Technical Overview of H13 Hot-Work Tool Steel

Introduction

H13 tool steel is a versatile chromium-molybdenum-vanadium hot-work steel, widely recognized for its excellent combination of high toughness, wear resistance, and red hardness. Classified within the H-series (Hot-Work) group according to AISI standards, it is also known as DIN 1.2344 or JIS SKD61. H13 exhibits exceptional resistance to thermal fatigue and can withstand prolonged exposure to elevated temperatures, making it a preferred material for demanding tooling applications. Its air-hardening capability allows for minimal distortion during heat treatment, a significant advantage for complex die geometries. Furthermore, H13 can be heat-treated to achieve ultrahigh-strength levels (yield strength > 1380 MPa / 200 ksi).

Chemical Composition

The nominal chemical composition of H13 tool steel is carefully balanced to achieve its desired properties. Typical ranges are as follows:

- **Carbon (C):** 0.35% - 0.45%
- **Chromium (Cr):** 4.75% - 5.50%
- **Molybdenum (Mo):** 1.10% - 1.75%
- **Vanadium (V):** 0.80% - 1.20%
- **Silicon (Si):** 0.80% - 1.25%
- **Manganese (Mn):** 0.20% - 0.60%
- **Phosphorus (P):** ≤ 0.030% (Control is critical)
- **Sulfur (S):** ≤ 0.030% (Control is critical)
- *Note: Small amounts of Copper (Cu) may sometimes be present.*

The relatively high chromium content imparts hardenability and resistance to softening at high temperatures. Molybdenum further enhances hardenability and hot strength. Vanadium contributes significantly to wear resistance through the formation of hard vanadium carbides and helps maintain fine grain size during heat treatment.

Microstructure

In the annealed condition, H13 typically exhibits a microstructure of ferrite and spheroidized carbides. After proper hardening and tempering, the microstructure consists primarily of tempered martensite with a fine, uniform dispersion of alloy carbides. Key carbide types precipitating during tempering include:

- **MC:** Vanadium-rich carbides, typically < 200 nm, contributing significantly to wear resistance and secondary hardening.
- **M6C:** Molybdenum-rich carbides.
- **M23C6:** Chromium-rich carbides, generally larger (> 200 nm).

Microstructural homogeneity is crucial for optimizing toughness. Ingot solidification can lead to segregation, potentially forming bands of eutectic carbides. Inhomogeneous distribution of vanadium carbides can slightly reduce toughness compared to similar grades like H11 Mod. Minimizing impurities like phosphorus and sulfur is essential to prevent intergranular embrittlement. Non-metallic inclusions can act as stress risers, negatively impacting fatigue life and toughness. Production methods like Electro-Slag Remelting (ESR) or Vacuum Arc Remelting (VAR) are often employed to enhance microcleanliness and structural homogeneity for critical applications.

Heat Treatment

H13 is an air-hardening steel, simplifying the hardening process and minimizing distortion and residual stresses, especially in large sections.

- **Annealing:** To achieve maximum softness (approx. 220 HB max), heat uniformly to 870°C - 900°C (1600°F - 1650°F), soak thoroughly, and cool slowly in the furnace (e.g., 15-20°C/hr or 30-40°F/hr) down to about 600°C (1110°F), followed by air cooling. An isothermal anneal involves heating to 880°C (1615°F), cooling to and holding at 750°C (1380°F), then controlled cooling for a granular pearlite structure (192-235 HBW). Protective atmospheres (neutral salt, vacuum, controlled atmosphere) are recommended to prevent decarburization.
- **Stress Relieving:** For annealed material, heat to 650°C - 675°C (1200°F - 1250°F), soak for 1-2 hours, and cool slowly. For hardened material, stress relieve at a temperature approximately 25°C (50°F) below the final tempering temperature.
- **Hardening:** Preheat thoroughly, typically in two stages (e.g., 650°C/1200°F then 850°C/1560°F). Austenitize by heating uniformly to 1010°C - 1050°C (1850°F - 1920°F). Soaking time is typically 20-45 minutes once the steel reaches temperature. Quench in still air, forced air/gas, or oil (for smaller sections or maximum hardness). Aim for an as-quenched hardness of 50-54 HRC.
- **Tempering:** Temper immediately after quenching, while the steel is still warm (around 50°C/125°F). H13 exhibits secondary hardening, with peak hardness often achieved around 510°C - 540°C (950°F - 1000°F). Tempering is typically performed at higher temperatures, 540°C - 650°C (1000°F - 1200°F), depending on the desired balance of hardness and toughness. Double tempering is strongly recommended (minimum 2 hours per temper). Avoid tempering in the range of

425°C - 525°C (800°F - 975°F) due to potential temper embrittlement, which reduces toughness. High tempering temperatures provide significant stress relief and dimensional stability.

Mechanical Properties

H13 offers a good balance of strength, hardness, and toughness, particularly at elevated temperatures. Properties are highly dependent on the tempering temperature.

- **Hardness:** Typically tempered to 42-54 HRC for hot-work applications.
- **Strength:** Can achieve tensile strengths exceeding 2070 MPa (300 ksi) when tempered for maximum hardness, though typically used in the 1380-1800 MPa (200-260 ksi) tensile strength range.
- **Toughness:** Possesses good impact strength and fracture toughness, although slightly lower than H11 Mod due to higher vanadium content. Toughness generally increases with higher tempering temperatures (at the expense of hardness and strength). ESR/VAR processing significantly improves toughness.
- **Wear Resistance:** Excellent resistance to abrasive wear due to the presence of hard vanadium carbides.
- **Red Hardness:** Retains substantial hardness and strength at elevated operating temperatures.
- **Thermal Fatigue Resistance:** Exhibits very good resistance to heat checking and cracking caused by cyclic heating and cooling.

Typical Room Temperature Longitudinal Properties (Example Data):

Tempering Temp.	Tensile Strength	Yield Strength (0.2%)	Elongation	Red. of Area	Charpy V-Notch	Hardness
540°C (1000°F)	~2010 MPa (291 ksi)	~1675 MPa (243 ksi)	~9.6%	~30.6%	~21 J (15.5 ft·lb)	~56 HRC
595°C (1100°F)	~1540 MPa (223 ksi)	~1320 MPa (192 ksi)	~13.1%	~39.3%	~31 J (23.0 ft·lb)	~45 HRC
650°C (1200°F)	~1275 MPa (185 ksi)	~1100 MPa (160 ksi)	~15.0%	~45.0%	~40 J (30.0 ft·lb)	~40 HRC

(Note: These are typical values and can vary based on specific heat treatment, section size, and production route.)

Physical Properties

- **Density:** Approx. 7.80 g/cm³ (0.282 lb/in³)
- **Coefficient of Thermal Expansion:** Approx. 12.4 µm/m·°C (6.9 µin/in·°F) in the range 20-425°C (68-800°F)
- **Thermal Conductivity:** Moderate; decreases slightly with increasing temperature.
- **Modulus of Elasticity:** Approx. 210 GPa (30.5×10^6 psi)

Fabrication

- **Machinability:** Fair in the annealed condition (approx. 70% of 1% carbon steel). Machining becomes difficult after hardening.
- **Weldability:** Considered weldable using appropriate procedures, typically involving preheating and post-weld heat treatment (PWHT) similar to the original tempering cycle. H13 filler materials are recommended.
- **Surface Treatments:** Readily accepts surface treatments like nitriding (gas or plasma) after final heat treatment. Nitriding significantly increases surface hardness (>1000 HV / >70 HRC equivalent) and wear resistance without substantially affecting core properties due to H13's high tempering resistance. This is advantageous for applications involving severe wear, such as extrusion dies.

Applications

H13 is extensively used in applications requiring high strength and resistance to thermal shock and softening at elevated temperatures:

- **Die Casting:** Dies for aluminum, magnesium, and zinc alloys.
- **Extrusion:** Dies and tooling for aluminum and brass extrusion.
- **Forging:** Hot forging dies, punches, inserts.
- **Plastic Molding:** Injection molds, compression molds, particularly for abrasive or high-temperature plastics.
- **Other Tooling:** Mandrels, cores, die holders, shear blades for hot work.
- **Structural Components:** Historically used in aerospace, though often superseded by materials with higher fracture toughness for critical structural parts.

Conclusion

H13 tool steel remains a cornerstone material for hot-work tooling due to its well-balanced properties, including high hot strength, excellent toughness, good wear resistance, and superior thermal fatigue resistance. Its air-hardening nature simplifies heat treatment and enhances dimensional stability. Proper heat treatment and consideration of production methods (such as ESR/VAR for improved cleanliness and toughness) are critical to realizing the full potential of this versatile grade for demanding industrial applications.

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