Press Release

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New design strategy for high-performance steels

International research team develops steel for liquid gas transport and storage.
Results now published in the journal Science.

Exploring sustainable manufacturing and processing paths, liquid gases like nitrogen and hydrogen are becoming increasingly important. However, transporting and storing these gases remains challenging and costly due to embrittlement effects. Currently used steels are expensive due to their high nickel content. A research team, including scientists from the German-based Max Planck Institute for Sustainable Materials (MPI SusMat), has designed a new steel that withstands ultralow temperatures while exhibiting high strength and ductility. Their findings were recently published in the journal Science.

Dislocation cutting at cryogenic temperatures

The researchers developed a steel composed of iron, manganese, aluminum, nickel, and carbon. These elements form a robust matrix characterized by locally ordered zones and precipitates. “The steel achieves its exceptional low-temperature strength through temperature-dependent solid solution strengthening. This distinctive effect induces shearing in typically brittle nanoparticles, thereby facilitating deformation,” explains Mohamed N. Elkot, postdoctoral researcher at MPI SusMat and co-author of the publication.

“It has been known that precipitates can lead to mechanically strong alloys. However, until now, B2 nanoprecipitates were considered nonshearable. This is the first time, dislocation cutting has been observed in high-strength steels when the temperature decreases to near liquid nitrogen temperatures. We induced this shearing mechanism by designing a compositionally complex alloy,” says Zhangwei Wang, a professor at Central South University in Changsha, China, and the corresponding author of the publication.

Achieving better properties with compositionally complex alloys

Compositionally complex alloys consist of at least five major elements, unlike conventional alloys that use one or two prevalent elements. This design strategy harnesses different, often opposing effects, such as the intense strengthening and strain hardening provided by otherwise impenetrable brittle nanoprecipitates. Additionally, it introduces ductility through the sequential shearing of nanoprecipitates with ongoing deformation. This results in a lightweight, compositionally complex steel with ultrahigh cryogenic tensile strength of up to 2 gigapascals and a remarkable tensile elongation of 34%.

The MPI SusMat team is designing compositionally complex alloys for various applications such as magnets and structural materials. The newly designed steel serves as a model system for future developments. It is less expensive due to its low nickel content and suitable for lightweight design due to its high strength. The current study thus paves a new route for designing high-performance structural materials.

This research was conducted in collaboration with researchers from the Central South University in Changsha (China) and the East China University of Science and Technology in Shanghai (China).

Original publication

F. Wang, M. Song, M.N. Elkot, N. Yao, B. Sun, M. Song, Z. Wang, D. Raabe: Shearing brittle intermetallics enhances cryogenic strength and ductility of steels. In: Science 384 (2024) 1017. DOI: 10.1126/science.ado2919

International research team develops steel with ultrahigh cryogenic tensile strength and tensile elongation, two crucial aspects for the transport and storage of liquid gases like nitrogen and hydrogen. Copyright: Adobe Stock 85363175

At the Max Planck Institute for Sustainable Materials (MPI SusMat), we are exploring climate-neutral, resource-conserving approaches to produce, utilize, and recycle essential materials for modern societies. We seek to produce metals using hydrogen instead of fossil fuels, extend material lifespans, enhance recyclability, and minimize waste. When developing materials that fulfil these requirements, we are increasingly relying on artificial intelligence to make the process significantly more efficient. The institute conducted its research under the name Max-Planck-Institut für Eisenforschung GmbH until 2024.

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