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Mechanical Property Enhancement of Tool Steel for Solid Expandable Tubular Mandrels

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INTRODUCTION & AIM

- Solid Expandable Tubular (SET) technology enables *in-situ cold expansion* of downhole tubulars for diameter restoration, zonal isolation, and well life extension.
- The **expansion mandrel**—a conical steel tool—undergoes severe wear, compressive, and frictional stresses during expansion.
- **D6 tool steel** was selected for the mandrel due to its:
  - High wear and abrasion resistance.
  - Excellent dimensional stability and compressive strength.
  - Capability for tailored heat treatment and through-hardening.
- **Aim:** To determine the **optimum heat treatment sequence** (annealing, quenching, tempering) that maximizes hardness, strength, and ductility of D6 steel for SET mandrel applications.

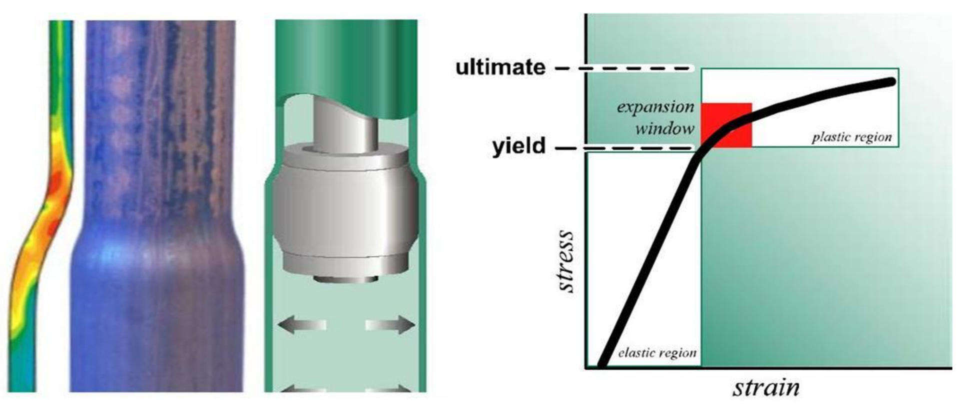

Figure-1 Schematic diagram and principle of tubular expansion using a conical mandrel

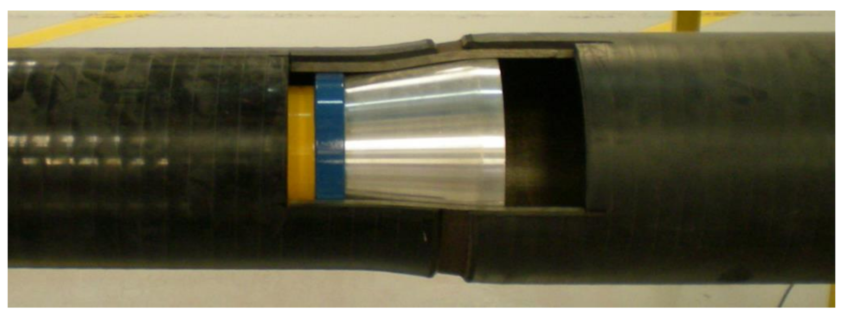

Figure-2 Cutaway section showing expansion cone (mandrel) and aligner

Figure-3 Solid expandable tubular test rig at Sultan Qaboos University, Muscat

METHOD

- D6 tool steel samples subjected to:
  - **Annealing** → **Austenitizing** → **Air (A)** or **Oil (O)** quenching → **Single (T)** or **Double (TT)** tempering.
- Six tempering temperatures investigated: **100°C–600°C.**
- Mechanical tests performed to **ASTM standards:**
  - Rockwell hardness (HRC).
  - Charpy V-notch impact toughness.
  - Tensile testing for yield and ultimate strength.

Microstructure and fractography studied via optical and SEM analysis to relate structure to properties.

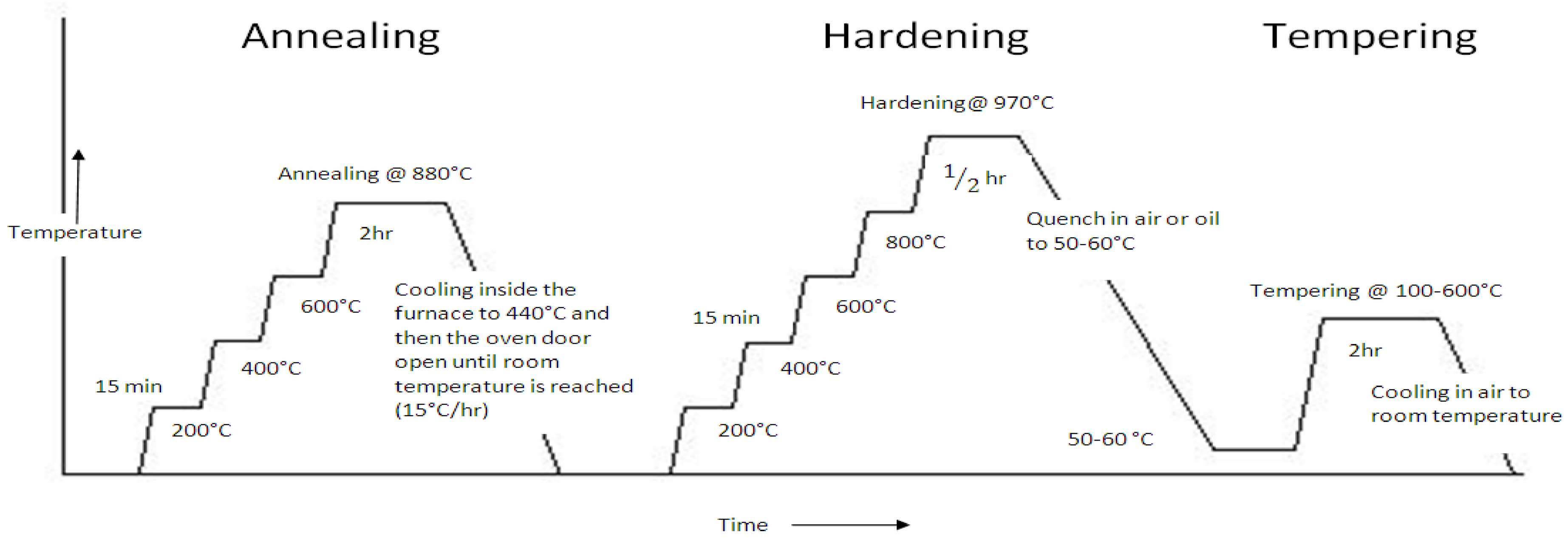

Figure-4 Graphic illustration of the heat treatment process

RESULTS & DISCUSSION

- **Single tempering** led to variable hardness and lower strength due to retained austenite and incomplete stress relief.
- **Double tempering (DT)** improved property uniformity and secondary hardening.
- **Oil-quenched double tempered (DTO, 400°C):**
  - Highest hardness: **57 HRC**.
  - Adequate strength but lower ductility.
- **Air-quenched double tempered (DTA, 400°C):**
  - Slightly lower hardness: **52 HRC**.
  - Superior tensile and yield strengths with better ductility.
- **Microstructural findings:**
  - Fine tempered martensite with reduced retained austenite at 400°C.
  - Improved carbide distribution promoting toughness and wear resistance.

Overall: DTA-400°C provides optimal balance between hardness, strength, and ductility—ideal for repeated mandrel expansion cycles.

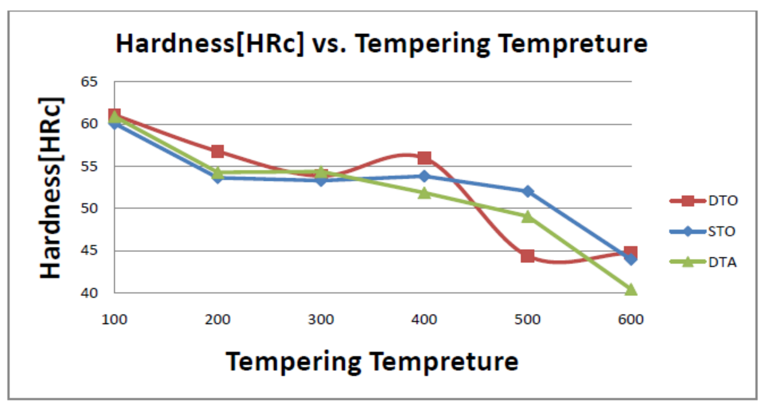

Figure-5 Variation of hardness against tempering temperature for different heat treatments

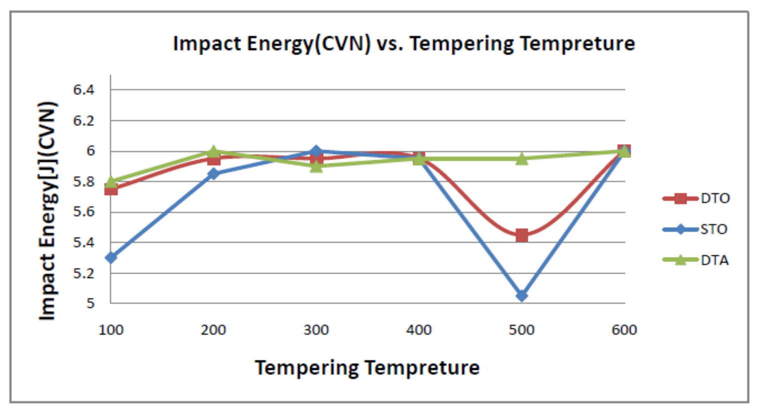

Figure-6 Variation of impact toughness against tempering temperature for different heat treatments

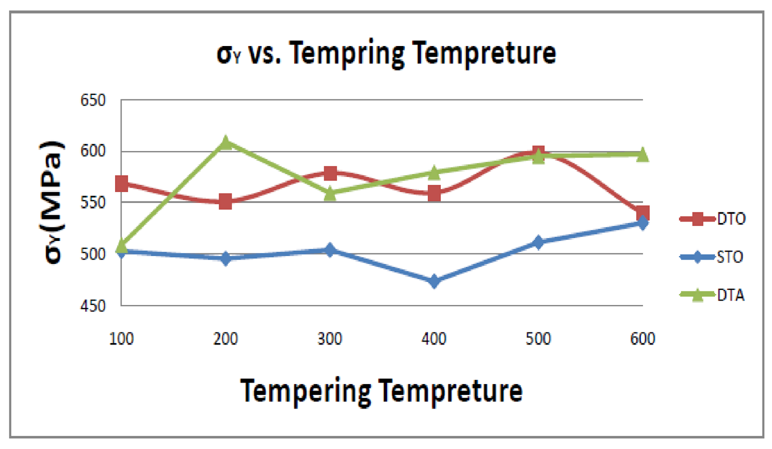

Figure-7 Variation of yield strength against temperi temperature for different heat treatments

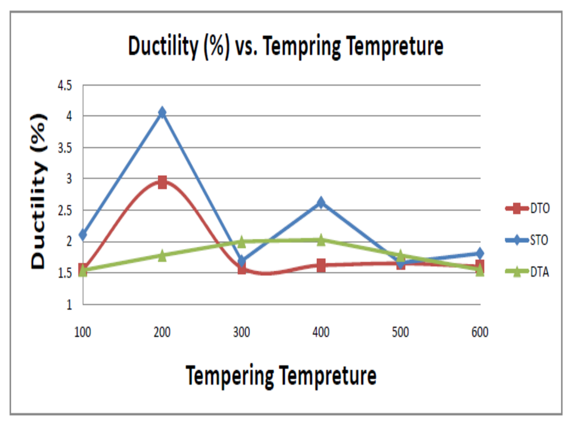

Figure-8 Variation of ductility against tempering temperature for different heat treatments

CONCLUSION

- Heat treatment significantly influences the mechanical response of D6 tool steel for SET applications.
- **Double tempering** enhances structural stability and mechanical uniformity.
- **Optimal condition:** Air-quenched, double tempered at **400°C (DTA-400)**.

Recommended for **longer mandrel life, better dimensional control**, and **improved expansion reliability** in oilfield environments.

FUTURE WORK

- Evaluate **wear and frictional behavior** of treated samples under simulated downhole expansion conditions.
- Perform **finite element analysis (FEA)** of mandrel stress–strain behavior using experimentally determined material data.
- Investigate **surface engineering** options (e.g., nitriding, PVD coatings) to enhance wear and corrosion resistance.
- Extend study to **alternative tool steels** (e.g., D2, H13) for comparative performance mapping in SET tools.