PhD proposal:

Metallurgical engineering of a new molybdenum prehardened steel for plastic injection moulding and mechanical applications

Industrial context and scientific objectives

There are greater demands to strengthen tool steel used for plastic moulding or mechanical engineering applications, with the target of producing better and longer lasting components at a better cost, with a more efficient use of resources, energy, and a reduced CO_2 footprint.

Plastic injection moulding is a widely used manufacturing process having the advantage of producing many identical parts in a short time and at a low cost used for various applications such as household appliances, consumer electronics, optical and medical parts, automotive industry, food and packaging.

While it is nowadays possible to machine hard materials over a wide range of cutting speeds, prehardened grades are generally available for hardness levels ranging from 30 to 40 HRC only. To achieve higher properties, mould makers are increasingly using ASTM A681 H11 or H13 grades, which are used in the annealed condition and require final heat treatment of the parts.

Those steels were designed long time ago for hot working processes such as forging, die casting, and hot stamping processes where they are exposed to severe working conditions with rapid changes in temperature up to 600°C and high mechanical loads [1]. Whereas they provide today adequate solution for higher strength, they present two main shortcomings for plastic moulding applications: i) the high chromium content in H11 or H13 decreases the thermal conductivity, which is a critical property for effective heat dissipation and fast cooling of the thermoplastic [2]; ii) the subsequent heat treatments and final machining of the components result in longer cost and development times compared to mould parts directly machined from a high quality prehardened steel block.

Industeel has recently demonstrated the industrial feasibility of obtaining by quenching and tempering heavy plates up to a thickness of 250 mm having a hardness of 44 HRC class (1400 MPa UTS) with excellent machinability. The overall good balance between strength and toughness will also open the door to the manufacture of tool parts used in mechanical engineering applications. However, the exact role of alloying elements and optimum microstructure are not fully understood.

In a preliminary work [3,4], in-situ high energy X-ray diffraction (HEXRD) tests have been carried out at the DESY synchrotron in Hamburg to follow the decomposition of retained austenite involving the formation of large M_3C carbides during the tempering treatment. But the HEXRD was not appropriate to provide quantitative information about the formation of nano-precipitates at the origin of secondary hardening occurring simultaneously.

The scientific objective of this PhD project is to explore, in new grades containing Mo, the coupling phenomenon between the decomposition of the retained austenite and the secondary precipitation of stable or metastable alloyed carbides during tempering in the martensitic or bainitic matrix.

Methodology

Three selected Mo-rich compositions will be lab-cast and be studied after various lab-scale heat treatments. The evolution of the microstructure (major phases and precipitates) and resulting mechanical properties will be recorded for different tempering conditions (time, temperature and heating rates).

The first axis of the present project consists in conducting complementary large-scale facilities experiments and post-treatment of resulting data: HEXRD to explore the evolution of major phases (martensite, bainite, retained austenite and large carbides) and small-angle neutron scattering (SANS) experiments to measure the nanoscale precipitates in the aged steels at the Laue-Langevin Institute (Grenoble, France). Recent research has also demonstrated the potential of anomalous small-angle x-ray scattering (ASAX) to estimate the volume fraction of Mo-rich precipitates with beam energies close to the absorption edge of Mo [5].

The second axis of this project will aim at optimizing the choice of the composition of one new Mo-bearing grade and the corresponding industrial production route. Through the interpretation of these results and the conclusions of the first axis, a final composition will be proposed with its corresponding optimized heat treatment. This new grade will be produced on an industrial scale and characterized to compare with the expectations from the previous study and requirements.

Our offer and conditions

Starting date: from Jan 2024

Duration: 3 years

Location: Lille (min 80%), Le Creusot, Toulouse

Academic supervision: Pr. Myriam Dumont, Arts et Métiers Institute of Technology, MSMP, HESAM Université, F-59000 Lille and Pr. Moukrane Dehmas, Interuniversity Center of Materials Research and Engineering (CIRIMAT) in Toulouse

Industrial supervision : Dr. David Quidort, Centre de Recherches des Matériaux, Industeel, ArcelorMittal Group, F-71200 Le Creusot

Salary: 28 k€ gross annual (CIFRE fellowship)

The successful candidate (H/F) will benefit from a 3 years full-time employment contract from Industeel, a leading European producer for special steel plates from carbon & low alloy steels to stainless steels and nickel-based alloys. Industeel is a wholly owned subsidiary of ArcelorMittal, that offers dynamic research environment and multiple career opportunities.

The work of the first axis will be carried out mainly at the MSMP laboratory of Arts et Métiers Institute of Technology in Lille, under the supervision of Pr. Myriam Dumont, and in close collaboration with the Interuniversity Center of Materials Research and Engineering (CIRIMAT) in Toulouse under the supervision of Pr. Moukrane Dehmas. The expertise of Prof. Denis Delagnes (Institut Clément Ader, Albi) will add force and experience in the project team. The work of the second axis will be carried out in Le Creusot with regular travels for the successful candidate and short stays with the industrial team.

Your profile

- Masters-level degree or graduate of Engineering school (Mines, Centrale, ENSAM, INSA, INPs, UTC…) in Materials Science or Mechanics
- Strong motivation for advanced experimental techniques and simulation/modelling
- First experience in metallurgy, steels, large scale experiments, diffraction or diffusion techniques would be a plus
- Ability to work/interact with both academic and industrial teams
- The PhD student is expected to be self-motivated, creative, and capable of critical thinking

Candidates (H/F) should provide a CV, a letter of motivation, and the names and e-mail addresses of 2 references to Myriam Dumont (myriam.dumont@ensam.eu) and to David Quidort (david.quidort@arcelormittal.com).

References

[1] Mesquita, R.A. Tool Steels: Properties and Performance; CRC Press, FL, USA, 2016.

[2] Son, J.-Y.; Lee, K.-Y.; Shin, G.-Y.; Choi, C.-H.; Shim, D.-S., "Mechanical and Thermal Properties of the High Thermal Conductivity Steel (HTCS) Additively Manufactured via Powder-Fed Direct Energy Deposition", Micromachines 2023, 14, 872.

[3] M. Dumont, M. Perruchot, M. Messaadi, M. Lachal, D. Quidort, B. Malard, D. Delagnes, M. Dehmas, "Effect of tempering on retained austenite in high-strength tool steels", Conférence « Matériaux », Lille, France, Oct. 24 – 28, 2022.

[4] C. Almeida Da Fonseca, M. Messaadi, M. Lachal, M. Guatteri, D. Quidort, D. Delagnes, M. Dehmas, M. Dumont, " Effet des paramètres d'austénitisation sur l'évolution de la microstructure et des propriétés après revenu d'une nouvelle nuance d'aciers pour moules", Conférence « Moules & Outils 2023 », Albi, France, Nov. 9 – 10, 2023.

[5] E. Claesson, "Carbides in martensitic medium carbon low alloyed tool steels studied with small angle scattering techniques, electron microscopy and atom probe tomography", PhD thesis, KTH Royal Institute of Technology, Stockholm, 2023.