

Nb
Niobium

Niobium in advanced
high strength steel fasteners

Disclaimer

The information in this presentation has been prepared by Companhia Brasileira de Metalurgia e Mineração jointly with its subsidiaries (together hereinafter “CBMM”) for information purposes only and solely with the only purposes of introducing the company’s activities in 2018. This document and its contents are confidential and are being provided to you solely for your information and may not be reproduced, retransmitted, downloaded, posted, displayed, modified, reused, broadcast, transmitted or further distributed to any other person or published, in whole or in part, by any medium or in any form for any purpose. The opinions presented herein are based on information gathered at the time of writing and are subject to change without notice. CBMM relies on information obtained from sources believed to be reliable but does not guarantee its accuracy or completeness. This presentation may contain certain forward-looking statements and information relating to CBMM that reflect the current views and/or expectations of the CBMM and its management with respect to its performance, business and future events. Forward-looking statements include, without limitation, any statement that may predict, forecast, indicate or imply future results, performance or achievements, and may contain words like “believe”, “anticipate”, “expect”, “envisages”, “will likely result”, or any other words or phrases of similar meaning. Such statements are subject to a number of risks, uncertainties and assumptions. We caution you that a number of important factors could cause actual outcomes to differ materially from the plans, objectives, expectations, estimates and intentions expressed in this presentation. The copyrights and other intellectual property rights (such as design rights, trademarks, patents, among others) in any material contained in this presentation and copies thereof belong to CBMM or used under authorized license by CBMM. In any event, neither CBMM nor any of its affiliates, directors, officers, shareholders, agents or employees are or will be liable to any third party for any investment or business decision made or action taken in reliance on the information and statements contained in this presentation or for any for any damages, losses, expenses or costs whatsoever (including without limitation, any direct, indirect, special, incidental or consequential damages, loss of profits or loss opportunity) arising in connection with your reliance on any information at this presentation, even if CBMM has been advised as to the possibility of such damages. You should therefore verify the information contained in this presentation before you act upon it. The information contained in this presentation has not been independently verified. This presentation and its contents are proprietary information. CBMM’s names and logos and all related trademarks, trade names, and other intellectual property are the property of CBMM and cannot be used without its express prior written permission.

Contents

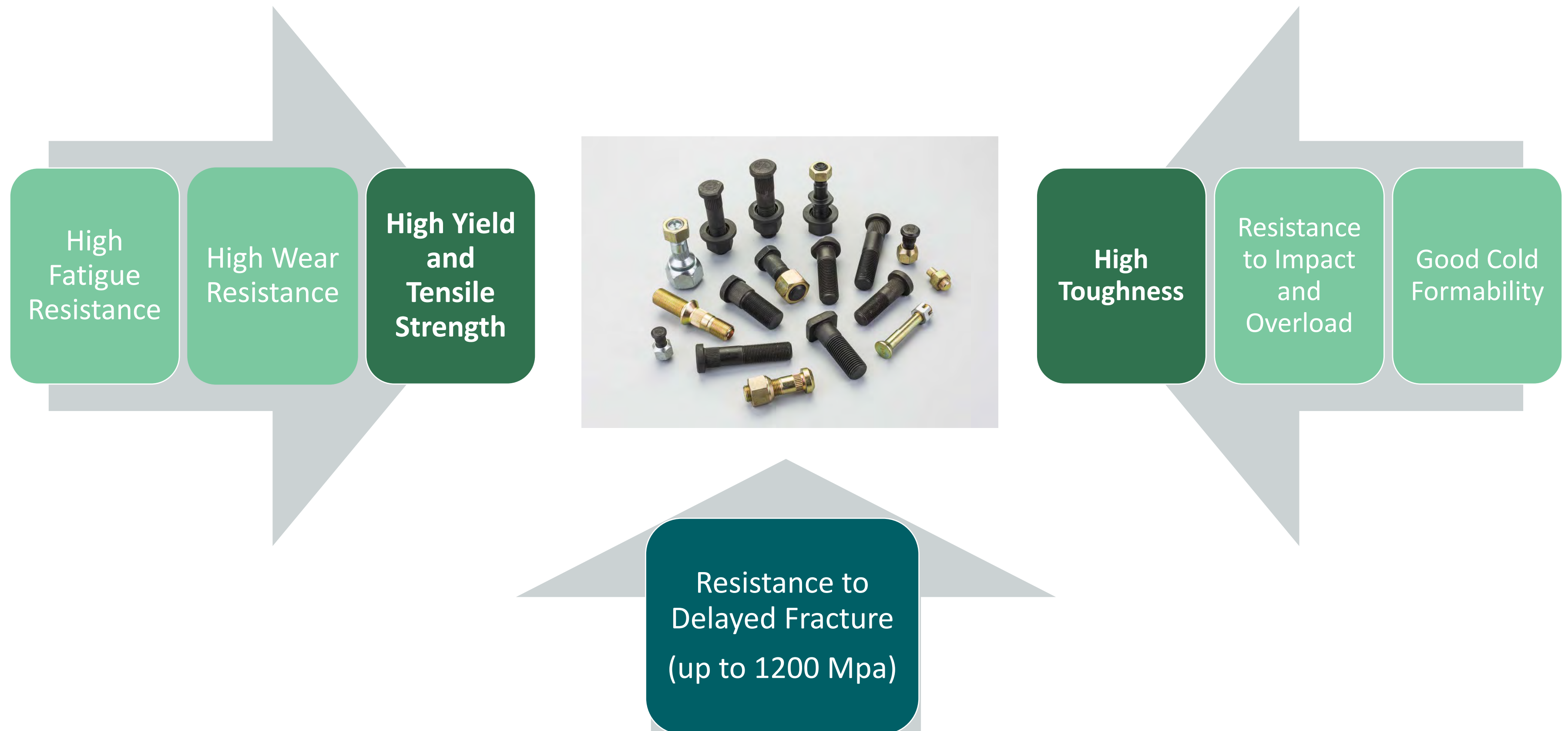
- Cold heading steels for fasteners
- Key properties of cold heading steels
- Benefits of Niobium
- Technical case studies

Cold heading steels

- Manufacturing process for fasteners and fixings
 - Bolts, nuts, screws, rivets etc.
- Uses cold working process
 - Higher productivity
 - Reduced costs
- High speed process in which wire rod is shaped into required shape using compression
 - Volume of metal remains constant
 - Increases tensile strength

OEMs have competing requirements

- Modern automotive cold heading steels need to balance a number of potentially conflicting properties



Trends in development of cold heading steels

- Delayed fracture resistance
- Improved cold formability
- Optimize heat treatments via thermomechanical processing to achieve:
 - Greater productivity
 - Better energy efficiency
 - Improved product performance
 - Reduced environmental impact

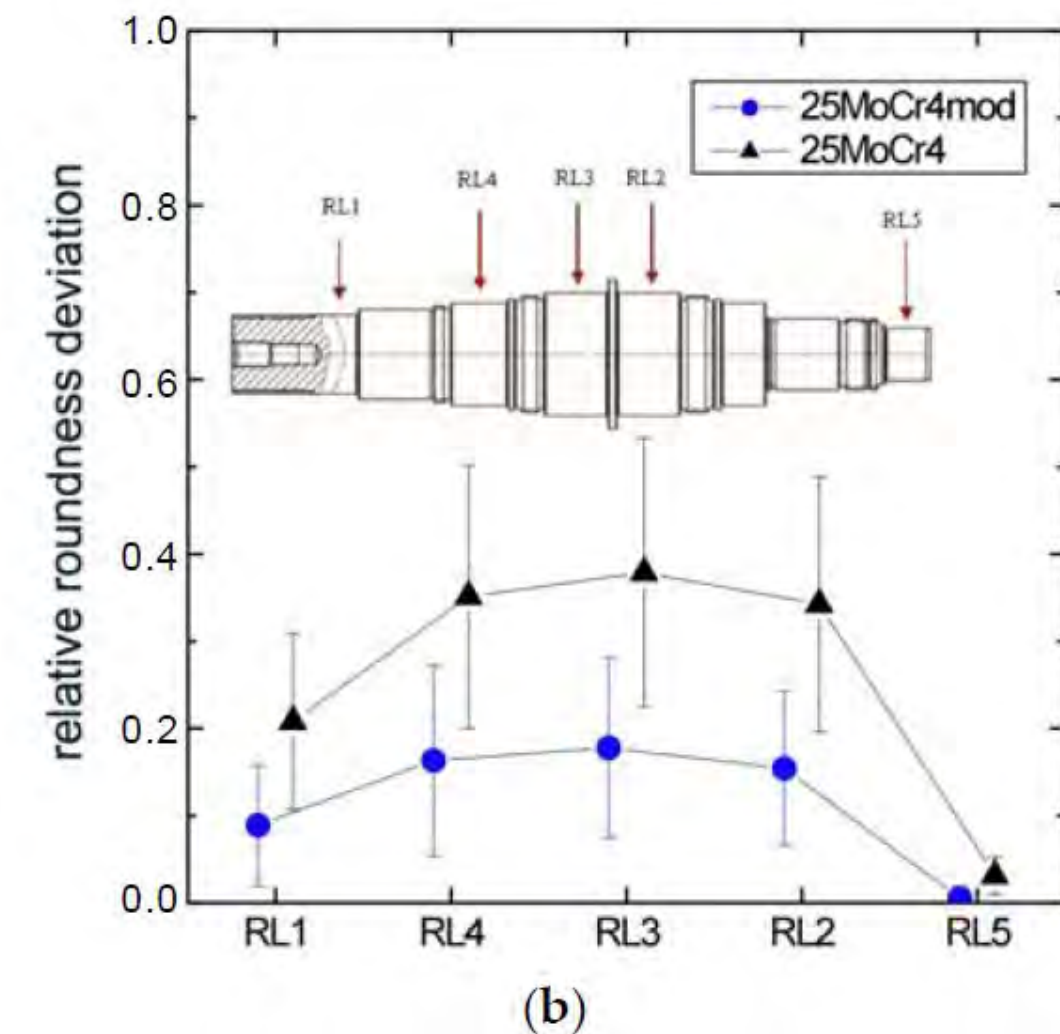
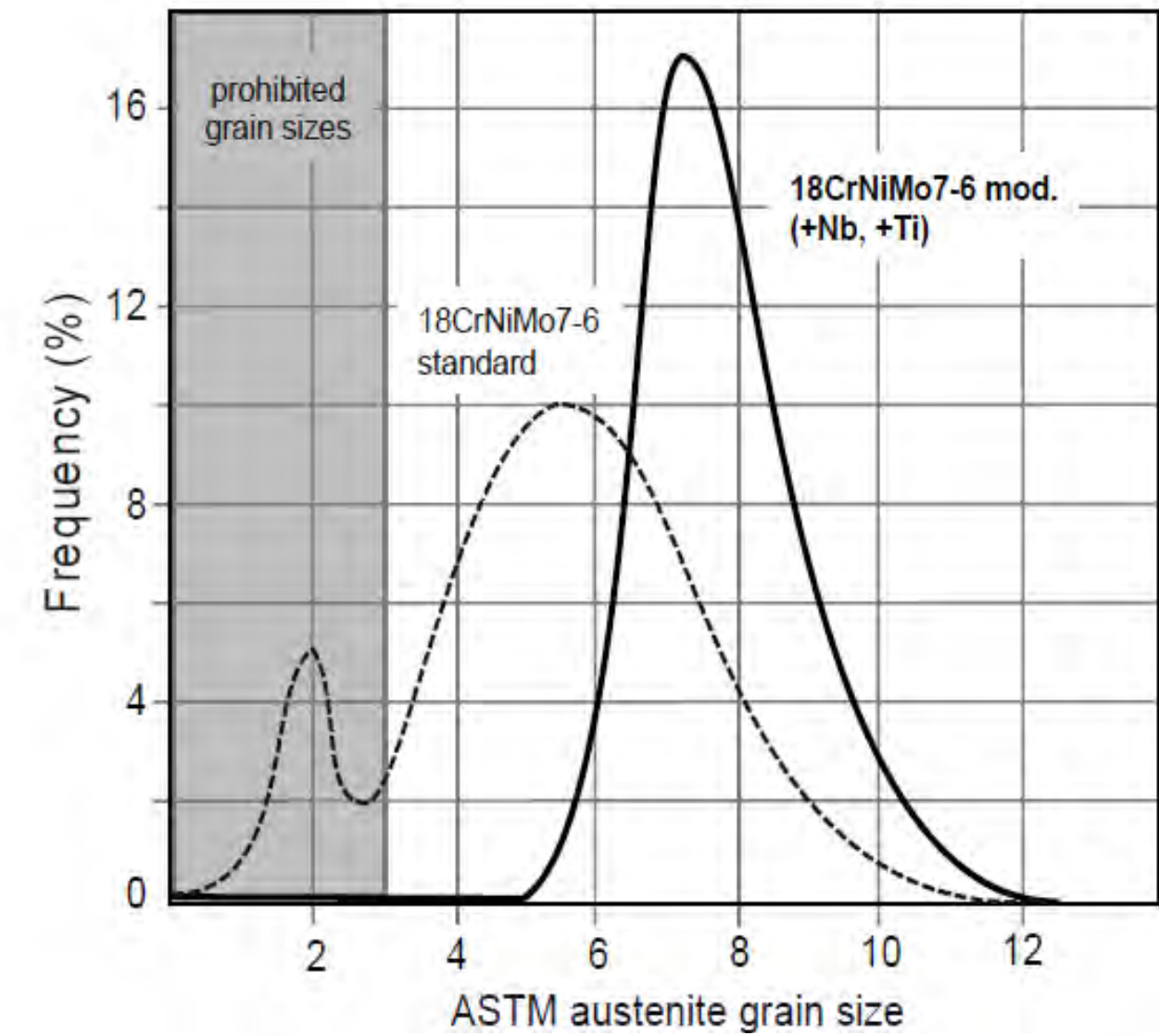
But conventional cold heading steels need expensive hardening and tempering heat treatments to reach desired properties

Niobium grain reduction

Niobium application gives two significant benefits

- Significant reduction in grain size
 - Improving toughness, fatigue resistance and hardenability
 - Once formed, cracks do not propagate easily

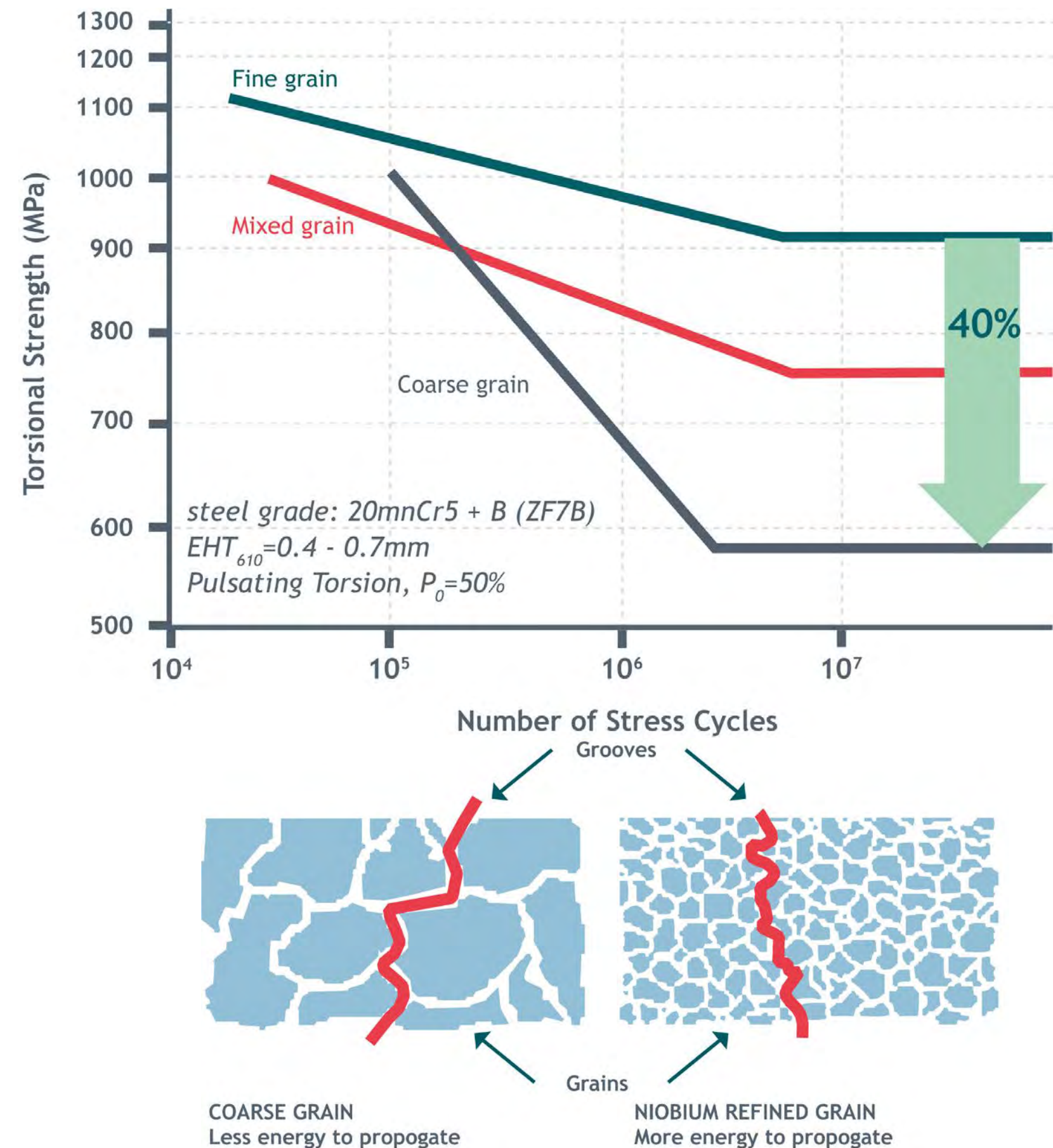
- Narrower distribution of grain sizes
 - Improving dimensional stability after heat treatment



Source: T. Tobie , F. Hippenstiel and H. Mohrbacher, *Optimizing Gear Performance by Alloy Modification of Carburizing Steels*, Metals, October, 2017

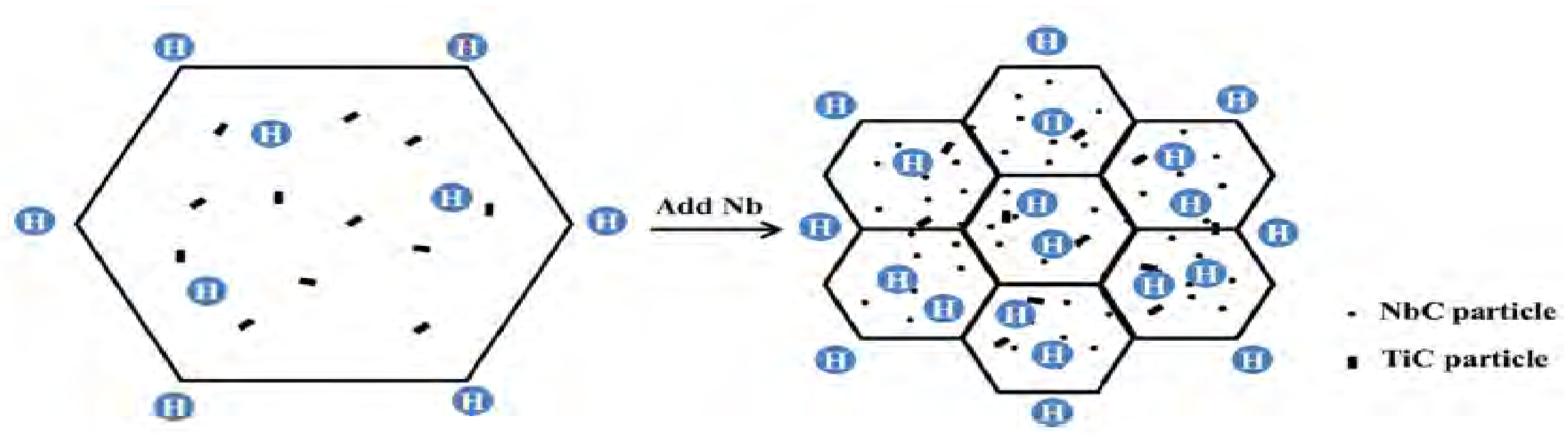
Better cold heading steels

- Steels with large grains are more likely to fail under stress
 - Cracks more likely to form
 - Once formed, cracks propagate more easily
- Niobium is strongest grain refining alloy
 - Prevents formation of large grains even at very high process temperatures
 - Assures homogeneous microstructural phase distribution, creating desired mechanical properties without costly heat treatments through use of thermomechanical processing
 - Improve strength, toughness and fatigue resistance
 - Reduces the hydrogen embrittlement tendency found in extra high strength cold heading steels=



Niobium's role in resisting hydrogen embrittlement

- The mechanism by which Niobium improves delayed fracture resistance in steels is unknown at present
- The two main proposals relate to
 - Niobium/Carbon acting as a hydrogen trap - main mechanism
 - The grain refinement effect of Niobium (C,N) - secondary mechanism



Summary for cold heading steels for fasteners

- Trend towards use of microalloying and thermomechanical processing to eliminate the need for costly post cold heading heat treatment
- Niobium reduces the hydrogen embrittlement tendency found in very high strength cold heading steel
- Thermomechanical rolling mill process in cold heading steels ensures the optimization of microalloying strategies

Source: Kimura, Toshimitsu and Yutaka Kurebayashi. "Niobium in microalloyed engineering steels, wire rods and case carburized products." International Symposium on Niobium 2001