Steel Basics — Where Do Steel Properties Come From?

The properties of the steel materials we machine in our shops are the result of a complex interplay between chemical composition, developed by hot and cold work, and further controlled by various thermal treatments to develop microstructures.

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The definitions provided here are to facilitate understanding by shop practitioners, not to cover every subtle aspect of the concept.

Hardness is resistance to penetration**.** (Some folks would say resistance to abrasion but in the steel industry we test for hardness using penetration tests like Brinell, Rockwell and Vickers)

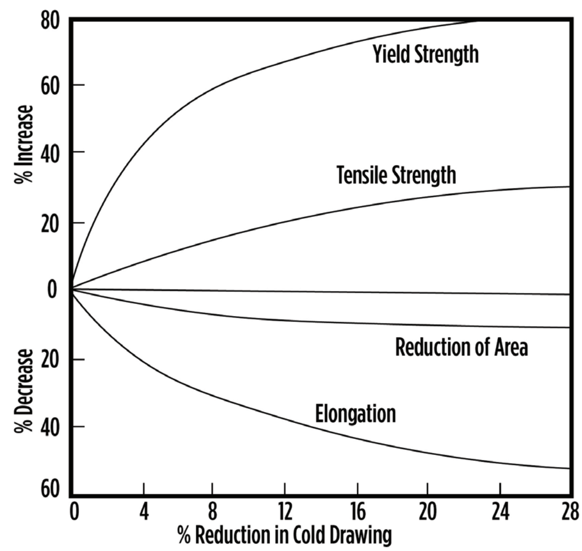
Toughness is a measure of how much force the steel can withstand without fracturing — it is measured by Charpy or Izod Impact Tests which are described in ASTM Standards.

Tensile Strength is how much force is required to break a single piece of material under tension.

Yield Strength is how much force the material can withstand before permanently deforming. (In steel, we use 0.2 % of the unstressed length as the determining deformation.)

Ductility is a measure of how much tensile stress a material can withstand without breaking. The % elongation in 2” or 8” is the most common measure used in commercial practice for metals for our shops.

Steel’s properties are potentiated by its chemical composition. At the time it is first cast (solidified) the amount of carbon and other chemical elements making up the steel give it the potential to develop further mechanical properties through further processing to change its microstructure. Carbon is the greatest influencer of the properties and microstructure attainable by the steel.



Hot working is a process where the material is plastically deformed (shaped) at very high temperatures. This process alters the grain structure and alignment as well as dimensions of the product.

The as-cast steel is composed of a coarse dendritic structure. By hot working, this structure can be broken up into a finer more uniform grain size as a result of the mechanical work and subsequent return to ambient temperature which improves ductility most of all.

Cold Drawing/ Cold Working is a process where the material is strengthened by plastic deformation (shaping) at ambient temperatures. This process is also called work hardening. Cold drawing involves pulling bars through dies to reduce their size, thus imparting cold work and changing size.

Drawing at ambient temperature raises the yield strength substantially, the tensile strength somewhat, and decreases the ductility. This cold work does increase the steel's hardness compared to its prior hot rolled condition.

Thermal treatments

Annealing. After cold working, the steel may be too brittle or hard to be successfully further worked or processed. By heating the steel, then allowing to to slowly cool, the tensile strength, yield strength and hardness can be reduced, making the steel easier to work.

Austenitize and quench.The steel can be raised to above its austenitizing temperature, and then liquid quenched to produce a rapid transformation into another microstructure called martensite. Martensite is very hard and that hardness is solely a factor of its carbon content. Martensite is very brittle in the untempered condition.

Hardenability is a factor of the chemical make-up that determines the ability of the steel to transform to martensite. This is why I said that the chemistry "potentiates" the development of properties.

Tempering relaxes some of the internal stresses, lowering the hardness and increasing both ductility and toughness from the untempered condition. Tempering is performed by reheating the steel to relax stresses and allows some precipitation of carbides from the martensite phase.

Precipitation hardening is used to develop higher mechanical properties in stainless steels such as 17–4 pH (type 630). Because of the addition of elements like copper or columbium (niobium for all you IUPAC purists) and tantalum. By heating to different temperatures, the material can develop different properties. In Condition A, solution treated (annealed) the Charpy impact test is not even relevant because this condition is susceptible to stress corrosion cracking. In Condition H 900, precipitation or age hardened, its Charpy impact at room temperature is 16 ft-lb. At condition H 1025 the impact goes up to 40 ft-lb, at condition 1150 M, the impact strength can reach 100 ft-lbs. (Data from Carpenter Steel for Custom 630)

So "Where do steel properties come from?" The Carbon content is a necessary ingredient of any steel that enables it to develop its potential properties through various processes of hot working, cold working, annealing, quenching and tempering and precipitation hardening.

Other chemical elements play a role in developing grain size, hardenability, and other effects in the final product.

Takeaways

- Carbon is the greatest influencer of the properties attainable by the steel.
- Hot working improves the ductility of the as-cast steel.
- Cold working enhances the tensile strength, yield strength and hardness, reducing the ductility.
- Thermal treatments are used, if there is sufficient carbon, to alter microstructure, and thus the bulk mechanical properties of the steel.

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Further Reading

The Meaning of Cold Work and Steel Parts
http://bit.ly/PMPA-PM1019-1
5 Benefits of Cold Work in Steels
http://bit.ly/PMPA-PM1019-2
Cold Drawings Effect on Mechincal Properties
http://bit.ly/PMPA-PM1019-3
Ductility As Measured by Tensile Testing
http://bit.ly/PMPA-PM1019-4
Upset Testing Steel in Compression
http://bit.ly/PMPA-PM1019-5
How Plastic Deformation Makes Machining Possible
http://bit.ly/PMPA-PM1019-6
Depth of Hardness
http://bit.ly/PMPA-PM1019-7

Miles Free is the PMPA Interim Director with over 40 years of experience in the areas of manufacturing, quality, and steelmaking. He helps answer "How?, "With What?" and "Really?". Miles' blog: pmpaspeakingofprecision.com Email: mfree@pmpa.org Website: pmpa.org