Heat Treating Steel

By Ken Brunskill

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TECHNICAL TALK AND TOUR SUMMARY FOR DECEMBER 2003

This month the speaker was our President, Ken Brunskill who discussed heat-treating steel in the home work shop. Ken also arranged a tour of Edwards Heat Treating prior to the meeting so we could see the actual process as done by professionals. We were introduced to Bill Edwards who is third generation in the family business.

The reasons for heat-treating include:

- To increase the hardness of a material,
- To soften a material,
- To relieve internal stresses so material can be machined without warpage, and
- To improve the physical properties of a material.

At Edwards, heat-treating is done by heating or cooling depending on the material and the desired outcome. Ken focused his talk on the hardening of steel. He pointed out that steel is unique among the common engineering metals. Properly hardened steel can cut soft steel. The commercial value of this phenomenon is inestimable.

What happens to the steel when it is heat-treated for hardening?

There are three steps in hardening steel.

1) Heating the steel part to a high temperature, 1350 to 1650 °F, and holding it there until uniformly heated throughout. At this critical point, the iron in the steel dissolves the carbon and alloying metals. The resulting solid solution is austenite. The heating must be rapid, but not at so high a temperature as to cause surface deterioration and excessive warpage.

2) Hardening by quenching the part in oil, water, or air to induce the formation of martensite, which is the hardest microconstituent of steel.

3) Tempering by re-heating the part to a temperature below the critical range to obtain the desired hardness and toughness.

Which steels can be hardened for cutting purposes?

- High Carbon steels (01, 06, A2, D2, W1, etc) can be heat-treated to make a tool that will cut mild steels. Low Carbon steels or "mild steels" (1010, 1018) cannot be heat-treated to make a cutting tool.

Commonly used tool steels

- 01 Tool Steel – Oil Hardening, Good for Punches & Dies, Cams, Rollers.
- 06 Tool Steel – Oil Hardening, Same as 01 except it is free machining.
- S7 Tool Steel – Presumed to be more durable, uses would include Chisels, Punches, etc.
- A2 Tool Steel – Air Hardening, Excellent wear and abrasion resistance. Ideal for punches and dies. Holds dimensional accuracy during heat-treating.
- W1 Tool Steel -- Water Hardening, Readily obtained and easy to work in the home shop
- 4140 & 4340 Alloy Steels– These are not considered tool steels, but are good tough duty steels for leaf springs, and heavy wear applications.

- 4XX Series Stainless Steels – Medium corrosion resistance, toughness, etc..

How to Determine a Steel Alloy

Bill Edwards told us that a common source of trouble in obtaining good results is failure on part of the customer to know what type of steel was used to make the part. Since the critical point of the various alloys is different one can immediately see the problem.

- The simplest method is to keep the steel marked as purchased! The usual marking code is: W1-Red, O1-Yellow, and A2-Blue.

- A spark test can be made by grinding the sample metal under test and comparing the resultant sparks to that produced by a known alloy. Ken demonstrated the technique using various alloys. The spark pattern showed distinctions, such as, multiple bursts, spark shooting backwards, and degree of sparkling. If no sample is available, refer to reference books for a description of the sparks made by various alloys.

Preparation of Tool Steel Prior to Machining

Another impediment to getting a sound part after heat-treating is not removing enough of the scale and deteriorated surface metal before machining the part. Bill Edwards showed us several examples of parts that failed during heat-treating or shortly after being put into service because the machined surface was not free of scale.

Part Design Considerations

Certain design features can assure a successful heat-treatment of a part. For example, make certain that intersecting planes meet at a generous fillet. Avoid sharp inside corners that can be a starting point for cracks. Dill holes well away from the corners of part. Avoid drilling holes on a diagonal that passes through the opposite corners an inside square. Where possible, maintain a uniform part cross-section.

Home Shop Heat Treating

Right off Ken recommended the services of a professional heat treating shop for tools that are going to see continued, industrial service. However, for small tools used occasionally, such as D bits, simple milling cutters, punches, and the like, a home method is fine. The amateur toolmaker is urged to use the technical references listed for a complete, step-by-step description. Here are some pointers:

<u>Heating to Critical Temperature</u>

- Slow heating – Need to heat the part thoroughly.

- Flame control – Keep it off of the part, direct flame will cause excessive scale.

- Soaking for uniform heat – Allow the interior of the part to come up to temperature. Look up the critical temperature to be reached for the particular alloy being used. Assuming the critical temperature and the Curie point of a metal is the same, bring the heated piece near a hanging magnet. If the part has reached its critical temperature, the part will exhibit no magnetic properties and the magnet will not move or turn toward the part.

- Scale caused by oxygen getting to the surface and decarburizing the steel is the cause of part surface failure.. At Edwards, the ovens were flushed with either a reducing or inert gas during a heat run to prevent surface deterioration.

Quenching to Harden

Whether using water or oil, use plenty of it to assure the part doesn't overheat the liquid. If cooling in air, avoid non-uniform air currents.

- For W1 use clean water

- For O1, O6, and similar alloys, use oil. Special quenching oil is not critical, quantity is more important. Ordinary vegetable oil is recommend. Motor oils work, but the additives leave a residue that is hard to remove. Further, if the kitchen oven is used for tempering, the smell might spell the end of your heat-treating career.

  Continuous movement of the part in the liquid quenching medium is important. Insert the part so the cooling is uniform to minimize warpage

- For A2 hang the part in still air.

Tempering the Part.

After quenching, the part is at its maximum hardness and is very brittle. Except for scrapers, the part is unusable in this state. Re-heating the part reduces the hardness, but in return ductility and toughness are increased. Tempering even a little bit relieves stress and toughens the part.

- Make sure part has cooled completely from hardening. Must be able to hold it in your hand..

- Polish or grind off scale, if present, to expose a clean bright surface. Upon heating for tempering, this surface will develop an oxide coating whose thickness will assume various colors as the temperature increases. By observing these colors, a rough approximation of the tempering temperature can be had. Obviously, the use of a calibrated oven considerably improves the accuracy of this step.

- When the part has reached its tempering temperature it is removed form the heat and quenched in the same type of medium used for hardening.

References

1. *Heat-Treating Steel- An Amateur's View* by Randolph Constantine, HOME SHOP MACHINIST, Nov/Dec 2003, Pg. 50

2. *Decalescence Versus Cherry Red in Heat-Treating* by Robert T. Wright, LIVE STEAM, March 1979, Pg. 40

3. *Hardening, Tempering and Heat-Treating* by Tubal Cain, Nexus Special Interest Books (see ad in Model Engineer)

4. *Tool Engineer's Handbook* F. W. Wilson Editor-In-Chief, McGraw-Hill Book Company, Inc. 1949, 6th Printing 1954

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Technical Summary by Stephen Vitkovits