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Mechanisms Behind the Cryogenic Effect in High Manganese Steels

High manganese austenitic steels are widely used in components exposed to severe impact and abrasion, such as shovel teeth, rock crushers and grinding equipment. Their durability arises from a deformation mechanism known as twinning-induced plasticity (TWIP). As these steels deform during service, they undergo intense work hardening, allowing the surface to become progressively stronger and more wear-resistant while the core remains tough.[1]

Recent research indicates that deep cryogenic treatment (DCT) – cooling steel to extremely low temperatures – can enhance TWIP behavior and extend wear life in demanding industrial environments.

Crusher mantles used in gold mining. *Credit: J. Cahn*

The TWIP Mechanism in High-Mn Steels

High-manganese steels are fully austenitic at room temperature, with a face-centered cubic (FCC) crystal structure. Unlike many structural steels that strengthen through phase transformations, these alloys rely on deformation twinning.

Under mechanical stress, mirror-like twin structures form within the crystal lattice. These twins subdivide grains into fine regions that block dislocation motion. As deformation continues, twin density increases, producing strong strain hardening.[2]

This behavior is valuable in mining and mineral-processing equipment. Components such as shovel teeth or crusher liners experience repeated impacts and large plastic strains. TWIP enables high-Mn steel to adapt in service: the surface hardens under load while the interior retains toughness needed to absorb shocks.

Deep cryogenic treatment can further influence how and when these twins form.

Structural Effects of Deep Cryogenic Treatment

Deep cryogenic treatment cools steel to temperatures below −230°F using liquid nitrogen. Originally used to improve wear resistance and dimensional stability in tool steels, DCT is now being explored for austenitic high-Mn alloys.[3]

Characterization studies reveal several structural changes after treatment:

- Slight contraction of the austenite lattice
- About 40% reduction in microstrain
- Nearly two-thirds reduction in dislocation density
- Formation of uniform compressive residual stresses

Although lowering dislocation density might seem counterintuitive, these changes alter how the steel responds during deformation.

Earlier and More Extensive Twinning

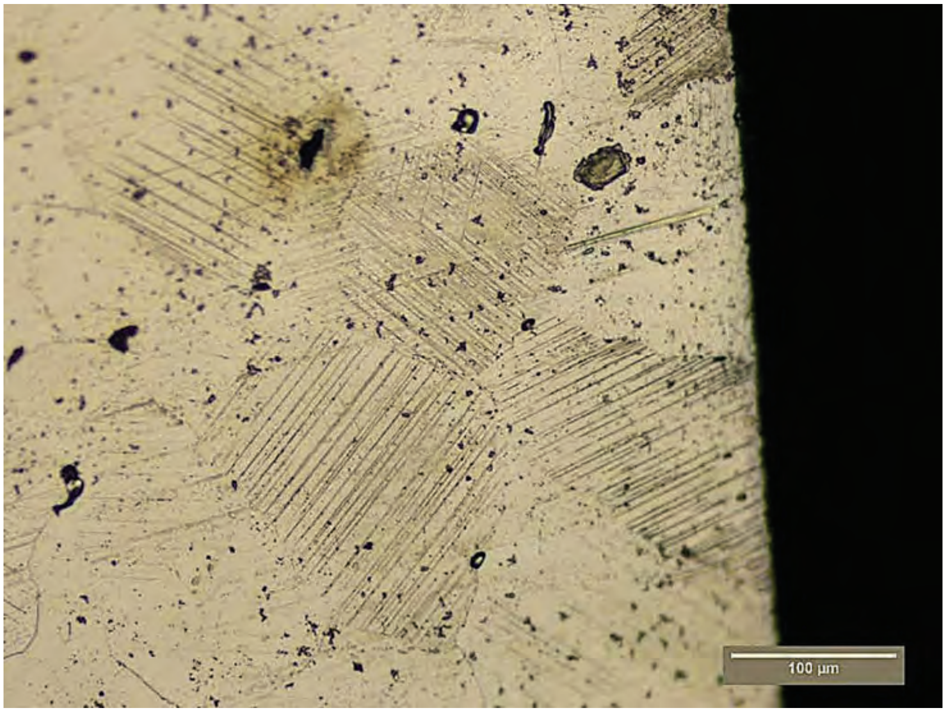
Comparisons between treated and untreated steels show that cryogenic treatment promotes earlier twinning. In treated material, deformation twins appear at about 5% strain, earlier than in conventional steel.

As deformation continues, the treated alloy develops higher twin density. Secondary and tertiary twins form, creating a hierarchical network of intersecting twins within grains.

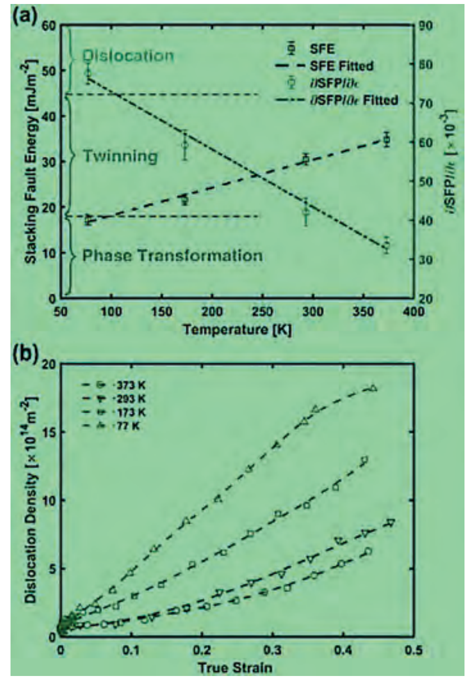
This refined twin structure provides several advantages:

- Twin boundaries impede dislocation motion
- Strain-hardening capacity increases
- Dislocation storage during deformation improves

Although the starting defect density is lower, the treated steel accumulates



18% Mn Twins. *Credit: J. Cahn*



SFE and deformation pathways in TWIP steel.
Credit: Tang et al, Acta Materialia

dislocations more effectively during deformation. Interactions between dislocations and twin boundaries sustain high work hardening, improving resistance to abrasion and impact damage.[4]

Thermodynamic Role of Stacking-Fault Energy

The enhanced twinning behavior is linked to stacking-fault energy (SFE), which governs deformation mechanisms in FCC metals.

In high-Mn steels, SFE determines whether plastic deformation occurs mainly by dislocation glide, martensitic transformation, or twinning. TWIP occurs within an intermediate SFE range that favors partial dislocations and stacking faults.

Deep cryogenic treatment modifies this balance through compressive residual stresses generated during cooling. These stresses alter the Gibbs free-energy conditions for stacking-fault formation.

According to the Olson-Cohen thermodynamic model, stacking-fault energy depends on the chemical driving force between phases, lattice strain energy, and interfacial energy. The compressive stresses and slight lattice contraction produced by DCT reduce the effective SFE.[5]

Lower SFE promotes the dissociation of perfect dislocations into Shockley partial dislocations, which generate stacking faults and deformation twins. As a result, twins form more easily and propagate earlier during deformation.[6]

Improved Toughness and Wear Resistance

Mechanical testing confirms the benefits of enhanced twinning. Cryogenically treated high-Mn steel shows improved toughness, with Charpy impact energy increasing from about 95 J to 122 J.

Fracture surfaces reveal ductile dimple rupture with significant crack deflection. The dense twin network disrupts crack propagation paths, forcing cracks to change direction and dissipate energy.

In applications such as shovel teeth or crusher liners, this combination of higher toughness and stronger work hardening translates into longer wear life.

A Practical Post-Casting Enhancement

A key advantage of deep cryogenic treatment is its practicality. Unlike alloy redesign or complex thermomechanical processing, DCT can be applied as a post-casting treatment to existing high-Mn steel components.[7]

By modifying the thermodynamic state of austenitic high-Mn steels and enabling more effective twinning-induced plasticity, deep cryogenic treatment offers a practical route to extending service life of critical wear components operating in harsh industrial environments.

References

[1,2,5] Hajipour, P., Tian, B., Sun, S., Cahn, J. And Li, L, Twinning-Assisted Toughening of High-Manganese Steels by Deep Cryogenic Treatment, Publication under review, 2026

[3] Cahn, J., The Cold Cure, ***Cold Facts***, Volume 41, Number 2, 2025

[4] Tang, L., Wang, L., Wang, M., Liu, H., Kabra, S., Chiu, Y. And Cai, B., Synergistic Deformation Pathways in a TWIP Steel at Cryogenic Temperatures: In situ Neutron Diffraction, Acta Materialia 200, pp 943 - 958, 2020

[6] Woo, W., Kim, Y.S., Chae, H.B., Lee, S.Y., Jeong, Y.S., Lee, C.M., Won, J.W., Na, Y.S., Kawasaki, T., Harjo, S., and An, K: Acta Materialia, 2023, vol. 246,

[7] Cahn, J., The Science of Cryogenics, ***Cold Facts***, Volume 41, Number 3, 2025