VTZ 2018

Vakuové tepelné zpracování
a tepelné zpracování nástrojů

VACUUM HEAT TREATMENT AND HEAT TREATMENT OF TOOLS

Proceedings of Abstracts

20 – 21 November 2018
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První písemná zmínka o městě Púchov je z roku 1243, kdy v darovací listině uvádí král Béla IV. muže jménem Puch, vlastníka stejnojmenné osady. Městská práva byla udělena v roce 1471. V 16. století se zde usadili novokřtěnci z Moravy a po bitvě na Bílé hoře zase mnoho moravských bratří, kteří se zde živili často jako tkalci. V roce 1650 zde pobýval i Jan Amos Komenský. V 2. polovině 19. století byl Púchov spojen železnicí s Bratislavou a Žilinou, v roce 1937 pak přes Lyský průsmyk s Horní Lidčí, Vsetínem a Hranicemi na Moravě. V období Rakousko-Uherska patřilo město do Trenčínské župy, později bylo jako okresní město v Žilinském kraji. Od roku 1960 byl púchovský okres zrušen a přičleněn k okresu Považská Bystrica. Od roku 1996 je Púchov znovu okresním městem.

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The first written reference dates back to 1243, when Béla IV., King of Hungary, signed his gift certificate to Vychlap Bechend. In this reference are also mentioned Leustrak`s son and Puch from his immediate vicinities. The word „puch" is of Indo-European origin and it can be translated as „puffed up", „haughty" and „ov" is a possessive suffix, therefore this name can be translated as a former „land of Puch". In 1471, Matthias Corvinus, the King of Hungary granted urban righs to Puchov. In the 16th century, the Baptists of Moravia settled there, and after the Battle on Bílá hora (1620), also many Moravian brethren, who often lived here like weavers. In 1650 a signifiant personality of european life was lived here – Ján Amos Komenský. In the 2nd half of the 19th century Puchov had been connected with Bratislava and Žilina by railway. Afterwards, in 1937, the connection was built up also with the Czech country and Moravia. From the beginning of 20th century, many factories were built here, for example Syderolit and Syenit for producing facing, Matador for producing tires, or Rolný- the first production of clothes in Slovakia. Today its name is Makyta. The city of Púchov with approx. 19 000 inhabitants is a very economically and culturally developed town and it is still continuing to improve itself. Since 1996, Púchov has been a district town in the Zilina region.

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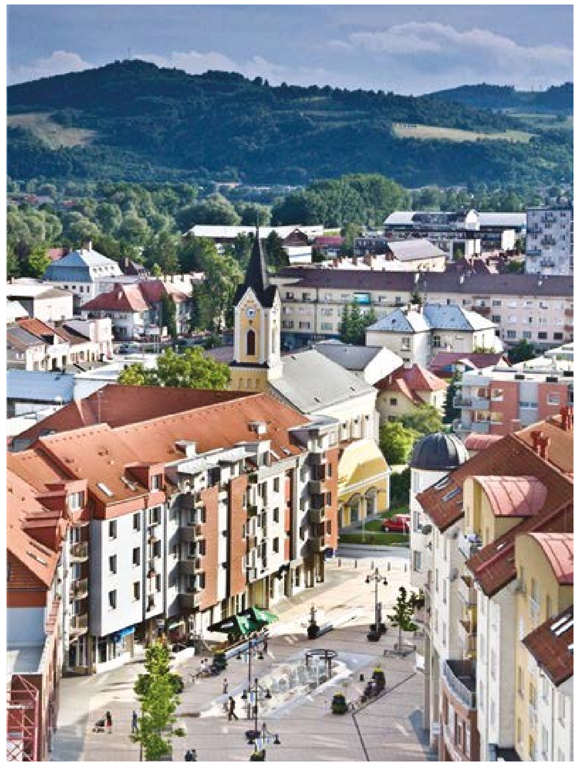

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01 Vakuum v procesech a zařízeních tepelného zpracování

Vacuum in heat treatment processes and equipment

Pavel Stolař
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Vakuum nebo nízký tlak jsou široce užívány při tepelném zpracování kovů, aby se zamezilo nežádoucím povrchovým reakcím jako jsou oxidace nebo oduhličení případně aby se podpořily požadované reakce např. při nízkotlaké cementaci nebo nitridaci.
Referát uvádí přehled typických aplikací vakua či podtlaku v technologiích tepelného zpracování, prezentuje jejich stav techniky a očekávaný vývoj procesů a zařízení

Vacuum or low pressure is widely used in the heat treatment of metals to avoid unwanted surface reactions such as oxidation and decarburization of machine parts or to support required chemical reactions such as carburising by low pressure carburising or nitriding.
The paper presents typical applications of vacuum or low pressure heat treatment technologies, state of the art and the expected development of processes and equipment.

02 Lomová houževnatost a odolnost proti opotřebení u nástrojových ocelí pro práci za tepla ve vztahu k podmínkám tepelného zpracování

Fracture toughness and wear resistance of hot work tool steel related to heat treatment conditions

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It will be about the procedure we are using to measure fracture toughness, effect of composition and heat treatment parameters on fracture toughness and other mechanical properties, possibilities to model response of hot work tool steels on different heat treatment parameters depending on the composition, effect of processing routes – ESR, conventional etc. and different inclusions/defects on properties and finally about heat treatment parameters and incorporation of deep cryogenic treatment on wear resistance of hot work tool steels and how abrasive wear resistance depends on fracture toughness and hardness.

03 Metalurgické pochopení vlivu kryogenního zpracování nástrojových ocelí

Metallurgical understanding of the effect of cryogenic treatment of tool steel

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In the ´40ies of the last century, Cohen c.s. in the USA and Gulyaev c.s. in the USSR, independently conceived the idea to improve hardenable steel's properties by subjecting it to a cryogenic treatment. Their activities departed from two observations reported as early as 1925 by Mathews:

- retained austenite is always present in medium- and high-carbon steels after hardening to room temperature;
- immersion of steel in cryogenic liquids reduces the fraction of retained austenite and increases hardness.

In the late ´70ies, R.F. Barron c.s. gave the proof that in particular their wear resistance, can be improved importantly by cryogenic treatment. They investigated the effect of various treatment parameters on wear resistance, among which, the cooling rate to cryogenic temperature, the lowest temperature reached during the treatment, the holding time at cryogenic temperatures, and showed that the holding time plays an important role on the effect of the treatment. They suggested that the (partial) transformation of retained austenite during treatment and the formation of fine carbides on subsequent tempering enabled by an unknown mechanism that takes place at cryogenic temperature are the mechanisms responsible for the improved wear resistance.

The debate on the mechanisms happening in steel at cryogenic temperatures and on how these influence the response to wear have continued for half century. Nevertheless, the metallurgical understanding of the microstructural changes involved in cryogenic treatment of steel is still premature.

The effect of cryogenic treatment on the properties of D2 and D3 tool steel well characterizes the debate. Among the steel investigated by Barron, D2 showed the most positive response to cryogenic treatment. In the early ´90ies, Collins and Dormer systematically investigated the effect of various treatment parameters on hardness and concluded that two mechanisms occur at cryogenic temperatures:

- athermal, i.e. independent of time, transformation of austenite into martensite;
- low temperature "conditioning of martensite", an unidentified time-dependent mechanism that would be rate controlled by the diffusion of carbon and thereby promotes fine precipitation of carbides during reheating to, or above, room temperature.

About 25 years later, the latter mechanism was supported by Das c.s., who added quantitative information on the effect of the holding time at 77 K on the carbide population and on the resistance to wear. In the late ´90ies Mohan Lal c.s. considered D3 steel. The material was austenitized to minimize the fraction of austenite retained after cooling to room temperature and it was then cryogenically treated at 77 K for various holding times. The work showed that cryogenic treatment can improve the wear performance and that the holding time is of fundamental importance. They concluded that the, presumed athermal, martensite formation during cryogenic treatment cannot be the reason for improved wear resistance. During the last decade, the opposite conclusion was arrived at by Gavriljuk c.s. D2 steel was austenitized at particularly high temperature, significantly higher than specifications from the supplier, and time-dependent formation of martensite at cryogenic temperature was demonstrated. Moreover, it was revealed that the isothermal martensite formation at cryogenic temperature leads to the development of carbon clusters and modifies the crystallography of the

carbides that precipitate on tempering. It was concluded that the time-dependent formation of martensite is the key factor to understand the effect of cryogenic treatment on tool steels.

The activity in our department aimed at clarifying the fragmentary and controversial picture that emerges from the literature.

Firstly, our activities focused on 100Cr6. Synchrotron XRD in combination with magnetometry showed that martensite forms during cryogenic treatment on cooling, on isothermal holding and on re-heating, and that the fraction transformed is maximal when cryogenic treatment is performed directly after quenching. It was also revealed that martensite formation evokes compressive stresses in austenite at temperatures higher than 135 K, whereas no compression builds up in austenite when martensite forms at $T < 135$ K. The compression on austenite was interpreted as a consequence of the elasto-plastic mechanical interaction between the austenite and martensite phases during transformation at temperatures above 135 K. Additionally, it was observed that cryogenic treatment facilitates the thermal decomposition of retained austenite, which starts at a temperature approx. 20 K lower in cryogenically treated specimens as compared to conventionally treated ones.

In the last 10 years, time-dependent martensite formation was investigated in numerous ferrous alloys. These included stainless steels, Fe-C and Fe-N. The investigation showed that time-dependent martensite formation in Fe alloys is the rule rather than the exception and certainly not an anomaly. In systems forming martensite with lath morphology, the formation of martensite is purely time dependent and can be suppressed on fast cooling to the boiling point of nitrogen, i.e. 77 K, followed by fast reheating to room temperature. In systems forming plate martensite, the twinned martensite cannot be suppressed but the dislocated martensite can be suppressed and is time dependent. Although time-dependent martensite formation is sluggish at 77 K, it is pronounced in the temperature range 100 - 230 K, which implies that cooling and heating rates to and from cryogenic temperature are important. The investigations also showed that isothermal holding at cryogenic temperature is effective to minimize the content of retained austenite in steel, provided that the treatment is extended for several, say dozens, of hours.

Investigation of D2 steel is our most recent activity. Treatment included various austenitization and tempering temperatures, to cover a broad spectrum of material´s conditions. Retained austenite was present in all samples after quenching to room temperature. It is shown that cryogenic treatment reduces the fraction of retained austenite, but does not eliminate it. Isothermal martensite formation takes place in the temperature range 100K – 220 K and is fastest at approx. 150 K, consistent with literature data from Gavriljuk et al. A cryogenic cycle including prolonged storage at boiling nitrogen temperature minimizes the fraction of retained austenite in the material, even though isothermal transformation at 77 K proceeds negligibly slowly. The isothermal formation of martensite is associated with magnetic softening, which can be interpreted in terms of rejection of carbon from solid solution in martensite, which supports Gavriljuk et al.´s work. Additionally, in situ investigation of tempering reaction shows that, prior to decomposition, which occurs beyond 770 K, retained austenite is enriched in carbon from martensite and further stabilized. This phenomenon happens in the temperature interval 475-625 K, which is the most applied range for tempering of D2 grade. These observations suggest that the volume fraction of retained austenite in the material has an influence on the volume fraction of carbides that precipitates in martensite. Prolonged isothermal holding at 77 K minimizes the fraction of retained austenite (carbon sinks), and thus maximizes the amount of carbon dissolved in martensite. This promotes the driving force for carbide precipitation in martensite during tempering (prior to austenite decomposition). Consequently, a larger volume fraction of carbides has to precipitate, a higher nucleation rate is achieved, i.e. finer carbides develop and carbide precipitation can occur at a lower temperature than in conventionally hardened steel.

04 Vliv kryogenního zpracování na vlastnosti nástrojových ocelí

Effect of sub-zero treatment on properties of tool steels

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It is widely accepted in professional community that any improvement of service life of tools reduces the tooling costs, and assists to increase the labour productivity by decreasing the needs for either the re-grinding of tools or their replacement. This requires, among others, extraction of the main mechanical properties of tool materials, by development of newer treatment routes. The current paper describes the impact of different heat treatment routes (austenitizing, sub-zero treatments, and tempering) on the main mechanical properties (hardness, flexural strength, toughness) of tool steels, which is demonstrated upon an example of Vanadis 6 steel. It is reported on improvement of hardness due to the sub-zero treatment but also on the fact that the toughness of the material cannot be inevitably deteriorated by the application of this kind of processing. Finally it is demonstrated that both these properties, despite their conflicting relationship in most cases, can be improved simultaneously when the material is treated in proper way.

05 Odolnost proti opotřebení nástrojové oceli D2 pro práci za studena po plynové nitridaci kombinované s kryogenním zpracováním

Wear resistance of D2 cold work tool steel after gas nitriding combined with deep cryogenic treatment

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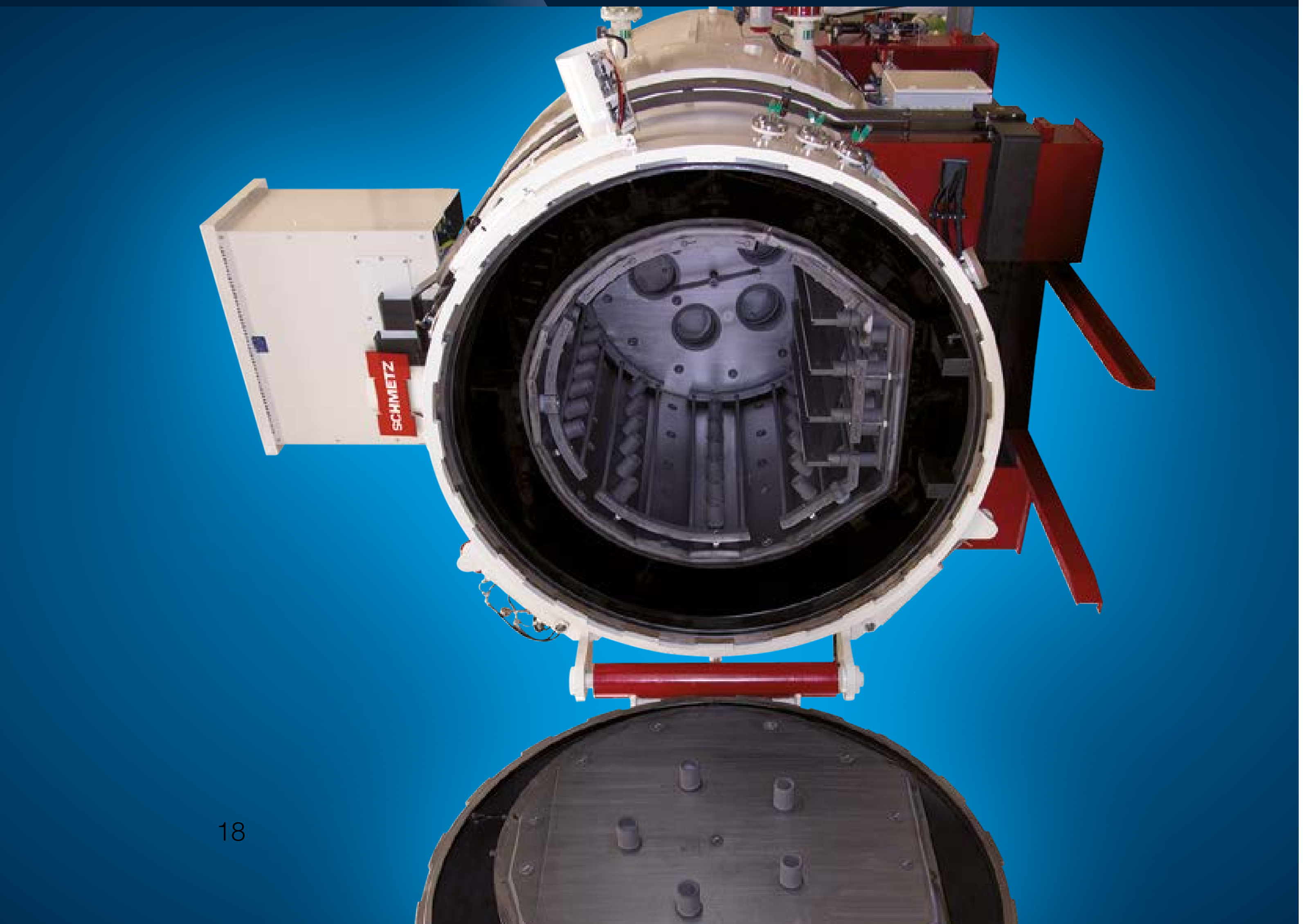
Plynová nitridace s následným tepelným zpracováním v kombinaci s kryogenním zpracováním (DCT) vytváří nitridované vrstvy specifických vlastností. Vrstvy s unikátními vlastnostmi jsou výsledkem rozpouštění podpovrchových vrstev nitridů železa a následné difuze dusíku během austenitizace. Proces kryogenního zpracování zaujímá v procesním cyklu místo mezi kalením a popouštěním. Jemné precipitáty karbonitridů se tvoří během procesu DCT a popuštění. Tento výzkum je založen na porovnání nových nitridovaných vrstev s vrstvami po konvenční nitridaci. Experimentální ocelí byla nástrojová ocel pro práci za studena AISI D2 s ekvivalenty DIN 1.2379 / X153CrMoV12. Chemicko-tepelné zpracování bylo vyhodnoceno a porovnáno na základě měření tvrdosti a rozsáhlým testováním odolnosti metodou pin-on-disc v rozdílných podmínkách zkoušení.



Gas nitriding with subsequent heat treatment in combination with deep cryogenic treatment (DCT) produces nitrided layers with specific properties. Layers with unique properties result from the dissolution of subsurface layers of iron nitrides and subsequent nitrogen diffusion into the substrate during austenitization. Process of deep cryogenic treatment takes place between the quenching and tempering steps. Fine precipitates of carbonitrides eventually form during DCT and the tempering process. This research is based on comparison of novel nitrided layers with conventionally nitrided layers. The experimental steel was AISI D2 cold work tool steel with equivalents DIN 1.2379 / X153CrMoV12. The thermochemical treatment methods were evaluated and compared based on hardness measurement and the extensive wear testing by the pin-on-disc method in different conditions of testing.

06 Tepelné zpracování vícenásobně reverzně kovaného nástroje

Heat treatment of tool forged by repeated alternate upsetting and drawing out

Antonín Kříž, Vojtěch Průcha, Soňa Benešová
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Mnoho odborných textů se věnuje procesu tepelného zpracování rychlořezných ocelí, přičemž výchozí struktuře polotovarů není věnována odpovídající pozornost. Proto se tento článek věnuje nejen vlivu výchozí struktury na výsledné vlastnosti tepelně zušlechtěné oceli k výrobě nejen řezných nástrojů, ale také sonotrod (speciální nástroj pro ultrazvukové svařování). Jak experimenty prokázaly, jemnost rozbitých primárních karbidů ovlivňuje vlastnosti následné zušlechtěné matrice a vznik sekundárních karbidů. Jak vyplývá z dosažených výsledků, rozhodující vliv tak má způsob protváření výchozího polotovaru, čímž se zvýší homogenita rozmístění i velikost primárních karbidů. Do protikladu jsou uvedeny případy, kdy soustředění karbidů mělo za následek vznik trhlin po tepelném zušlechtění. Článek zahrnuje také proces všestranného kování, kterým je zajištěno dosažení požadované výchozí struktury.

Klíčová slova:
protváření nástrojové oceli, primární a sekundární karbidy, tepelné zušlechtění rychlořezných ocelí

Although heat treatment of high-speed steels has been covered in numerous treatises, their microstructure before treatment still receives insufficient attention. This article therefore explores the relationship between the initial microstructure and resultant properties in heat treated steels for cutting tools and sonotrodes (special tools for ultrasonic welding). As shown in experiments, the size of fragments of primary carbides affects the properties of the matrix after heat treatment and the precipitation of secondary carbides. Hence, the decisive factor is the method by which the initial stock is mechanically worked, as it may produce primary carbides with more uniform distribution and size. In contrast, the article lists some cases where clusters of carbides caused cracking after heat treatment. The article also covers multidirectional forging by which the desired initial microstructure is obtained.

Keywords:
amount of working in tool steels, primary and secondary carbides, heat treatment of high-speed steels

07 Nízkotlaká cementace a žíhání v leteckém průmyslu

Low pressure carburizing and annealing in aircraft industry

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Due to its far-reaching responsibility, the aircraft industry forms one of the most demanding sectors for any supplier in terms of quality of the equipment, the process and eventually the end-product.
Heat treatment technology is no exception thereto; on the contrary, standards as the AMS2750 have been established and are constantly updated to categorize heat treatment equipment with regard to pyrometry. NadCap takes it further with restrictions for continuously calibrated measuring chains for all process relevant instrumentation.
Special materials call for special processes, neutral or thermo-chemical vacuum heat treatment, and recently particularly low pressure carburizing, has proven to be the preferred choice of manufacturers of aircraft gear box components. The rather small lot sizes involve small surfaces to be carburized. Whilst usually the challenge is the upper limitation as to the total surface to be carburized in one batch, the task here is to meet case depth requirements with low tolerances and realize utmost homogenous carburization in the small loads finding just the right balance between insufficient and exceeding carbon exposure.
New, complex parts entail various case depths on the same part, which makes it indispensable to get carbide formation and further distortion under control.
The furnace suppliers must go beyond providing their usual equipment and master different challenges in developing new features and processes, even furnace concepts, to enable the end-user to manufacture high quality products in accordance with its industry's high standards.

08 Procesní média ve vakuovém tepelném zpracování. Kapalné kalicí prostředky a ochranné nátěry - vlastnosti a aplikace

Process media in Vacuum Heat Treatment.
Liquid Quenchants and stop-off paints - Properties and Application

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Quenching is a very important part of the heat treatment process and its success. The heat transfer characteristics of the quenchant strongly influence the parts' microstructure after heat treatment, the resulting mechanical properties of the quenched component but also the amount of internal stresses and distortion.
According to DIN EN 10052 quenching is defined as „Cooling a part faster than with still air". The quenching media commonly used for heat treatment of steel and aluminium parts are water, brine, aqueous polymer

solutions, quenching oils, molten salts and pressurized gases such as air, nitrogen, hydrogen and helium.
In regards to vacuum heat treatment processes the choice of the quenchant and also the choice of stop-off paint, its proper use and adaptation to the process is mandatory to make sure that the heat treated part meets the well defined requirements for safe, consistent and longtime functioning.
In this paper the main liquid quenching media and stop-off paints for vacuum heat treatment processes are presented with their physical and chemical properties and furhermore their typical applications in the car manufacturing industries.
Finally an outlook on the future development of liquid quenchants and quenching technologies is given.

09 NADCA 207-2016 jako návod pro systém řízení jakosti tepelného zpracování ocelí pro práci za tepla

NADCA 207-2016 AS quality manual for heat treatment of hot works steels

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Nadca 207-2016 je dokument vypracovaný severoamerickou asociací pro tlakové lití a stanovuje akceptační kritéria pro nákup oceli, pro tepelné zpracování a pro navařování. Samotný dokument velmi detailně popisuje postupy pro výše uvedené oblasti, nicméně pro to, aby tento dokument byl prakticky využitelný je nutno uvést do praxe systém řízení výroby forem pro tlakové lití, který tyto postupy uvede do praktického života. A to jak pro dodavatele oceli, pro provozy tepelného zpracování, tak i pro nástrojárny a uživatele forem. V přednášce jsou uvedeny některé principy, které je nutno aplikovat tak, aby výsledek celého procesu byly nsátroje s očekávanou životností.

Nadca 207-2016 is a document developed by the North American Die Casting Association and sets acceptance criteria for steel purchase, heat treatment and welding. The document itself describes in detail the procedures for the above-mentioned areas, however, in order for this document to be practically usable, it is necessary to put into practice a system for quality management of die casting tools, which will bring these processes into practical life. For steel suppliers, for heat treatment plants, for tool shops and for tools users as well. The lectures give some principles that need to be applied so that the outcome of the whole process is a tool with an expected life.

10 Zkušenosti s uplatněním normy NADCA v zakázkové kalírně

Experiences with the application of the NADCA standard in the hardening shop

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Životnost forem pro tlakové lití je významně ovlivněna aplikací optimálních materiálů, správně provedeného tepelného zpracování a kontrolních mechanismů. Volba materiálu, požadavky na tepelné zpracování a jeho kontrola je nastíněna v normě NADCA, poslední revize z roku 2016. Kontrolní mechanismy však nejsou výrobci vložek příliš využívány a tím zůstává i velmi často utajena kvalita či nekvalita materiálu vstupujícího do procesu. Otázka jakosti materiálu a provedeného tepelného zpracování je mnohdy položena až v okamžiku objevení problému např. v podobě vad na povrchu vložky nebo nedostatečné životnosti. Příspěvek představuje dlouholeté zkušenosti kalírny s testováním materiálů pro tlakové lití a výsledky těchto kontrolních procesů pro nejčastěji používané oceli.

The lifetime increasing of dies for die casting is significantly affected by the appropriate choice of material, the correct heat treatment and applied control mechanisms described by NADCA standard, the latest revision 2016. The die casting dies producers these control mechanisms very often neglect and so the initial condition and quality of the material is a secret. The questions about the quality of the material and heat treatment are placed when the problem is discovered, e.g. the surface failures on the dies or insufficient lifetime. The paper presents many years of experience with the testing of die casting materials and the results of these control processes for the most commonly used steels.

11 Plasmová nitridace a vliv materiálu

Plasma nitriding and influence of materials

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Prezentácia sa zameriava na samotný proces plazmovej nitridácie, vysvetlenie základných princípov procesu, voľbu materiálov vzhľadom na dosahované výsledky a porovnanie výsledkov z inými procesmi nitridácie.

Presentation is focused to process of plasma nitriding, clarification of base principles of proces, influence of used material to results after nitriding and difference between others process of nitriding.

Sx100
Dělení Materiálů

PX400/PX500
Broušení/Leštění

AMH55
Měření Tvrdosti

GDS900
GDS - Emisní Atomový Spektrometr

12 Návrh plazmové nitridace nástrojových ocelí pro optimální nosnost a přilnavost tvrdých povlaků

Plasma nitride layer design of tool steels for optimized load-bearing capacity and adherence of hard coatings

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Duplex surface layers produced by means of a suitable combination of plasma nitriding/nitrocarburizing and hard coating are characterized by a high resistance against complex tribological and/or corrosive stresses enhancing the strength and lifetime of tool steels. A central challenge of this kind of duplex treatment is the design of nitride layers to meet load-specific as well as coating-specific requirements.
The current study focuses on the influence of plasma nitriding parameters, e.g. treatment duration and gas composition of the N2-H2 plasma, and initial surface condition on the resulting nitride layer structure and properties of tool steels (AISI D2, AISI M2).
The characterization of nitride layers was performed by means of cross sectional thickness measurement determining the compound layer thickness (CLT), Vickers hardness measurement, glow discharge optical emission spectroscopy (GDOES), and X-ray diffraction (XRD). Surface roughness was evaluated using optical profilometry and scanning electron microscopy (SEM). The difference in tribological performance was verified by means of unlubricated linear-reciprocating sliding ball-on-flat tests against tungsten carbide.
Plasma nitriding process parameters are correlated to resulting nitride layer characteristics in order to provide a basic knowledge for the subsequent generation of a hard coating considering further surface conditioning steps.

13 Zlepšení odolnosti proti opotřebení u austenitické oceli za použití kombinovaného zpracování elektronovým paprskem a následnou plasmovou karbonitridací

Improvement of wear resistance of austenitic steel by combined treatment using electron beam cladding and subsequent plasma nitrocarburizing

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The high passivation capacity of austenitic stainless steels leads to excellent corrosion resistance in a wide variety of corrosion media. However, the tribological properties of these steels prove unsatisfactory due to their low hardness and high tendency to adhesive wear. To improve the wear behaviour of austenitic steels

while maintaining corrosion resistance, thermochemical processes such as nitriding or nitrocarburizing in plasma can be used. These can be carried out as single process or in combination with coating processes, e.g. hard material coating. Furthermore, high-energy beam technology such as electron beam cladding can be used to generate wear resistant coatings of Fe- or Co-based alloys on austenitic steels.
The present paper presents the results of a new combination treatment consisting of electron beam cladding (EBC) of Co-based alloy (Stellite® 12) and a subsequent plasma nitrocarburizing (PNC). The influence of two different beam deflection techniques on the structure and phase formation of the wear protection layer, the resulting hardness, as well as the bonding of this layer to the base material and the dilution ratio are shown. The subsequent plasma nitrocaburization led to the formation of a 3-4 µm thick layer enriched with nitrogen and carbon.
The characterization of this modified layer was performed using high-resolution imaging techniques (SEM) as well as glow discharge optical emmision spectroscopy (GDOES), energy dispersive X-ray spectroscopy (EDX) and X-ray diffraction (XRD).
The significant improvement in wear resistance compared to the untreated base material was demonstrated by means of abrasive (scratch test) and adhesive-abrasive (pin-on-disc) wear tests. Corrosion resistance was investigated by recording current density potential curves and long-term investigations in corrosive media.

14 Ověření možnosti průniku dusíku do oceli pomocí N-kalení

Verification on Possibility of Nitrogen Infiltration into Steel by N-Quench

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N-Quench, which is a new surface heat treatment to infiltrate nitrogen into the steel parts in austenite phase and then they are quenched for hardening, is gathering attention today in the nitriding field in terms of low distortion while maintaining the higher effective case depth (ECD) than conventional nitriding. N-Quench is conducted mainly between 680 °C to 800 °C, where the two-phase region of ferrite and austenite exist, but there are a few research reports about nitrogen behavior on the higher temperature than 800 °C due to ammonia decomposition. From our research results, in general furnace such as resistance heating, no nitrogen infiltrated into the specimen at 930 °C. On the other hand, in our furnace with infrared heating, nitrogen infiltrated into the specimen at 930 °C successfully with less ammonia introduction than former furnace. Therefore, in this study, the limit of ammonia decomposition is assessed and possible solutions to expand N-Quench area, especially how to increase the case hardening depth, is examined.

Keywords:
surface heat treatment, nitrogen infiltration, quench, ammonia decomposition, nitriding

15 Přehled vakuových pecí pro procesy tepelného zpracování

Overview of vacuum furnaces for heat treatment processes

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Heat treatment processes of various components and loads have most different requirements regarding several domains. The basic single chamber vacuum furnace and its further special technology developments of the last decades are complying a wide range of demands.
Different pumping systems and possibilities of hot zone insulations allow the necessary vacuum level according to the different hardening, annealing or brazing applications. Hot zone insulations are graphite or molybdenum.
Hot zone in rectangular or circular design correspond to commandments of component and material to be treated. Choice of the different versions of quenching gas stream guidance realize optimal distortion results. For example the gas stream flow in vertical or horizontal direction in a straight line through some large flaps of the rectangular hot zone is recommendable for the most applications. Gas flow through nozzles of round hot zones have advantages for other applications like large size die casting moulds.
High gas pressure assisted by powerful engines, or the technology of the separate quenching area, can reach fast cooling speeds. This allows the hardenability of components with larger cross sections or hardenability of some middle alloyed steel qualities.
Integrated cryogenic systems realize fully automatic, uninterrupted processes with hardening, sub-zero treatment and several tempering. Process cycle is done in single chamber vacuum furnace with complete load-thermocouple-control and –documentation. Herewith the retained austenite content is reduced. Therefore time shifted size alteration of the hardened components is minimized.
Special achievements in furnace construction manage lower energy consumption and environmental benefits.

16 Údržba vakuových pecí a grafitových komor

Service of vacuum furnaces and graphite chambers

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V rámci příspěvku budou představeny grafitové materiály, vyskytující se ve vakuových pecích a popsány principy údržby zařízení pro vakuové tepelné zpracování.

The paper will present graphite materials used in vacuum furnaces. Principles of maintenance of the vacuum heat treatment equipment will be discussed.

17 Modernizace řízení starších vakuových pecí pomocí programu Control Web

Modernization of control system of old vacuum furnaces using PC and Control Web

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Článek popisuje technické a provozní zkušenosti s nahrazením původních řídících systémů šesti starších vakuových pecí Ipsen a Schmetz. Zabývá se výběrem řídícího programu, spoluprací mezi metalurgy, programátorem a pracovníky údržby při oživování pecí a také technickými aspekty této modernizace. Na závěr je popsáno sestavení databáze procesů s možností ukládání průběhu jednotlivých procesů.

The article describes the technical and operational experience of replacing the original control systems of six older vacuum furnaces Ipsen and Schmetz. It follows up the selection of the proper control program, the cooperation between metalurgist, programmer and maintenance staff in furnace revitalization as well as the technical aspects of this modernization. Finally, we describe how to build a process database with the ability to store the progress of each process.

Žáruvzdorné kovy v konstrukci pecí a strojírenství

Refractory metals in furnace construction and engineering

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Použití těžkých kovů (molybden, wolfram, tantal) jako komponentů pecí pro zařízení pro tepelné zpracování ve vysokých teplotách a ve vakuu. Tyto kovy mají vysokou teplotu tavení (2 500 – 3 500 °C), vysokou tepelnou vodivost a nízkou kontrakci, velkou hustotu. Tyto vlastnosti garantují dlouhou životnost v těchto extrémních podmínkách. Vyrábět z nich lze celé hot (pracovní) zóny pecí, příslušenství např. stojany, válečky, atd. Materiály jsou vyráběny výhradně práškovou metalurgií, což zajišťuje homogenní vlastnosti ve všech směrech.

It is going about the use of heavy metals (Molybdenium, Tungsten, Tanatalum) like components of furnaces in high temperatures and in vacuum. These metals have big melting point (2500 - 3500 °C), high thermal conductivity and low contraction and big density. It is warranty for long life time. From these metals and alloys is possible to produce the completely hot zones and accesoirs. The production is powder metallurgy, it is warranty for homogenius properties on all directions.

19 Vývoj technologie svařování pomocí elektronového paprsku pro výrobu aditiv AlSi10Mg

Development of an electron beam (EB) welding technique for additive manufactured (AM) AlSi10Mg

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In recent years, Additive manufacturing (AM) processes such as Electron Beam Additive Manufacturing (EBAM) and Selective Laser Melting (SLM) have become more widespread in the production of industrial components with excellent dimensional tolerances and good mechanical properties. Limitations on the size of such parts, however, mean that robust and reliable techniques are necessary for joining AM components with conventionally manufactured complementary parts. Therefore, this study examines an electron beam welding (EBW) process for AlSi10Mg and investigates the results.
It is known that aluminium alloys processed by SLM show a higher porosity and are sensitive to the formation or redistribution of pores during welding processes compared to conventionally produced material. Such findings were confirmed by the experiments, and investigations were carried out to reduce porosity in the welded zone. Blind welding seams were produced by EBW on specimens generated by SLM, continuous, sand and die casting. The resulting samples were characterized by metallographic investigation of cross sections, hardness measurements and ultrasonic testing of the joints.
It was found that rapid beam deflection methods such as multi-spot or multi-process techniques can be applied successfully to reduce the formation of pores in the welding process. The porosity in the welding zone of the AM material could be decreased to the level of the base material. Other approaches like the removing of the porous surface layer of the AM part or preheating before the welding process did not result in a higher welding quality. The results show that additive manufactured AlSi10Mg may be welded using EBW techniques with high joint quality.

20 Vliv morfologie grafitu na nitridaci a na opotřebení stabilní litiny ve srovnání s metastabilní zpevněnou povrchovou vrstvou z litiny

Influence of graphite morphology on the nitriding and wear behaviour of stable solidified cast iron compared to metastable solidified surface layer of cast iron

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Grey cast iron is a widely used material in industry due to its near-net-shape and cost-effective production. The mechanical properties of the matrix microstructure (ferritic/perlitic) can be significantly improved by volume heat treatment, e.g. quenching and tempering or ADI, but the soft graphite is retained. It is well known that the graphite morphology has a significant influence on the stress behaviour. For improving the tribological load behaviour thermal or thermochemical surface processes and their combinations are suitable.
The paper is focused on comparative investigations of the nitriding and wear behaviour of cast iron materials with perlitic matrix but different graphite morphologies (EN-GJL250: lamellar graphite; EN-GJS600: nodular graphite) and ledeburitic cast iron surfaces generated by electron beam remelting (EBR). For all variants, the gas nitriding (GN) was carried out at 540 °C/16h. The aim was to generate a detailed knowledge about both the depth-dependent layer structure after nitriding depending on the matrix microstructure and/or the graphite morphology and the resulting tribological behaviour. For this purpose, the surface layers were removed stepwise (approx. 3-5 μm) and then at each level examined using XRD, hardness measurements and wear testing.
The phase composition of the compound layer is only influenced from the matrix microstructure (perlite or ledeburite). The graphite morphology has a significant influence on the surface coverage with compound layer and thus on the wear behaviour. Despite large areas are not covered in the case of nodular graphite, they act as a lubricant and wear particle reservoir under moderate stresses. In the case of lamellar graphite, a crack network is formed and abrasive particles are produced subsequently, which resulting in a wear increasing effect. The EBR produces a graphite- free surface, which enables the formation of a closed compound layers (EBR+GN) and thus leads to a significant improvement in abrasive wear behaviour in the scratch test.

21 Porovnání laboratorních a provozních zkoušek odolnosti proti opotřebení pro vybrané nástrojové oceli pro práci za studena

Study of differences between results from laboratory tests and tests of real tools for selected cold work tool steels

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Stále rostoucí tlak na výkon a odolnost nástrojů zvyšuje požadavky na použité materiály a výběr optimálního tepelného zpracování. Byly porovnávány vlastnosti nástrojových ocelí vyrobených klasickou i práškovou metalurgií (1.2379, Vanadis 23) a to po různých režimech tepelného zpracování. Na několika sériích byla provedeno kryogenní zpracování při -90 °C nebo -196 °C vždy s výdrží 4 hodiny. Zmrazování bylo zařazeno mezi kalení a popouštění. Mechanické vlastnosti byly hodnoceny zkouškou tvrdosti, pevnosti v tříbodovém ohybovém a odolností proti opotřebení metodou Pin na disku. Bylo provedena metalografická analýza pomocí světelné a elektronové mikroskopie. Na základě dosažených výsledků bylo provedeno vybrané tepelné zpracování pro oba materiály a vyrobeny zkušební tvářecí nástroje, které byly použity v provozu. V průběhu jejich nasazení bylo hodnoceno opotřebení (změna tvaru a objemový úbytek). Následně byly porovnány výsledky laboratorní zkoušek se zkouškami v provozu.

The growing pressure on tool performance and durability increases demands on the materials used and on the choice of optimal heat treatment. The properties of tool steels produced by conventional and powder metallurgy (1.2379, Vanadis 23) were compared after different heat treatment modes. Cryogenic treatment was performed in several batches for 4 hours at -90°C or -196°C. Cryogenic treatment was inserted between quenching and tempering. Mechanical properties were evaluated by hardness tests and three-point bending strength and wear resistance by Pin-on-disk tests. Metallographic analysis was performed using light and electron microscopy. On the basis of the results obtained both materials were subject to selected heat treatment and experimental forming tools produced which were used in operation. During operation the wear of the tools (shape change and volume loss) was assessed. Results of the laboratory tests were then compared with operation tests.

22 Možnosti úplné automatizace přípravy metalografických vzorků a měření tvrdosti v provozech tepelného zpracování

Possibilities of complete automation in metallographic sample preparation and hardness testing in thermal processing Operations

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V současnosti se slovo „Produktivita“ skloňuje ve všech pádech více než kdy jindy. A platí to pochopitelně i pro pracoviště kontroly kvality, laboratoří metalografie a metrologie.
Kontrola kvality dílů po tepelném zpracování je stále důležitější pro zajištění jakosti výsledného produktu. Zvyšují se stále jak nároky na kvalitu výbrusů a přesnost měření, tak i požadavky na kvantitativní hodnocení. Typickým příkladem kontroly je vyhodnocování mikrostruktury po tepleném zušlechťování jako velikost zrna, vyhodnocení zbytkového austenitu, měření hloubky cementace, nitridace, měření obsahu uhlíku v oceli apod., protože všechny tyto hodnocené parametry výrazně ovlivňují kvalitu konečného produktu.
V naší přednášce se zaměříme na různé možnosti plné automatizace procesů kontroly kvality, které současné nejmodernější technologie umožňují. Některé technologie zmiňované v naší přednášce byli navrhovány individuálně a ve spolupráci s uživatelem právě pro provozy kontroly jakosti v tepelném zpracování. Cílem těchto speciálních a individuálních řešení pro plnou automatizaci je zaručit maximální produktivitu pracovišť metalografie a metrologie bez současného kompromisu k přesnosti finálního výstupu měření.

At present, the word „Productivity“ is more than ever used in every fall. And, of course, this also applies to workplaces of quality control, metallography and metrology laboratories.
Quality control of parts after heat treatment is increasingly important for ensuring the quality of the final product. The demands on the quality of samples and measurement accuracy as well as the requirements for quantitative evaluation are still increasing. A typical example of control is the evaluation of the microstructure after heat refinement such as grain sizing, residual austenite evaluation, CHD measurement, nitriding, carbon content measurement in steel, etc., because all these parameters significantly influence the quality of the final product.
In our lecture we will focus on various possibilities of full automation of the quality control processes that current state-of-the-art technologies enable. Some of the technologies mentioned in our lecture were designed individually and in cooperation with the user for quality control operations in heat treatment. The aim of these special and individual solutions for full automation is to guarantee maximum productivity of the metallography and metrology workplaces without compromising the accuracy of the final measurement output.

23 Metalografická príprava vzoriek pred meraním tvrdosti

Metallographic samples preparation before hardness Testing

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- Zariadenia na prípravu vzoriek
- Metodika prípravy vzoriek pred meraním tvrdosti
- Chyby v príprave vzoriek ovplyvňujúce výsledky meraní

- *Samples preparation equipment*
- *Sample preparation methodology before hardness testing*
- *Failures in the sample preparation samples influencing the measurement results*

24 Kontrola tepelného zpracování pomocí měření tvrdosti.

Inspection heat treatment by hardness testing

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- Obecná teorie měření tvrdosti
- Způsoby měření tvrdosti po tepelném zpracování
- Možné chyby při měření
- Představení moderní technologie usnadňující měření tvrdosti.

- *General theory of hardness testing*
- *Hardness testing at heat treatment*
- *Possible mistakes at hardness testing*
- *Introducing advanced technology facilitate hardness testing.*

25 Automatický systém měření tvrdosti AMH55

Automatic hardness testing system AMH55

Jan Kuna
Leco Empowering Results, Czech Republic

- Automatický systém měření tvrdosti AMH55
- LECO přístroje pro přípravu metalografických vzorků

- *Automatic hardness testing system AMH55*
- *LECO instruments for sample preparation*

26 Měření hloubky tepelně zpracované vrstvy

Case depth measurement and analysis

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Hodnocení hloubky tepelně zpracované vrstvy je významná zkouška pro stanovení správného tepelného zpracování kovových dílů. Podle četnosti a důležitosti této zkoušky je možné zvolit některou z uvedených instrumentací pro její provádění. Jednoduché řešení pro zjišťování hloubky tepelně zpracované vrstvy představuje klasický tvrdoměr doplněný o kameru a programové vybavení, umožňující ruční měření průběhu tvrdosti. Dokonalé řešení pro měření tvrdosti představuje automatický měřicí systém, umožňující liniové, plošné a sériové měření zkoušených dílů. Je-li rozhodující rychlost měření hloubky tepelně zpracované vrstvy, je vhodné využít speciální tvrdoměr, který stanoví hloubku vrstvy z jediného vtisku.

Assessment of the case depth is a significant test for specification of the correct heat treatment of metal parts. Depending on frequency and importance of such test one of the below instrumentation can be chosen for its testing. Classic hardness meter equipped with a camera and software enabling manual measurement of the hardness course represents a simple procedure for measurement of the case depth. A perfect solution for hardness testing is automated testing system providing line, areal and serial measurement of tested parts. Should speed of the case depth testing be a decisive criterion a special hardness meter measuring depth of a layer from a single indentation is applied.

27 Vliv volby parametrů při indukčním kalení na deformaci a vlastnosti výrobků z nástrojových ocelí

Parameters which affect distortion and properties in induction heat treating process of tool steels

Jiří Hájek, David Rot, Jakub Jiřinec, Ondřej Chocholatý
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Článek se zabývá volbou proměnných při indukčním kalení jednoduchých strojních součástí z nástrojových a konstrukčních ocelí. Experimentální program byl zaměřen na měření deformací vzniklých během indukčního kalení nástrojových i konstrukčních ocelí. Sledována byla závislost deformace na procesních parametrech indukčního kalení. Samostatná kapitola se věnuje problematice vztahu volby kalícího média a deformace kalené součásti. Jako kalící médium byly zvoleny voda a roztoky polymerů. Během kalení bylo variováno jak s teplotou kalícího média tak rovněž z koncentrací roztoků polymerů. Vyhodnocována byla primárně tvrdost povrchu, metalografie kalených součástí a změny v geometrii součásti. V případě roztoků polymerů byla rovněž sledována korozní odolnost povrchu v závislosti na zvoleném roztoku polymerů. Výstupem experimentů je specifikace základních proměnných v procesu indukčního kalení jednoduchých strojních součástí.

The article deals with the most important variables in the induction hardening process of simple machine parts made from tool and structural steels. The experiment was focused on measuring the deformations arising during induction hardening. Heating, frequency, quenching media, coil design, etc. all have an influence on the distortion of machine parts. These factors were mostly monitored in the experiments. The longest section deals with the relationship between the quenching media and the deformation of the hardened part. Water and polymer quenchants were used. During quenching, the temperature of the quenching media and the concentration of polymer solution was varied. Parameters such as a hardness, metallography and geometry of the component were measured. For the polymer solutions, the corrosion resistance of the surface was also monitored. Corrosion resistance was observed in relation to the concentration of the polymer solution.

Čištění dílců před tepelným zpracováním ve vakuu

Cleaning of parts prior to heat treatment process in vacuum

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Nezbytnou součástí před každým tepelným zpracováním dílců je řada mycích a čistících kroků. Při tepelním zpracování ve vakuu je nezbytné dosáhnout co nejvyšší čistoty povrchu. Nedostatečně provedené čištění vede zpravidla k oxidaci povrchové vrstvy a nežádoucímu zbarvení povrchu, tedy k tomu, čemu má právě zabránit při tepelném zpracování vakuum.

Cleaning and degreasing steps are essential part prior to every heat treatment of parts. The proper carry-out of cleaning has utmost importance in vacuum heat treatment. Insufficient or improper cleaning may cause discoloration and oxidation of surface layer, which should be just avoided by vacuum treatment.

Poster session

01 Vliv provozní teploty na kulová ložiska

Influence of operating temperature on rolling bearings

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Rolling bearings are among the most widely widespread components in the engineering industry. A critical issue is damage to functional surfaces of rolling bearings, which has arisen during the operation. A neglected area is the monitoring of the production temperature and its impact on components. We undertook this study to damage of functional surfaces bearings. It was decided that the optimal procedure is comparing to three samples, each with another type of damage. We believe this solution will aid determine the cause of damaged bearings. This work has shown the adverse effect of residual austenite and residual stresses caused by the production process on the dimensional stability of the bearing components.

02 Mikromechanizmus lomu kryogénne spracovanej nástrojovej ocele Vanadis 6

Fracture micromechanism of cryogenically processed Vanadis 6 tool steel

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The main goal of the presentation is to analyze the effect of cryogenic processing and tempering on selected mechanical properties and fracture micromechanism of Vanadis 6 high alloy cold work tool steel. The samples were processed in cold nitrogen gas at -140 °C for 17 and 48 hours. Subsequently, the samples were twice tempered at temperatures of 170 – 600 °C, and a single specimen was not tempered. The hardness was measured by using a Zwick 3212 hardness tester, by a Vickers method. The hardness of sub-zero treated Vanadis 6 steel decreases with increasing tempering temperature. The highest hardness of the specimen 960 HV10 was achieved by tempering at 170 °C and the lowest hardness 790 HV10 resulted from tempering at the highest tempering temperature, i.e. 530 °C. However, the hardness of conventional heat treated samples was less than 800 HV10 in full range of tempering temperatures. The static three-point bend test was performed on 10 x 10 x 100 mm test specimens, and the fracture toughness was determined on specimens 10 x 10 x 55 mm with surface roughness of Ra = 0,1 µm. Fracture surface images were acquired by using scanning electron microscopy equipped with an EDS detector. The bending strength of sub-zero treated steel manifest relatively constant value depending on tempering temperature by taking into the standard deviation and maximum was achieves of 3549 ± 235 MPa at a high tempering specimen at 530 °C. The highest value for conventional heat treated samples was 2932 ± 129 MPa. The fracture toughness of sub-zero treated samples has an increasing character with increasing tempering temperature, with maximum 19.4 MPa.m1/2 at tempering temperature 330 °C. Compared to conventional heat treated samples, the values are not significantly different, whereas the maximum value was 19.6 MPa.m1/2 at the tempering temperature 170 °C. In the case of the high tempering temperature of 530 and 600 °C, the KIC value of sub-zero treated samples dropped to 17 MPa.m1/2 and then rise up to 17.52 MPa.m1/2. Also, KIC of conventional heat treated samples has decreasing character with increasing tempering temperature, with minimum 14.8 MPa.m1/2 at tempering temperature 530 °C. One of the result of the experiments is that, sub-zero treatment at temperature -140 °C for 17 and 48 h, has no significant impact to bending strength and fracture toughness. However, a slight improvement in high tempered samples, is obvious. But the hardness of sub-zero treated samples is significantly better, compare to conventional heat treated samples.

03 Vplyv zmrazovania a popúšťania na mikroštruktúru a lomovú húževnatosť ledeburitickej nástrojovej ocele

Influence of sub-zero treatment and tempering on the microstructure and fracture toughness of ledeburitic tool steel

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Influence of sub-zero treatment (SZT) and tempering on the microstructure and fracture toughness of Cr-V ledeburitic steel Vanadis 6 was examined. The samples were heat treated using following schedules: heating to the austenitizing temperature 1050 oC in a vacuum furnace, hold at the final temperature for 30 min. and nitrogen gas quenching (5 bar). In SZT, conventionally heat treated (CHT) specimens were cooled down immediately after quenching from the room temperature to the temperature of liquid helium (-269 °C), kept there for 17 h and then re-heated to the room temperature. Double tempering was performed at the temperatures from the range 170 – 530 °C, whereas each tempering cycle was realized with a hold of 2 h. The microstructure after SZT consists of matrix formed by martensite, small amount of retained austenite and carbides. The character of matrix microstructure changes with increasing the tempering temperature expectedly. The as-quenched hardness for conventionally heat treatment steel, which was no tempered was 838 ± 4 HV10. The hardness of the SZT steel soaked in liquid helium for 17 hours and no tempered was correspondingly higher, e.g. 904 ± 5 HV10. These results show that the as-quenched bulk hardness of the Vanadis 6 steel is improved due to the sub-zero treatment. The hardness of all the samples then decreases with increasing the tempering temperature. As a result the hardness of the specimens tempered in the range of temperatures commonly used for secondary hardening is lower for SZT steel than what is achieved after conventional quenching and tempering. In the case of CHT, the fracture toughness KIC of untempered material achieves average values of 16.4 MPa.m1/2 and, due to the tempering it firstly increases to 19.6 MPa.m1/2 with subsequent slight decrease at medium tempering temperature and rapid decrease when tempered at the temperature normally used for secondary hardening, respectively, to a value of 14.8 MPa.m1/2. For the material after application of SZT in liquid helium for 17 h, the fracture toughness before tempering was 14.3 MPa.m1/2 (i.e. lower than that for CHT steel). Then, the fracture toughness increases with tempering temperature to more than 18 MPa.m1/2 and rather slightly decreases at a tempering temperature of 450 °C. What is interesting the values of KIC are higher for SZT steel than those for CHT steel at the temperature of secondary hardening (530 °C).

Keywords: ledeburitic steel, sub-zero treatment, martensite, retained austenite, carbides

04 Vliv kryogenního zpracování na vlastnosti nitridační vrstvy

The effect of cryogenic treatment on the properties of the nitriding layer

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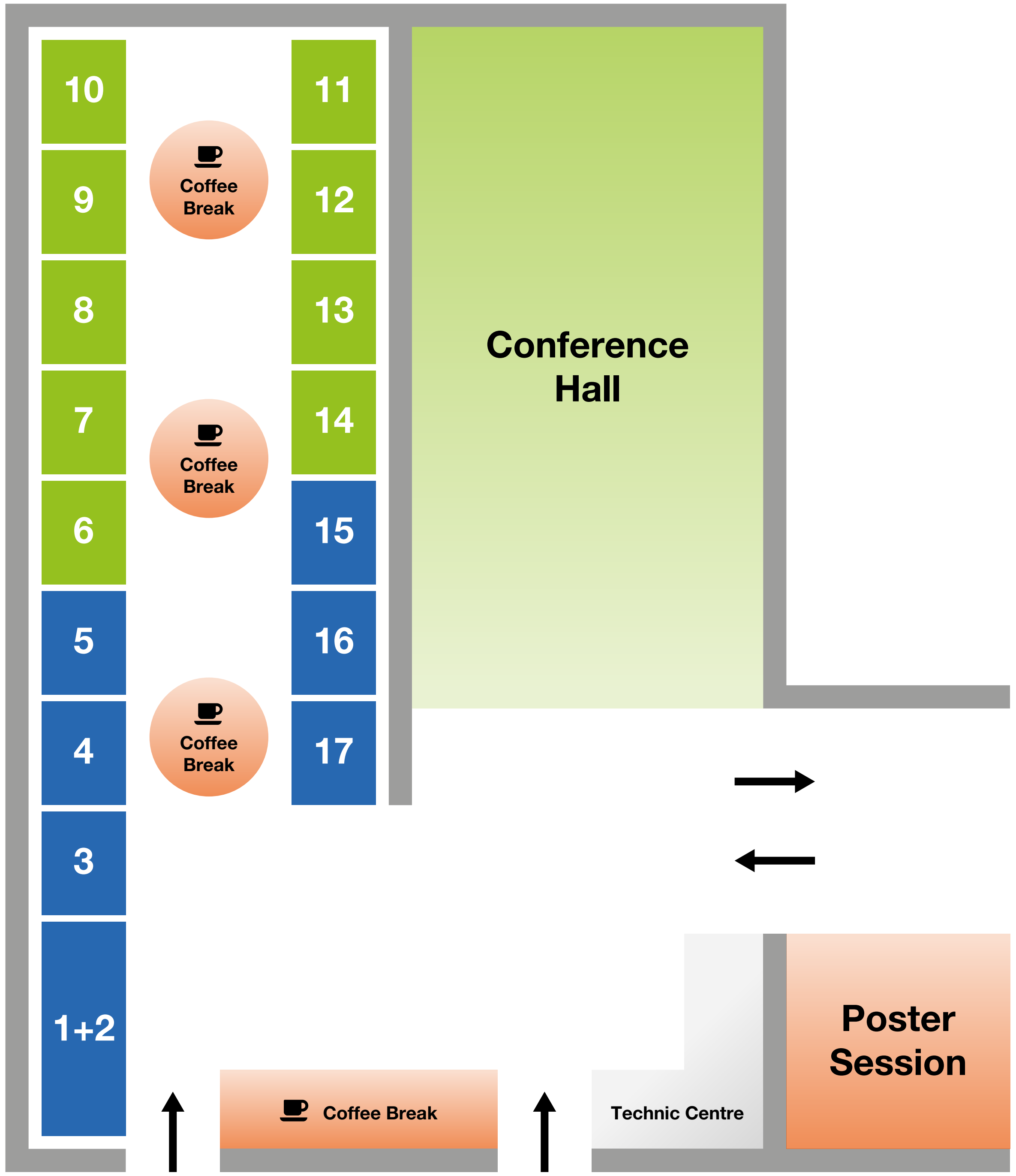
Aim of this experiment is to create higher dispersion of formed nitrides by use of cryogenic treatment in nitriding process. This should lead to better wear resistance, corrosion resistence, toughness and hardness of nitriding layer. Use of cryogenic treatment should lead to decrease amount of retained austenite, better dimensional stability and lower residual stress. This article describes influence of cryogenic treatment on individual steps of heat treatment and covers properties of nitriding layer.



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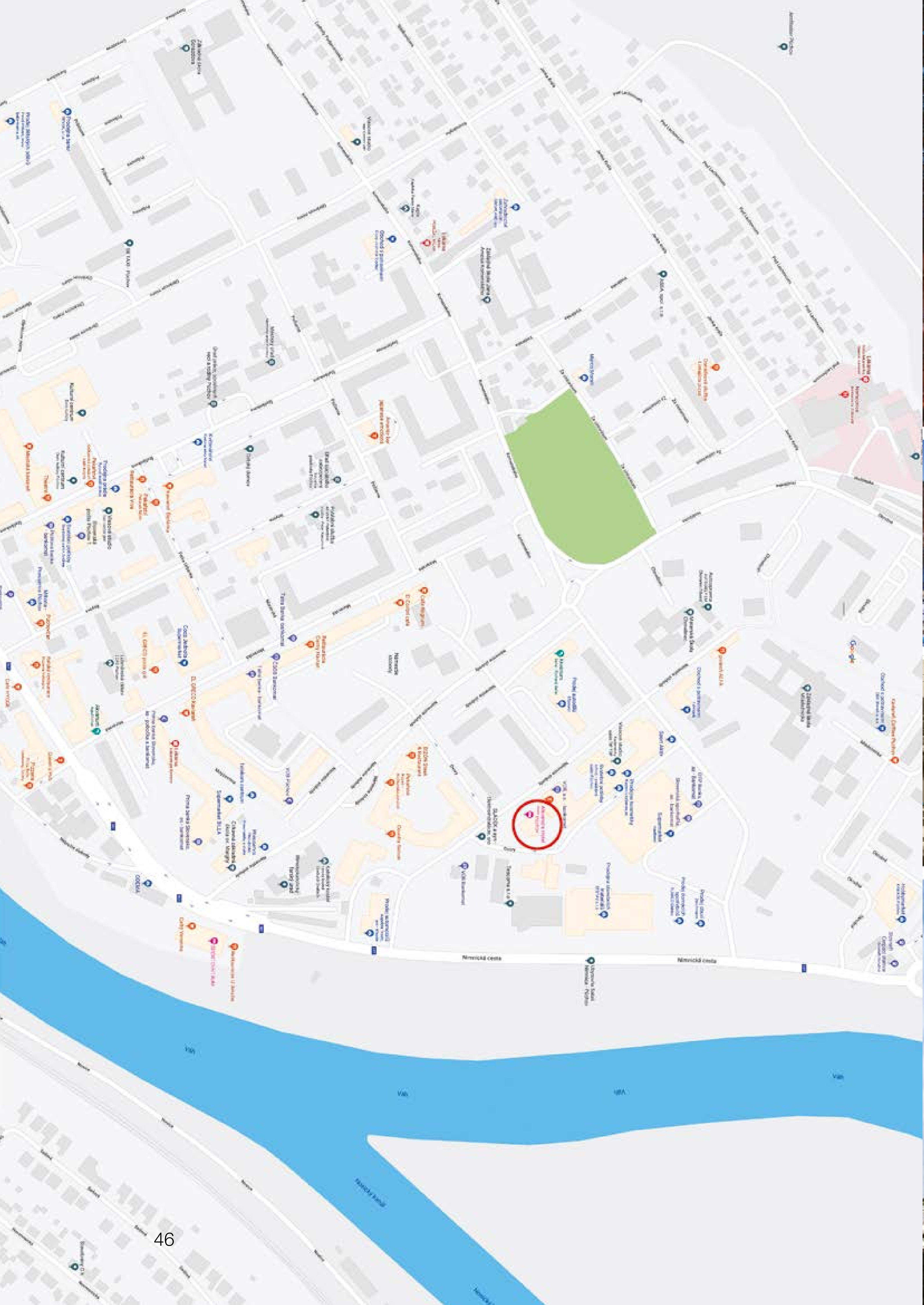
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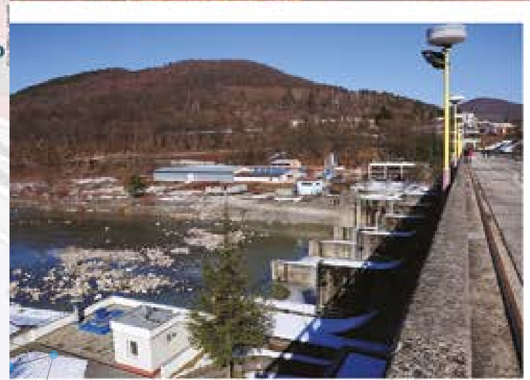

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