Role of Cryogenic Cycle Design in Tailoring Mechanical Performance of D2 Tool Steel

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Achieving a balance between hardness and fracture toughness in D2 tool steel continues to be a significant challenge, as improvements in hardness and wear can often lead to a decrease in toughness and fatigue resistance. This study clarifies the effects of deep cryogenic treatment (DCT) and cyclic deep cryogenic treatment (CDCT) protocols on this trade-off, with a particular focus on the significance of cycle design and reheating strategies. All samples were hardened at 1000°C for 30 minutes, then double tempered at 350°C. They were then subjected to conventional heat treatment (CHT), DCT, or CDCT with different cycle counts and durations: 2×2 hours, 4×1 hour, 8×30 minutes, 2×30 minutes, and 2×3 hours, with room temperature as the reheating strategy. Additional variants included reheating to −50°C as well as to 100°C. Hardness measurements were carried out using Rockwell and Vickers scales, while fracture toughness was assessed using circumferentially notched and fatigue pre-cracked tensile bar specimens. DCT and all CDCT variants increased hardness by 1-2 HRC compared to CHT, but toughness decreased by 11-54%. The CDCT-2×2 h variant reached 59.3 HRC with a toughness of 19.2 MPa·$m^{1/2}$, maintaining the hardness level of DCT while recovering about 3.3% of the toughness. Other CDCT methods achieved similar hardness levels but exhibited lower toughness than both DCT and CDCT 2×2 h. These results demonstrate that careful management of cryogenic cycling can reduce the hardness–toughness trade off, with CDCT 2×2 h offering a viable route for applications demanding both high wear resistance and improved fracture tolerance.

Keywords: coldwork tool steel, deep cryogenic treatment, cyclic treatment, hardness, fracture toughness, microstructure