Technical Review of H13 Tool Steel Hardness Characteristics

1. Introduction

H13 is a chromium-molybdenum-vanadium hot-work tool steel, widely classified as a Group H steel by the AISI (American Iron and Steel Institute) system. It is a medium-alloy, air-hardening steel renowned for its excellent combination of red hardness, toughness, and resistance to thermal fatigue. These properties make H13 a preferred material for a variety of demanding hot-work applications, including die-casting dies, plastic-injection-mold tooling, forging dies, and extrusion tooling. Understanding and controlling the hardness of H13 steel through appropriate heat treatment is critical to optimizing tool performance and service life.

2. Definition and Measurement of Hardness

Hardness is a fundamental mechanical property of materials, defined as their resistance to localized plastic deformation, such as indentation or scratching. For tool steels like H13, hardness is a key indicator of wear resistance and strength. Common scales used to quantify hardness include Brinell (HB), Rockwell (HRC), and Vickers (HV). The choice of scale often depends on the material's hardness level and the specific testing requirements.

3. Hardness Characteristics of H13 Steel in Various Conditions

The hardness of H13 tool steel is highly dependent on its metallurgical condition, which is primarily controlled by heat treatment processes.

3.1. Annealed Condition

In its fully annealed state, H13 steel exhibits its lowest hardness, facilitating machinability. The typical maximum hardness in the annealed condition is approximately 220 HB (Brinell Hardness). This soft condition is essential for shaping and preparing the tool before the hardening process.

3.2. As-Quenched Hardness

After austenitizing (heating to a high temperature to form austenite) and subsequent quenching (rapid cooling), H13 develops a significantly higher hardness.

- For a standard 1-inch (25mm) cube, air-cooled from the austenitizing temperature, the as-quenched hardness is typically around **53 HRC (Rockwell C Hardness)**.
- The as-quenched hardness is influenced by section size. Larger sections, such as a 330 mm (13 in.) diameter bar air-cooled from 1010 °C (1850 °F), may exhibit a lower as-quenched hardness, around **45 HRC**, due to slower cooling rates in the core.

- Higher austenitizing temperatures generally lead to increased carbon dissolution in the austenite, resulting in higher as-quenched hardness, particularly in smaller sections that cool rapidly.
- Conversely, slower cooling of heavy sections can lead to the formation of bainitic structures, which have a lower as-quenched hardness that is less sensitive to variations in austenitizing temperature.
- H13 is characterized by its deep hardening capability, meaning it can achieve significant hardness throughout its cross-section even with air quenching. It can typically through-harden up to approximately a 2.5-inch (63.5 mm) diameter or a 1.5-inch (38.1 mm) square cross-section.

3.3. Tempered Hardness

The final working hardness and desired mechanical properties of H13 are achieved through tempering, a heat treatment process conducted after quenching.

- H13 is a secondary hardening steel. This means it achieves optimal properties, including hardness and toughness, when tempered at relatively high temperatures, typically above **510 °C (950 °F)**. This high tempering range also provides substantial stress relief and enhances microstructural stability, crucial for high-temperature service.
- Tempering curves for H13 generally show a decrease in hardness with increasing tempering temperature. However, a secondary hardening peak is often observed around **540 °C (1000 °F)**, attributed to the precipitation of fine, coherent vanadium-rich MC (metal carbide) carbides.
- Double tempering is generally recommended for H13 to ensure complete transformation of retained austenite and to achieve a more uniform and stable microstructure.
- The achievable tempered hardness range for H13 is broad, typically from **38 HRC to 57 HRC**.
- The selection of the tempering temperature is critical and must be based on the required balance of hardness, toughness, and thermal stability for the specific application, not solely on achieving a target hardness value. Tempering at approximately **500°C (930°F)** is often avoided due to the resultant combination of very high hardness and consequently low toughness.
- Insufficient tempering (short times or low temperatures) can lead to excessive hardness and brittleness, increasing the risk of premature tool failure or cracking.

4. Application-Specific Tempered Hardness Ranges

The optimal working hardness for H13 varies depending on the specific application:

- **General Die Casting Dies:** 42–52 HRC (A preferred hardness for

general-purpose aluminum die casting is 47 HRC).
- **Die Casting Inserts, Cores, Slides:** 46–52 HRC.
- **Die Casting Plungers:** 46–50 HRC.
- **Die Casting Shot Sleeves:** 44–48 HRC.
- **Die Casting Nozzles:** 32–42 HRC.
- **Optimal Working Hardness for Die Casting Tooling:** 44–48 HRC.
- **Tooling Requiring High Shock Resistance:** 40–44 HRC.
- **Forging Dies (Hammers/Mechanical Presses):** Typically heat-treated to the highest possible hardness that retains adequate toughness for wear resistance. Hardness can range from **47 HRC to 56 HRC**. For forgings of minimum severity, 53–56 HRC is used; for maximum severity, 47–49 HRC. A common range for H-series forging dies is 45–52 HRC to enhance abrasive wear resistance.
- **Extrusion Punches and Dies:** 48–52 HRC.
- **Plastic Mold Applications (especially ESR refined grades requiring high polish):** Often used at hardness levels around **40 HRC or higher**. For some mold applications, hardened and tempered H13 can be in the **48–54 HRC** or **54–56 HRC** range. Surface treatments like nitriding are often employed for enhanced wear and polish characteristics.

5. Surface Treatments for Enhanced Hardness

H13 steel can undergo various surface treatments to significantly increase its surface hardness, thereby improving wear resistance while maintaining core toughness.

5.1. Nitriding
Nitriding is a thermochemical case-hardening process that diffuses nitrogen into the surface of the steel.

- H13 is well-suited for nitriding due to its chromium content, which facilitates the formation of hard alloy nitrides.
- Maximum surface hardness after nitriding can approach **1100 HV (Vickers Hardness)**, which is equivalent to over **70 HRC**.
- The typical nitrided layer thickness ranges from **0.1 mm to 0.3 mm**.
- This combination of a tough core (often tempered to around 45 HRC) and an extremely hard nitrided case provides excellent performance in hot wear applications such as forging and extrusion dies. The high tempering resistance of H13 allows nitriding to be performed without significant loss of core hardness.

5.2. Boriding
Boriding, or boronizing, is another thermochemical surface hardening process involving the diffusion of boron atoms into the steel surface.

- Borided AISI H13 die steel can achieve a microhardness of approximately **1800**

HV. This is substantially higher than the hardness of conventionally hardened and tempered H13 (typically 540-600 HV) or even nitrided steels (650-1700 HV).

6. Microstructural Contributions to Hardness and Wear Resistance

The high wear resistance of heat-treated H13 steel is derived from two primary microstructural features:

- **Hard Martensitic Matrix:** The quenching process transforms the austenite into a hard martensitic structure, which forms the bulk of the steel's matrix.
- **Hard Alloy Carbides:** H13 contains strong carbide-forming elements such as chromium (Cr), molybdenum (Mo), and vanadium (V). During austenitizing, some carbides dissolve, but a portion of undissolved alloy carbides remains. During tempering, fine secondary carbides precipitate. The primary types of carbides contributing to hardness and wear resistance in H13 are:
    - **Vanadium-rich MC carbides:** These are extremely hard (approximately 84 HRC) and play a crucial role in secondary hardening and wear resistance.
    - **Molybdenum-rich M$_{6}$C carbides.**
    - Chromium-rich M${23}C{6}$ carbides.
      The type, size, distribution, and volume fraction of these carbides are critical factors influencing the overall mechanical properties of the steel.

7. Conclusion

The hardness of H13 tool steel is a critical parameter that can be precisely controlled through careful heat treatment. The selection of an appropriate heat treatment cycle, including austenitizing temperature, quenching medium and rate, and tempering temperature(s) and time(s), is paramount to achieving the optimal balance of hardness, toughness, wear resistance, and thermal stability for a given application. Proper control over these parameters is essential to maximize tool life and prevent premature failures in demanding hot-work environments.

Aobo Steel
www.aobosteel.com
sales@aobosteel.com

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