment on the nitrided AISI H13 steel generated an increase in the depth of the nitrided layer of 57%, caused by the additional diffusion of nitrogen towards the core of the specimen, a reduction in the microhardness of approximately 30% in the region of the new nitrided layer and 9% to 20% increase in core microhardness.

In this new nitrided layer, formed after quenching, it was possible to identify, by X-ray diffraction, a reduction in the intensity of the peaks of the ε nitride phase, disappearance of the γ' phase, the appearance of new peaks, such as α' phase (martensite ), γ-phase (retained austenite), CrC carbides and V(C , N) carbonitrides.

**Speaker Country**:

BRASIL

**Register for the Tom Bell Young Author Award (TBYAA)?**:

No

**STEEL / 108**

## Insufficient heat treatment and retained austenite in tool steels and high-speed steels

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Heat treatment of tool steels and high-speed steels comprises of hardening and multiple tempering in order to adjust the required material properties. After hardening, the material contains martensite and a significant amount of retained austenite which is due to an incomplete transformation of austenite into martensite because of their high alloying contents. Beside the formation of secondary hardening carbides, multiple tempering should also lead to a complete transformation of retained austenite into martensite when tempering is applied at temperatures above the secondary hardening peak. This transformation can be supported by sub-zero treatments a various heat treatment steps. However, insufficient heat treatment can result in small amounts of retained austenite even after tempering above secondary hardening peak. Resulting effects are dimensional instabilities and internal stresses after the heat treatment leading to limited tool performance. In this paper different insufficient heat treatment scenarios are discussed based on dilatometer measurements and X-ray diffraction experiments. Furthermore, the stability of retained austenite at different heat treatment steps is addressed.

**Speaker Country**:

Österreich

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**SURFACE ENGINEERING / 109**

## Inductive heat treatment of high-speed steels

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In order to avoid distortion of long and thin tools made out of high-speed steels during heat treatment, a continuous inductive heat treatment can be applied. A classical inductive heat treatment device consists of several inductors, which are aligned, in a row with a certain distance to each

other. Due to this configuration, the material can undergo temperature variations during heat treatment resulting in undefined dwell times at the requested temperature. Consequently, the hardness varies over the cross section of the bar material. In this paper, a new configuration, which shows significant improvement, will be presented and discussed. The new configuration was developed based on Gleeble experiments and Finite Element simulations using DEFORM. The results of experiments and simulations were verified on a test device.

**Speaker Country**:

Österreich

**Register for the Tom Bell Young Author Award (TBYAA)?**:

**Poster** / **110**

## Prospects for the use of additive manufacturing technology for manufacturing metal matrix composite materials

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Selective laser melting technology (Powder Bed Fusion - " material melting in a pre-formed layer" according to ASTM classification) is one of the most promising additive manufacturing technologies because it has a number of fundamental advantages such as zero-waste, versatility, the ability to manufacture complex-shape parts with high accuracy that are not inferior to and sometimes exceeding in their physical and mechanical characteristics parts obtained by traditional shaping. Additive technologies allow the use of a wide range of powder materials, varying the composition of the applied material directly in the application process according to the functional purpose of the inner and outer parts of the model. The use of laser additive technologies should reduce the manufacturing time and cost of complex parts in single and small-scale production. Combining the idea of composite materials and high precision additive manufacturing technologies in the processes of three dimensional product shaping is an urgent scientific and technical task.

This work demonstrates the prospects for using selective laser melting technology for manufacturing specific parts from aluminum-based alloys. This area is especially in demand in the aerospace and automotive industries. The influence of the selective laser melting parameters on structure formation of aluminum-based alloys was studied using the methods of optical analysis, X-ray diffraction and X-ray spectroscopy analysis. According to the obtained results of mechanical tests of samples produced in different directions, differences in strength characteristics depending on the direction were revealed. The results of the performed experiments demonstrate the rational regimes of selective laser melting technology for aluminum-based alloys, depending on the produced direction. In this work recommendations are provided on the technological process of selective laser melting for manufacturing aluminum alloy products with a high complex of physical and mechanical properties.

**Speaker Country**:

**Register for the Tom Bell Young Author Award (TBYAA)?**: