Molybdenum Symposium 2024 - Mo4Steel 2024

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Book of Abstracts

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SUSTAINABLE PERFORMANCE WITH MO ALLOYED STEELS / 2

The beneficial actions of Molybdenum to reduce friction and to save carbon allowances

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Diluted molybdenum presents two facets for friction reduction:
-as molybdenum compounds in oils and greases and
-as alloying element in tribo-materials.
Treat rates effective for friction reductions by alloying or blending molybdenum range for both cases between 0.3-0.6 wt.-% and reduce friction between 30% to 50% under the regime of mixed/boundary lubrication as well as illuminate an effective and economical action of molybdenum to reduce friction and thus CO2 in the use phase of machineries.

Speaker Country:

Germany

THE POWER OF MOLY / 3

The effect of Mo addition on hydrogen embrittlement in pipeline steels

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In recent years, hydrogen appears to be a promising alternative to fossil fuels, therefore evolvement of materials for hydrogen transportation and storage facilities is of immense importance. However, exposure of high-strength steels to hydrogen can have a detrimental influence on their performance due to elevated susceptibility to hydrogen embrittlement (HE). In previous studies, the effect of Mo content on the resistance of martensitic steels to sulfide stress cracking was reported. During the sulfide stress cracking, the formation of a sulfide layer on the material surface can affect hydrogen-induced crack propagation. In the case of sulfide-free conditions, there is limited knowledge about the role of Mo in commercially available martensitic steels and its effect on hydrogen embrittlement behaviour.
This study clarifies the role of Mo carbides in the hydrogen uptake of tempered martensitic steels with different chemical compositions and heat treatment. The trapping behaviour of steels and the effect of divergent Mo content on hydrogen diffusivity and HE has been studied utilizing an Electrochemical Permeation Test and Thermal Desorption Spectroscopy (TDS). Slow Strain Rate Tests (SSRT) of electrochemically charged steels were performed to elucidate mechanical performance. The carbide distribution and microstructure of tested steels were observed using high-resolution Scanning Electron Microscopy (SEM), Electron Backscatter Diffraction (EBSD) and X-ray diffraction

(XRD).
The results of electrochemical charging revealed higher uptake of hydrogen for the alloy with higher Mo content. TDS analysis indicated one peak below 300 °C in the case of both alloys. Mo carbides manifested the ability to trap hydrogen after long-term atmospheric exposure, hence showing characteristics of strong trapping sites. Change of the heat treatment resulted in the control of Mo carbides size and dispersion, as well as dislocation density. The results implied that the steel with higher Mo content, finer Mo2C carbides, and lower dislocation density exhibits superior resistance to HE.
Keywords: hydrogen embrittlement, Mo carbides, martensitic steels

Speaker Country:

Austria

THE POWER OF MOLY / 4

Interplay between alloying and tramp element effects on temper embrittlement in bcc iron: DFT and thermodynamic insights

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The details of the temper embrittlement mechanism in steels caused by impurities are unknown. Especially from an atomistic point of view, there are still open questions regarding their interactions with alloying elements such as Ni, Cr, and Mo. Therefore, we used density functional theory to investigate the segregation and co-segregation behavior and the resulting influence on the cohesion of three representative tilt grain boundaries in iron. The results are implemented in a multi-site and multi-component kinetic and thermodynamic model for grain boundary segregation, to gain insights into the temporal and final grain boundary coverage. Our results show that the segregation tendency of As, Sb, and Sn is stronger than that of the alloying elements and significantly mitigates the grain boundary cohesion. Depending on the GB type, interactions between Sb and Sn vary from negligible to strongly attractive, which increases the likelihood of co-segregation. The cohesion-weakening effect is further amplified when elements such as Sb, Sn, and As co-segregate, compared to their individual segregation. In contrast, the co-segregation of Ni and Cr does not significantly increase the enrichment of impurities at grain boundaries, and their impact on cohesion is found to be negligible. The ability of Mo to mitigate reversible temper embrittlement is primarily attributed to its cohesion-enhancing effect and its capability to repel tramp elements from GBs, rather than scavenging them within the bulk, as suggested by previous literature.

Speaker Country:

Austria

MOLYBDENUM BOOSTING PROCESS EFFICIENCY / 5

Benefits of Molybdenum to produce heavy steel plates via the direct quenching process

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For economic and environmental reasons, quenched as well as quenched and tempered steel plates are nowadays produced using direct quenching (DQ) if feasible, as one process step can be omitted compared to conventional quenching. However, the DQ process has significantly higher demands on process control. This requires precise matching of the alloy concept with the process parameters. Molybdenum is ideally suited to meet all the requirements of the DQ process. EBSD measurements show that molybdenum can delay recrystallization to such an extent that a pronounced pancaking of the austenite can be achieved during finishing rolling. At the same time, molybdenum shifts the ferrite nose in the CTT diagram to slower cooling rates. This delay of the phase transformation during quenching ensures a fully martensitic microstructure over the complete plate thickness. A precise understanding of the effects of molybdenum during the entire production process allows the microstructure to be adjusted in a targeted manner. With the knowledge of how the microstructure is related to the product properties, the alloy concept can be adapted precisely to customer requirements. This enables the production of ultra-high strength steel plates with excellent toughness properties for a wide range of plate thicknesses.

Speaker Country:

Germany

THE POWER OF MOLY / 6

Understanding of Molybdenum effects on the dynamic and static softening mechanisms in hot rolled low carbon steels: basic principles and processing implications

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Molybdenum is a well-known alloying element in steels, which in combination with other microalloying elements, is usually added to achieve high strength and high toughness property combinations. The effect of Mo retarding austenite recrystallization, both dynamically and statically, due to its strong solute drag effect, is the main mechanism acting during hot rolling. This contribution delves into the static and dynamic softening behavior of molybdenum-alloyed low carbon steels, aiming to elucidate its role during the different steps of the hot working process, from hot rolling down to phase transformation as well as the consequences in the final mechanical properties.
For that purpose, several low carbon steels with varying molybdenum contents were subjected to different thermomechanical processing conditions and the individual effects of composition and processing parameters were studied. Microstructural characterization employed advanced techniques like electron microscopy, EBSD and transmission electron microscopy to assess grain size, microstructural substructures and precipitate morphology.
Molybdenum addition was observed to pancake the austenite grain size during processing, leading to finer microstructures after transformation. The effect of Mo in the static and dynamic recrystallization kinetics was evaluated and its direct effect on critical processing temperatures, such as the non-recrystallization temperature, Tnr, was computed. The understanding of these base mechanisms helps designing appropriate rolling strategies. This way, and even under conditions of high finishing reduction sequences, molybdenum alloyed grades showed effective strain accumulation avoiding the onset of dynamic and/or static recrystallization. This reduced the possibility of finishing the rolling

sequence with a mixed-grain structure, improving final microstructural homogeneities as well as improving toughness properties.
The findings provide valuable insights into the interplay between molybdenum, other alloying elements, microstructure, and softening mechanisms in low carbon steels. Tailoring molybdenum content and processing parameters can enable the design of microstructures with enhanced strength, toughness, and formability, catering to specific engineering applications.

Speaker Country:

Spain

MOLYBDENUM BOOSTING PROCESS EFFICIENCY / 7

Unlocking Performance: Leveraging Molybdenum for Enhanced Properties and Microstructure in Advanced TMCP-Processed API 5L-X80 Steel Plates

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The investigation into the effect of molybdenum content on rolling parameters and microstructure in API 5L-X80 steel plates, produced via Thermo-Mechanical Control Process (TMCP) combined with accelerated cooling, constitutes a pivotal inquiry in steel metallurgy. Molybdenum, recognized for its potential in augmenting steel's strength and corrosion resistance, serves as the focal point in this study. Through meticulous experimentation, we scrutinize the interplay between varying molybdenum content and critical rolling parameters—such as temperature, speed, and reduction ratio—alongside their resultant impact on microstructural attributes. This exploration extends beyond traditional boundaries, aiming to uncover multifaceted benefits associated with optimal molybdenum content. Such optimization promises enhanced productivity, cost reduction, and equipment depreciation mitigation, presenting significant advantages from the producer's perspective. Furthermore, the study delves into properties enhancement, including improved mechanical strength, toughness, and corrosion resistance, thereby elevating the overall quality of API 5L-X80 steel plates. The research culminates in tangible technical results, indicating that by increasing the molybdenum content to a certain threshold, a notable enhancement in mechanical properties, including tensile strength and hardness, is achieved, thus underscoring the practical significance of optimizing molybdenum content in steel production processes.

Speaker Country:

Iran

MOLYBDENUM BOOSTING PROCESS EFFICIENCY / 10

Liquid phase-enhanced molybdenum homogenization during sintering of PM steels

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Molybdenum is an attractive alloy element also in sintered steels. For optimum compactibility, admixing Mo as elemental powder would be desirable; however, homogenization during sintering requires high temperatures, which results in cost penalties. In the present study it is shown that the sintering temperatures required for Mo distribution can be significantly lowered if low-melting masteralloy powders are combined with Mo, the transient liquid phase generated from the masteralloy during sintering acting as solvent and transport medium for Mo. Furthermore, the elements introduced through the masteralloy improve the mechanical properties, in particular the sinter hardening capability, when combined with Mo.

Speaker Country:

Österreich

MOLYBDENUM BOOSTING PROCESS EFFICIENCY / 11

Modelling of the effect of a Mo-addition on the kinetics of precipitation reactions in high-strength micro-alloyed structural steels during heat treatment and hot-dip galvanizing

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High-strength structural steels offer several attractive advantages over mild steel, such as a higher strength-to-weight ratio and a reduced carbon footprint. Molybdenum plays an important role in achieving this goal, as it markedly improves the hardenability of steel. Heat treatment during production aims to find a balance between the desired strength and toughness for a given steel composition. While lower tempering temperatures generally lead to a higher strength, they are often connected with a reduced low-temperature toughness. High tempering temperatures, on the other hand, generally lead to an improvement of the low-temperature toughness at the cost of a lower strength.
Thermodynamic modelling of phase equilibria is a useful tool for the design of the heat treatment of microalloyed structural steels. Its possibilities can be augmented by modelling of the kinetics of precipitation reactions that take the actual temperature-time history into account, as this has a strong impact on the size and volume fraction of precipitates. Within the present investigation, the precipitation kinetics during heat treatment and hot-dip galvanizing of an S620 high-strength structural steel with and without molybdenum addition were modelled. This made it possible to investigate the effect of variations in heat treatment parameters and the steel composition. This was coupled with laboratory heat treatment trials and characterization of the mechanical properties. In the present case, it was found that a variation in tempering temperature has a stronger effect on carbonitride and cementite precipitates than a variation of the temperature during hot-dip galvanizing.

Speaker Country:

Deutschland

THE POWER OF MOLY / 12

The effect of molybdenum during hot rolling on the microstructure and mechanical properties of wear resistant steels

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In addition to wear resistance, an optimum balance of strength, toughness and formability is the ultimate goal for wear resistant steels. The microstructure of wear resistant steels are typically martensitic which can create high strength and hardness, but at the expense of toughness and formability. The key is to achieve the proper microstructures for high strength and high hardness, but also achieve optimum toughness and formability. Thermomechanical rolling is an effective way to improve the final properties of wear resistant steels via austenite deformation prior to quenching. Rolling below non-recrystallization temperature results in elongation of prior austenite grains in rolling direction, i.e. pancaking of austenite.
Therefore, the effect of microstructure on the mechanical properties of three thermomechanically rolled and direct quenched wear resistant steel plates was investigated. The prior austenite morphology and transformed microstructure was studied and compared to tensile properties, impact toughness and bendability. Decreasing the finishing rolling temperature increased the level of austenite pancaking. Centerlines of samples consisted mainly of auto-tempered martensite. With lower finishing rolling temperatures and higher reductions in the non-recrystallization regime the formation of polygonal ferrite and bainite increased at the quarter thickness. High fraction of polygonal ferrite seemed to have a detrimental effect on strength and impact toughness. Impact toughness is also impaired by the presence of coarse inclusions.
According to these results, it is recommendable to choose low finishing rolling temperatures to increase the pancaking of austenite, which improves the impact toughness and strength of wear resistant steel plates. However, finishing rolling temperature should be high enough to prevent the excessive formation of polygonal ferrite resulting in highly inhomogeneous microstructure. Also, the quenching should be rapid enough to ensure the homogeneous, mostly martensitic microstructure. By eliminating coarse inclusions via proper steelmaking operations, excellent impact toughness levels could be obtained.

Speaker Country:

Finland

MOLYBDENUM BOOSTING PROCESS EFFICIENCY / 13

Sinter hardening hybrid alloyed PM steels based on Mo prealloyed powder

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Sinter hardening is an economically attractive and environmentally friendly way to improve strength and hardness of sintered steels. Because of the lower cooling rates compared to e.g. oil quenching, steel grades with improved hardenability are required. Here it is shown that sinter hardening behaviour can be attained at moderate alloy element contents when base powders prealloyed with low amounts of Mo are combined with Mn-Si masteralloys. The low starting oxygen content of these base powders alleviates the effect of "internal gettering", i.e. oxygen transfer from the base powder to the masteralloy particles, which otherwise would have an adverse effect on the properties. Sintering at temperatures >1200℃ yields optimum properties, but also at belt furnace temperatures below 1150℃ attractive combinations of hardness and impact toughness are attained.

Speaker Country:

Austria

THE POWER OF MOLY / 14

The role of molybdenum on microstructure evolution in low-carbon steels

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This paper provides on overview of the fundamentals of molybdenum alloying on microstructure evolution in low-carbon steels. In particular, austenite grain growth and austenite decomposition will be analyzed in state-of-the-art line pipe and automotive steel grades that benefit from Mo alloying. Both experimental data as well as atomistically informed microstructure simulations will be discussed. In terms of austenite grain growth selected microalloying elements, e.g. Nb and Ti, may play a more dominant role than Mo in limiting austenite grain growth. This theoretically predicted phenomenon is verified with a systematic experimental study using laser ultrasonics to record grain growth in line pipe steels with different Mo alloying. Further, continuous cooling austenite decomposition tests in both automotive and line pipe grades confirm that Mo delays ferrite formation thereby promoting bainite formation. General conclusions on the potential benefits of Mo alloying will be made based on the above analysis also with respect to the interaction with increased levels of residuals as a result of moving towards a circular economy and the associated higher levels of scrap use in steel making.

Speaker Country:

Canada

SUSTAINABLE PERFORMANCE WITH MO ALLOYED STEELS / 15

Novel medium-carbon quench and press hardening steel for extreme wear applications

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More durable materials are constantly required to increase the efficiency and lifespan of different applications with main focus being on the reduction of emissions. Steels are the most used engineering materials due to the excellent combination of mechanical properties, usability, and low cost. In addition, there are many applications where steels are the only viable material choice, such as in harsh the conditions of mining and material handling and agricultural sector, where wear is the most dominant damage mechanism. Different wear-resistant steels are often utilized in the applications utilized in such conditions, where heavy abrasion inflicts rapid wear of materials. The demand for stronger steels with better wear-resistance in increasing along with the adoption of more powerful machinery. SSAB has developed a new wear-resistant steel M53 for facing the most extreme wear environments. The SSAB M53 is a microalloyed steel grade for quench and press hardening to be used in a wide variety of applications in different segments. The steel was especially engineered for polymer and oil quenching with the fine-grain microstructure designed to prevent the formation of hardening cracks. Heat treatments can be utilized to achieve the desired balance of hardness and toughness. Maximum hardness of 60 HRC can be achieved with rapid polymer quenching followed by low-temperature tempering for improved elongation and toughness properties. The chemical composition comprises microalloying and small additions of chromium and molybdenum to ensure hardenability. The M53 provides an economical and environmentally friendly alternative to more expensive carburized and triple layered steel materials. Here, the mechanical properties and microstructure of the developed M53 steel will be discussed.

Speaker Country:

Finland

SUSTAINABLE PERFORMANCE WITH MO ALLOYED STEELS / 16

Mo Alloyed Quenching and Partitioning Steels

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Quenching and Partitioning (Q&P) steels have seen substantial development and implementation in a variety of product groups. The microstructure of these steels consists of a martensitic matrix with film like retained austenite and is obtained by quenching from the austenitic phase field or from the intercritical region to a temperature intermediate between the martensite start and finish temperatures, followed by partitioning through extended holding at this temperature or holding at a higher temperature followed by final quenching to room temperature. Carbon depletion of martensite and enrichment of austenite is obtained during the partitioning treatment resulting in austenite retention in the final microstructure following room temperature quenching. Austenite decomposition may occur during the quenching from high temperature if insufficient hardenability is provided by the steel chemistry, during partitioning if carbon enrichment does not occur in time, and during final quenching if insufficient carbon enrichment occurred. The present contribution will investigate the effect of molybdenum alloying on the Q&P heat treating response. Molybdenum alloying of CMnSi steels has been shown to increase austenite retention levels and enhance strength/ductility combinations, and molybdenum alloying may prove effective towards Q&P implementation of aluminum containing steels. Perspectives on the role of Mo in Q&P sheet steels during galvannealing will be given.

Speaker Country:

USA

SUSTAINABLE PERFORMANCE WITH MO ALLOYED STEELS / 17

Material selection key challenges for CO2 transport and underground storage

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Nowadays, carbon capture, transport, and underground storage (CCUS) rises like one of the technologies for mitigating climate change and meeting one of the most challenging targets of the Paris agreement: 14% of the total CO2 emissions reductions by 2060 must come from CCUS. Moreover, in the Net Zero Emissions (NZE) scenario, it is called a CO2 storage capacity objective of 1200 Mt of CO2 per year by 2030.

Similarly to other types of wells, a CO2 injection well must be designed for the long term and with operational design lives of typically 40+ years followed by the need for continued integrity for a planned abandonment for over 10000 years. As a conclusion, it becomes clear that correct design, particularly in terms of the selected materials for well components is very critical.

In this context, the CO2 injection and sequestration in underground sites differs from the experience with relative pure CO2 injection due to the presence of impurities related to the CO2 source and the capture technology used. These impurities are mainly H2O, H2S, CH4, O2, SOx, NOx…Their type and quantity are key to the material selection of tubes for the transport and injection of the impure CO2.

It is especially critical to determine the solubility of H2O in the fluid to limit the risk of presence of liquid water. On the contrary, several chemical reactions with the rest of impurities likely occur giving rise to strong acids (H2SO4, HNO3, S0…) that provoke different types of corrosion in the CCUS systems: stress corrosion cracking (SCC), sulfide stress corrosion cracking (SSC) and localized corrosion (pitting and crevice).

For a long-term exposure in wet CO2, the recommended materials are corrosion resistant alloys (CRAs). Then, duplex stainless steels with high pitting resistance equivalent number (PREN) are very suitable to avoid the very frequent localized corrosion. In general, compositions with high content of Chromium, Molybdenum and Nitrogen are firm candidates for CCUS. At a higher level of impurities, Nickel content is also a key element and austenitic solid solution Nickel based alloys enter directly into this application.

Apart from the corrosion resistance, the requirements in mechanical properties depend on the CO2 state in each part of the CCUS chain. It is usually ship transported as liquid, as a dense phase fluid when is transported by pipelines or in its supercritical phase to be stored in saline aquifers or hydrocarbon reservoirs. Therefore, working conditions require very high pressures, and risks of sudden depressurizations introduce the high probability of supporting very low subzero temperatures related to the Joule-Thompson effect. Consequently, ductile to brittle transition temperatures shall be also considered in the material selection, thus austenitic CRAs have the advantage in this point. In parallel, the injection well requires high yield strength, so minimum values of 80 ksi, 110 ksi and even 125 ksi are usually demanded, which implies the use of cold hardened finished tubes.

As a main conclusion, CCUS systems integrity implies important material considerations and, in this sense, CRAs appear to be the most suitable and reliable materials for increasing their lifetime and therefore, for contributing to accomplish the targets expected by the global decarbonization strategy. In addition, chemical composition optimization is a must for sustainability and one of the key elements in these alloys is the Molybdenum.

Speaker Country:

Spain

SUSTAINABLE PERFORMANCE WITH MO ALLOYED STEELS / 18

Vital Role of Molybdenum in Oil/Gas Production

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In the half-century since the high-molybdenum concept first provided a quantum leap in SSC resistance, low-alloy steels with 0.75% Mo (and 0.035% Nb) have become firmly established worldwide as the premier tubular product for assuring reliable service in deep sour oil/gas wells. In arriving at this alloy chemistry, molybdenum concentrations up to 2.5% were examined and SSC test results are shown. The superiority of this alloy was confirmed by various H2S tests of plate supplied to a dozen companies. Then testing of full-sized commercial heats verified the excellent performance, and widespread commercial use followed. High Mo concentrations are now specified for sour grades in API document 5CT. The mechanism of the marked improvement afforded by the high molybdenum content is described.

Speaker Country:

USA

SUSTAINABLE PERFORMANCE WITH MO ALLOYED STEELS / 19

Catalytic effects of molybdenum-based oxide compounds in a turbulent flow processor

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Wastewater originating from industrial production and human life is usually polluted by refractory organic molecules, heavy metal ions, and bacteria that are difficult to be removed by ordinary wastewater treatment plants. Efficient methods for removing these pollutants rely on advanced oxidation processes. The acting reactive oxygen species (ROS) need to be added or are in-situ generated by action of catalysts. A flow processor developed by Bauer Energy Design proved to be highly efficient in removing pollutants from wastewater and biofilms from tube surfaces. The compelling simplicity and low cost of the reverse flow processor make it widely applicable. This device made from molybdenum alloyed stainless steel relies on multiple effects producing ROS, such as catalytic actions from Mo oxide and metal molybdates present in the passivation layer of the steel. Triboelectric effects and strong swirling of the flowing water further enhance the catalytic action. The major principles will be detailed. These functionalities are also applicable for treating hydrocarbons. Current experiences and future potential for optimizing fuels will be discussed.

Speaker Country:

Belgium

MOLYBDENUM BOOSTING PROCESS EFFICIENCY / 20

Use of Molybdenum for Recrystallization Control and Microstructure Development in Compact Strip Production

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Thermomechanical processing of flat rolled steel products manufactured by the compact strip process is limited by numerous physical constraints. Alloy and process designs are limited by the necessary avoidance of peritectic chemistry, relatively low equalizing furnace temperatures relative to traditional integrated mill methodologies, generally high baseline nitrogen levels, and the constrained balance of static recrystallization during roughing and strain retention during finishing from a reduced slab thickness. Accordingly, molybdenum may be employed as a strategic alloy addition independent of solubility constraints to control both post-recrystallization grain growth during roughing and strain retention of austenite during finish rolling. This contribution details the use of molybdenum in the manufacture of selected high strength low alloy and advanced high strength steel grades with the specific focus of molybdenum effects on austenite recrystallization kinetics during hot rolling and associated product microstructure and performance. Molybdenum is shown as a solute to improve product performance consistency, in part due to its mechanistic independence from both nitrogen variation and solubility considerations. Additional beneficial effects of molybdenum on microalloy carbide precipitation and austenite decomposition are presented within the frame of the compact strip process.

Speaker Country:

USA

THE POWER OF MOLY / 21

Mo in steels – An ab initio perspective

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The role of Mo in steels as an alloying element is manifold and often key to obtain excellent mechanical properties in the final product. In many cases, ab initio calculations on the atomic level can give valuable insights into the mechanisms at work, which then provides direct guidelines for alloy design and optimization.
Molybdenum is present in steels in solid solution and in various precipitated phases, leading to a diverse set of influences in the process-microstructure-property relationships. In dissolved state, Mo acts as a ferrite stabilizer and as solid solution strengthener, which can be quantified with ab initio methods in dependence on the specific composition and temperature. Furthermore, dissolved Mo binds to grain boundaries and by that affects the strength of grain boundaries and their mobility, which in turn slows down kinetics of grain growth, recrystallization, and phase transformation. For predictive modelling of these effects, accurate interaction energies are needed, which can only be obtained from ab initio calculations. In the form of precipitates, Mo-containing phases may contribute to precipitation strengthening or Hydrogen trapping. Ab initio calculation of precipitates and their interfaces with the Fe matrix helps to understand the effect of Mo in the relevant mechanism and

allows to derive material design guidelines.
In this talk, a short overview on the available ab initio approaches to study Mo effects in steels, how they link to higher scales, and some examples are provided.

Speaker Country:

Austria

MOLYBDENUM BOOSTING PROCESS EFFICIENCY / 22

Effect of molybdenum on the strengthening mechanisms of advanced HSLA-steels

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The production and use of conventional, cold-rolled, high-strength low-alloy (HSLA) steels is well established in different markets. HSLA steels are characterized by a low-carbon alloying concept and therefore have excellent weldability. Different strength classes and good local formability enable a wide range of applications.
The global automotive steel specification VDA239-100 currently defines grade CR460LA as the highest cold-rolled HSLA steel. Hot-rolled HSLA strip is standardly available with a minimum yield strength of up to 700 MPa. A simple transfer of such hot rolled HSLA concepts to cold rolled strip production is not possible.
The aim of this work was to extend the yield strength level of cold-rolled HSLA steels to above 500 MPa. Therefore, two chemical compositions based on a low-carbon concept were micro-alloyed with niobium while the second variant was additionally alloyed with molybdenum. The industrial production of the hot rolled coils took place at voestalpine Stahl GmbH. Afterwards different cold rolling degrees and annealing conditions were simulated in the laboratory to assess the influence of different strengthening mechanisms. The annealed samples were characterized using tensile testing and microscopy.
The results demonstrates that the addition of molybdenum leads to solid solution strengthening, an optimized precipitate and grain refinement strengthening and a largely suppression of recrystallization. This increases the yield strength by 30- 80 MPa for all conditions. Low cold reduction degrees and low annealing temperatures additionally leads to more robust process conditions in different final annealing treatments. For that reason, the use of low-carbon steels with niobium and molybdenum alloying in combination with established processing technologies for hot rolling, cold rolling and annealing is ideally suited for advanced HSLA steels.

Speaker Country:

Austria

THE POWER OF MOLY / 23

Molybdenum, and essential element in tool steels

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Tool steels are the alloys used to manufacture tools, dies, and molds that shape, form, and cut other materials such as steels, nonferrous metals, and plastics at either ordinary or elevated temperatures. They are either carbon, alloy or high-speed steels, capable of being hardened and tempered.
The high carbon and alloy contents of tool steels are used to produce very high strength and hardness by the formation of crystalline phases such as martensite and various alloy carbides. Later show a very high hardness and are, therefore, mainly responsible for an excellent wear resistance. The phases are arranged into microstructures by solidification or powder processing, hot rolling, and heat treatment. Many variations of this microstructure exist, depending on alloying and processing condition, and this plays a role in the performance of a steel under specific service conditions. However, major alloying elements in tool steels belong to the group of transition metals such as molybdenum, tungsten, and vanadium, as carbides formed by transition metals have strong interatomic bonding, high melting points, and unique electrical properties. In this presentation an overview on the influence of Mo on this arrangement of phases and as a result the properties in various tool steel systems is given.

Speaker Country:

Austria

THE POWER OF MOLY / 24

The power of Moly alloying – a brief history of sustainable steel metallurgy

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In 1891, the French company Schneider & Co. used molybdenum for the first time as an alloying element in armor plate steel and until the end of WW2 most of the molybdenum alloyed steels were indeed related to military applications. Yet surprisingly, Moly was the first time applied to increase the strength of automotive steel for the Wills Saint Claire that appeared in 1921. The recognition of a quantitative relationship between alloy composition, temperature, time, deformation, cooling rate from austenite and resulting transformation products in the beginning of the 1930s has triggered ever-growing research activities with the aim of improving manufacturing and properties of steel alloys. In that respect, the landmarking Climax market development program that started in the 1960s laid the foundation for a thorough understanding of the molybdenum's metallurgical functionality. Over the recent decades, the International Molybdenum Association (IMOA) continued the coordination of metallurgical research activities on behalf of the global molybdenum industry. It can be truly stated that no other alloying element to steel has such a versatile functionality as molybdenum. It not only significantly improves the properties of steels but also allows steelmakers to utilize more efficient processes with higher yields. This together with the superior performance of molybdenum alloyed steels in the respective applications is the key for sustainable solutions that societies nowadays are so urgently looking after. This presentation gives an overview of the principal metallurgical effects of molybdenum in modern steels and demonstrate how these can enhance efficiency and sustainability for a wide range of processes and applications.

Speaker Country:

Belgium

THE POWER OF MOLY / 25

Passivity and repassivation mechanism of stainless steels containing molybdenum

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In this work we studied series of stainless steels with varying Cr, Ni, Mn and Mo contents, to systematically break down the contribution of individual elements to the passivity of the alloys, and to understand repassivation mechanism after a damage occurs. To access the single element contribution on the stability of the alloys, ICP-MS is employed, a technique that is capable to elementally resolve the released materials from the alloys during corrosion and passivation. We use a newly designed electrochemical flow cell coupled with downstream ICP-MS detection. By systematically combining a material library we have successfully identified the influence of individual principal elements on the electrochemical properties and corrosion resistivity of alloys. We provide a detailed mechanistic understanding in the passive region. To characterize the passive layer, complementary XPS and LEIS measurements were performed, indicating that Mo forms insoluble passive layers that can however dissolve under cathodic conditions, and in the presence of chlorides.

Speaker Country:

Austria

FROM SUSTAINABLE MO MINING TO SUSTAINABLE STEEL / 26

Moly for Europe: The Greenland primary molybdenum mining project

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Greenland Resources Inc. is a Canadian mining company that owns 100% the Malmbjerg molybdenum project, a world class Climax-type pure molybdenum mineral deposit near tidewater in East-Central Greenland. The Malmbjerg project is supported by a recent NI 43-101 feasibility study. Accordingly, it is a world-class primary molybdenum deposit featuring a Climax-type ore of high MoS2 concentration and low levels of impurities. The Malmbjerg project has the potential of covering approximately 25% of Europe's annual molybdenum needs over a period of 20 years and could go into production before the end of this decade. This made it ad hoc an attractive project within the EU's Critical Raw Materials Act as part of the EU-Greenland strategic partnership.
The EU represents the second largest user of molybdenum worldwide as the metal is vital for European metallurgical and chemical industries. Despite being nearly self-sufficient in processing capacity for molybdenum concentrate, Europe so far has no molybdenum mining activity and fully relies on imports of concentrates from overseas. The prospect of having a molybdenum mining site on EU-associated territory, fully compliant with responsible sourcing demands, has received strong interest for long term offtakes from major EU industries.
The presentation will detail the features of the Malmbjerg deposit and outline the mining plan developed by Greenland Resources Inc. Particular attention will be attributed to highlighting the efforts done towards sustainable mining allowing lowest carbon-footprint and environmental impact. The down-stream processing scenario, all based in Europe, will be drafted demonstrating a strategically important independence from overseas supplies. Besides the technical aspects, progress in EU financing and offtakes will be discussed.

Speaker Country:

Canada

FROM SUSTAINABLE MO MINING TO SUSTAINABLE STEEL / 27

Navigating Europe's Raw Materials Landscape: Policies and Strategies

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Raw materials are crucial to modern economies.

In the context of Europe, ensuring a secure and sustainable supply of raw materials is vital for economic growth, innovation, and environmental stewardship.

This presentation delves into the intricate world of European raw materials policy and strategy.

The following key areas will be explored:

•Introduction to Raw Materials
•European Raw Materials Context
•EU Raw Materials Policy Framework
•Strategies for Raw Materials Security
•Innovation and Research:
•Challenges and Opportunities
•Conclusion

Speaker Country:

France

SUSTAINABLE PERFORMANCE WITH MO ALLOYED STEELS / 28

How the recycling of molybdenum metal and molybdenum-containing stainless steel scrap closes the loop

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coming soon…

Speaker Country:

Germany

SUSTAINABLE PERFORMANCE WITH MO ALLOYED STEELS / 29

Molybdenum alloyed stainless steel in mineral processing

Authors: Marie Louise Falkland[1]; Mikko Palosaari[2]

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The processing and refining of minerals need molybdenum alloyed stainless steels. In hydrometallurgical processes of primary or secondary resources of e.g.,lithium, nickel, cobalt, copper and manganese involves typically highly corrosive conditions due to the use of reagents such as sulphuric acid, chlorides, and in some cases high temperatures and pressures, so the optimum selection of materials of constructionfor items such as pressure vessels, thickeners, process tanks, and other process items is a key issue. Molybdenum alloying of stainless steel stainless steel increases their resistance in chloride containing media and in most acids and have shown to be usefulin these applications. The combination of corrosion resistance, erosion resistance and mechanical strength are the cornerstones in a sustainable material selection. This presentation will showcase reference cases of applications within mineral processing wheremolybdenum alloyed stainless steels are being used.

Speaker Country:

Sweden

MOLYBDENUM BOOSTING PROCESS EFFICIENCY / 30

Molybdenum – A sustainable Partner for the Special Steel Industry

Author: Frank Hippenstiel[1]

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Molybdenum is an essential alloying element in special and stainless steels as it for instance improves the corrosion resistance of stainless steels and increases the wear resistance of tool steels. Yet, molybdenum has also been established as the preferred alloying element in engineering steels, since it generally increases the hardenability as well as the toughness and tempering resistance. Great potential for optimizing processing by molybdenum alloying is seen for this group of steels in particular. A higher alloy addition of molybdenum can shorten heat treatment processes and thus reduce the CO2 footprint of special steel products. Accordingly, the intake of CO2 to the steel via the molybdenum alloying is being offset by reduced emissions due to more efficient processing. This overview lecture describes in a holistic contemplation the requirements and benefits of molybdenum in special and stainless steel production from melting over hot deformation to final heat treatment. The addition of molybdenum by various ferroalloy types as well as via recycled scrap will be particularly addressed. Examples of how molybdenum can be effectively used in modern alloy concepts for stainless steels and engineering steels for machinery will be provided.

Speaker Country:

Germany

FROM SUSTAINABLE MO MINING TO SUSTAINABLE STEEL / 31

Sustainable molybdenum for generations

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In 1987, the United Nations defined "sustainability" as "meeting the needs of the present without compromising the ability of future generationsto meet their own needs."
Addressing current challenges while protecting and improving tomorrow is a delicate balancing act, requiring credibility and experience, substantive resources,and humility. We are stewards responsible to generations before us, to our present stakeholders, and to future generations.
This paper is our view of the possibilities and constraints regarding responsible production, told from our perspective as a fully integrated company that hasserved the steel industry for over four generations – and is preparing for a sustainable future. In addition, the paper places our efforts in the context of broader molybdenum market considerations.

Speaker Country:

USA

FROM SUSTAINABLE MO MINING TO SUSTAINABLE STEEL / 32

Outokumpu Sustainable Stainless Steel from Raw Materials to End Consumers

Authors: Julian Gatzweiler[1]; Max Menzel[2]

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Speaker Country:

Germany

FROM SUSTAINABLE MO MINING TO SUSTAINABLE STEEL / 33

SSAB Fossil Free Steel Production Conversion

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Speaker Country:

Finland

SUSTAINABLE PERFORMANCE WITH MO ALLOYED STEELS / 34

Molybdenum alloying in advanced special steels: small amounts, big effects enhancing strength and sustainability

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The addition of molybdenum as an alloying element is critical for optimizing the performance of special steels in various demanding applications, including tooling, plastic molding, armor, abrasion resistance, pressure vessels and offshore industries. Molybdenum is commonly added to special steels to improve their strength, hardness, toughness, and wear resistance. In this presentation, we will explore some examples of modern special steels plates produced by ArcelorMittal Industeel and their applications, with special emphasis on the importance of molybdenum to their key properties. The small but critical addition of molybdenum to the steel composition allows manufacturers to produce stronger and more durable products, fully recyclable, without excessive use the resources. Across various sectors including construction, machinery, energy, and defense, the advantages of light weighting, corrosion resistance, longer lifetime contribute to a more sustainable future and reduce the environmental impact.

Speaker Country:

France

FROM SUSTAINABLE MO MINING TO SUSTAINABLE STEEL / 35

On the decarbonization activities at ArcelorMittal Industeel

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Speaker Country:

France

FROM SUSTAINABLE MO MINING TO SUSTAINABLE STEEL / 36

Molymet Belgium strategic partner in green Moly additives for the EU steel industry

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Speaker Country:

Belgium