It's Only Iron

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What follows is not meant to be an absolute discussion about IRON; but rather a bit of a primer on Steel often times mistakenly called Iron.

Please appreciate that the background of the writer is not as a metallurgist, and that much of what the writer has learned about steel has been learned from the "College of Hard Knox". The experiences of the writer in many cases has been extremely expensive both in monetary terms and product reputation terms.

When a Steel used in a product turns out to be less than ideal there are the costs of correcting the problem and the loss of reputation that is always attached to such a problem. In some cases even though a problem with the Steel used is corrected one may still loose future sales.

It is rare that one ever goes back to a restaurant where one has had a less than stellar experience whether it be a problem with the food or the service.

In an effort to produce the absolute best product available our Company has often been on the cutting edge in pushing the limits of the Steel / the raw material that goes into our products. This has allowed us to be a leading edge Company but our successes have not come without some product failures. As such today we are very careful as to the raw material, the building blocks that go into our products.

So let's talk about the types of Steel Plate normally available to use in building a product. Focusing on Steel Plate.

Steel Plate is characterized in three (3) broad categories:

1. Common Steel Plate,
2. High Strength Low Alloy Plate, and
3. Quenched and Tempered Steel Plate

Now, exploring each of these three broad types of Steel Plates

1. Common Steel Plate – a plate steel that no special effort goes into the making of. Common Steel Plate has no special strength or hardness characteristics. And, it is normally referred to as Hot Rolled or Merchant quality material. The Feed Stock to make this material can be almost anything the steel mill can turn into plate. Ever wonder where scrap cars go or old rusted steel machinery, well now you know. No special alloys

are used in making Common Steel Plate. The Steel Plate is simply rolled out and as long as it has at least a 35,000 psi yield strength it is good to go. There is no upper strength limit to be within specifications it only has to have a minimum yield strength of 35,000 psi. So there can be wide fluctuations in the strength of this steel plate one plate from another! No great effort is made to control any of the raw materials going into this steel plate as long as Carbon is below a certain specification, the plate will undoubtedly meet the minimum requirements for Hot Rolled plate. And, if this plate does not meet the minimum specs then the plate ends up on the secondary steel market as distressed material - off size, off chemistry, etc.

But the plate undoubtedly will still qualify as Mild Steel Hot Rolled / Common Steel Plate and who knows where it might end up.

2. High Strength Low Alloy Steel Plate – this is a type of Steel Plate that primarily gets its strength from alloys that are added in the steel making process. High Strength Low Alloy Plate is typically 50,000 psi (plus) yield strength up to 80 to 85,000 psi yield strength (92,000 to 97,000 psi tensile strength). The raw materials that go into this type of steel plate are much more controlled than what is allowed in Common Steel Plate. Though the High Strength Low Alloy plate is stronger than Common Steel Plate, it is still fairly soft material.

To Digress For A Moment With an Explanation of Some Steel Terms

At this point it might be good to discuss what the Yield Strength and Tensile Strength of Steel means, along with the Brinell Hardness of Steel and how the Brinell Hardness is determined.

The Tensile Strength and Yield Strength of steel.

The Yield Strength of steel as the name implies is the strength at which a steel sample (coupon) just starts / begins to give or “yield” as it is pulled on. And, it is the force required to achieve about a 2% elongation of the steel sample / coupon.

The Tensile Strength of steel on the other hand is the ultimate strength required to break a steel sample (coupon) at some point after the steel has yielded (2%). The Tensile Strength of steel is always greater than the yield strength of steel. The Tensile Strength of steel is typically 115% to 125% of the Yield strength of the steel being tested.

And, Brinell Hardness is directly proportional to the ultimate or Tensile Strength of steel, the higher the Tensile Strength, the higher the Brinell Hardness.

To understand how Brinell Hardness is measured, is to understand the relationship between a steel's Tensile Strength and a Steel's Brinell Hardness. The Brinell Hardness of steel is determined by applying a known force on a diamond point and measuring how far this diamond point in fact, penetrates the steel coupon / plate.

As a rough <u>rule of thumb</u> one can take the tensile strength of a steel sample times about 2.10 to 2.25 and arrive at the Brinell Hardness of that steel sample. Or, said another way divide the Brinell Hardness (which is fairly easy to measure) by 2.10 to 2.25 and one can determine the Tensile Strength of a steel sample

The Yield Strength of Steel will typically be about 85% +/- of the Tensile Strength of a piece of steel.

There is a SAE standard J417 DEC 83 / ASTM Standard E-140 (attached) which allows one to convert steel hardness to steel tensile strength.

Returning to High Strength Low Alloy Steel, the Brinell Hardness is typically no greater than 215 points of Brinell (which for all practical purposes is really fairly soft steel. Tensile Strength times 2.25 equals Brinell Hardness (95,000 Tensile Strength X 2.25 equals 215 points Brinell Hardness).

Also High Strength Low Alloy Steel typically does not go through any post processing after the steel slabs are rolled into plate. This steel plate is typically characterized as an "as rolled steel plate". However, what comes out from the plate rolling process is what one gets so the chemistry of this High Strength Low Alloy Steel must be more carefully controlled otherwise the final "as rolled strength" could be either too low or too high this steel is produced to a much tighter strength range than Hot rolled or Merchant Quality Plate.

Since High Strength Low Alloy steel plate is produced in a much more controlled manner, designers tend to utilize this type of steel in more critical applications than were one might use Hot Rolled Plate. Using this higher strength steel also allows the use of thinner steel sections, i.e. as the strength of steel goes up a resultant weight savings can be achieved.

3. Quenched and Tempered Steel Plate – the third type of steel. Quenched and Tempered Steel Plate typically has a yield strength from about 100,000 psi to over 180,000 psi with some Quenched and Tempered Steel Plate exceeding 200,000 psi yield strength. Substantially more than even High Strength Low Alloy steel plate.

   Quenched and Tempered Steel Plate gets it's strength advantage from the heat treating process plus the alloys that are added in the steel making process. As to the Tempering process if a steel mill is really good at what they do the steel plate being produced may only need to be quenched and not need tempering, in this case as the steel plate comes directly from the plate rolling process it is quenched and a finished product produced, this plate is then known as "as rolled - quenched plate" with no post tempering required for the finished product to meet final specifications.

   What is the Quenched and Temper process? This process is the same process that is used in produce chisels, punches, and drill bits.

   The Steel Quenching and Tempering Process

   a. The first step in this process consists of heating the steel plate being quenched to some temperature typically over 2000° Fahrenheit; each steel producer may have different quenching temperatures depending on the actual chemistry of the product being produced.

   b. After the steel plate has been heated to a predetermined critical temperature, the second step in this process is to quickly / rapidly quench the superheated steel plate. This quenching process can be likened to a freezing process wherein the steel plate is "Frozen" in its super critical state.

   The quenching medium is typically water though some steel producers use an oil quench.

   Part of the success in making high quality Quench and Tempered steel plate is the quenching medium and how this medium is applied. Is the critical heated steel plate immersed in the medium or is the quenching medium sprayed on to the critically heated steel plate. Typically as the critical heated steel plate leaves the plate rolling mill /plate rolling process it is clamped between platens and the quenching medium is sprayed onto both sides of the plate in the quenching process. If the plate is not held properly as it is quenched significant plate distortion can / will and does occur.

   For those steel plate producers who can critically and accurately control steel chemistry as the super heated plate is quenched, the finished quenched product can be / will be exactly on spec; this heating and quenching process then results in a finish steel plate product.

So when is steel plate tempering, to meet the required specifications of the quenched steel plate required?

A discussion relative to the amount of Carbon "C" in the steel chemistry as it relates to the maximum hardness of the quenched steel plate is pertinent. A basic concept of steel heat treating is that the higher the "C" the harder after quenching from a critical temperature that the steel will be. The percent or points of "C" in the steel chemistry is directly related to the hardness of a quenched steel plate. As a "gross rule of thumb" each point of "C" in the steel chemistry equates to approximately 20 to 25 +/- points Brinell in a quenched steel plate (dependent on many factors plate thickness, quenching process, etc.)

For those steel mills that can very accurately control the steel chemistry and in particular the "C" in the steel melt, quenching of the steel plate may be all that is required. However, for those steel mills that have difficulty maintaining a precise steel chemistry these mills typically will have a bit more "C" in their chemistry than required to guarantee achieving the minimum steel hardness needed to make spec.

In the quenching process as the super heated steel plate is quenched if the chemistry is not the exact chemistry needed to achieve a final product and more "C" is in the chemistry than needed to meet the needed hardness spec the resultant steel plate will be harder and out of spec. In this case tempering is then used to soften the over hardened steel plate to the correct final hardness spec being met.

c. It is in those steel mills that are not able to precisely control the chemistry (in particular the "C") of the steel melt versus some of the more sophisticated steel mills that a steel plate tempering process occurs.

The steel mills will put in a little more Carbon along with several other alloys in the steel melt just to insure that the steel plate when quenched will at least meet the minimum required hardness.

The end result of the steel plate quenching process then is a piece of steel plate that is often harder than required! To address this, the steel is then tempered. The tempering process is much like the original heating of the steel prior to quenching; but in this case the steel is only heated just enough to slightly soften the steel plate from its over hardened critical state.

Typical tempering temperatures can be 480° Fahrenheit to as much as 570 to 750° Fahrenheit all dependent on the chemistry of the steel and the particular steel mill. It possibly could be said that the more refined the steel making process the tighter the tempering temperature range.

As the steel plate is brought to the correct tempering temperature the steel plate softens ever so slightly to produce the specified steel. The tempering temperature is predetermined. The tempering process requires heating the previously quenched steel plate to a known temperature and letting the steel plate air cool for any post processing.

The production of Quenched and Tempered Steel Plate is clearly much more involved than producing either Hot Rolled / Merchant Quality steel plate or High Strength Low Alloy steel plate. When producing high strength heat treated steel plate, there is a lot more opportunity for production variations / quality variations to occur. Yet, at least in mobile equipment and high abrasive environments slowly but surely Quenched and Tempered Steel Plate is becoming the steel of choice.

Clearly in mobile transport equipment, the only reason for running the equipment is to move PAYLOAD? So the greater the difference between a vehicle's Tare or Empty weight and the vehicle's allowed Gross Weight the more payload that is carried!

Today, all manufacturers of Heavy Transport Equipment have embraced to varying degrees the use of higher strength quenched and tempered steel plate in their products. However, as recent as 25 years ago there was one Heavy Mobile Equipment Producer that in their equipment design would not allow any quenched and tempered steel plate to be welded to another similar piece of plate.

One of the largest USA Heavy Equipment Producers allowed some extremely promising steel plate, being introduced into the USA, to be fabricated very poorly, and at least in the USA this was the death knell for a very promising steel. A steel that in fact is being used successfully in Brazil.

Quite frankly horror stories abound about the miss application / miss fabrication of quenched and tempered steel plate, as such if using quenched and tempered steel plate their are some definite caveats to using it

Over the years the company that the writer heads has used five different sources for High Strength Quenched and Tempered Plate and today we only acquire this from one source, why?

Over our history we have used:

1. National Steel's XAR -15 plate, today this steel is being produced by Thyssen Krupp Steel. We stopped using XAR-15, in the steel consolidations of the 80's National Steel was merged and closed down, the story was the land on which the steel mill sat, near Detroit was worth more than the steel mill itself. We were successful with the XAR-15 product; however, we could plan when we formed this XAR-15 steel plate that about every tenth to twentieth plate would develop some type of crack.   We just welded these cracks up and put the material into the product.

2. Oregon Steel AR 450 - As National Steel's XAR-15 no longer became available we started to use a product from Oregon Steel. Unfortunately the results were not good. The most memorable disaster was producing two bodies for an Australian Customer, these two bodies which were shipped as prefabricated kits developed severe cracks in transport to Australia. In fact some of this Oregon Steel Material cracked sitting in our plate stock. Yes this material certainly met the hardness test but it failed the ductility test! We did not purchase any Oregon Steel Material after that. Yet today Oregon Steel probably makes a fine product; but, why chance it?

3. Algoma Steel – 450F the "F" stands for Formable which this product is; however, we stopped using this material as it has a wide 410 to 477 Brinell spread which translates into inconsistency from plate to plate. Going back to the discussion on steel plate Brinell and that Brinell is a fairly accurate indication of a piece of steels tensile strength does one really want to be using steel purchased as 450F material that could range from 208,000 tensile strength (410 Brinell) to 252,000 tensile strength (252 Brinell)? Strength, consistency is just not there with the Algoma product. And as will be touched on later this product has much lower Impact Toughness than other available quenched and tempered steels.

4. Dillidur 450V steel from Dillinger Hutte GTS is suppose to be on par with the steel we currently use. What convinced us to attempt to use this steel was that one major European Manufacturer of Heavy Mobile Transport Equipment uses this Dillinger Steel. At an equipment show the light shown just right on a truck body and even through the paint you could clearly read the Dillidur name. So if it was good enough for this leading European Manufacturer of Equipment to use then it must be good enough for us! We worked to purchase this product direct from the mill and incorporated it into both some water tanks and some truck bodies. Unfortunately for us that was a mistake. In the water tank, now granted these were 48,500 gallon water tanks, this product broke where it had not even been worked in the fabrication process i.e. welded on or formed and

the cracks were several inches away from any tank joints! In the truck bodies the pivots broke out and required fixing all at our own expense. We do not use any Dillidur 450 material today.

5. So what do we use? We exclusively use Hardox 450 in the past it was Hardox 400. All companies continually improve and refine their products and SSAB Hardox has done just that. Today SSAB is the recognized world leader in High Strength Quenched and Tempered Plate. The SSAB product is extremely consistent piece after piece. However this only comes at a price. We do however subscribe to a steel trading web site STEELBOSS.COM so that we can regularly check steel prices and see if we are paying anything other than a competitive price for the Hardox Product. From our market price checking the Hardox product is very competitively priced yes there may be a couple of cents difference; but, in the big scheme of things does this difference justifies our taking a chance on an alternative unproven product at least from our standpoint.

So what are some of the distinguishing characteristics of High Quality Quenched and Tempered Plate?

1. The Brinell Range that the steel is produced to, SSAB's Hardox 450 published specs state 425 to 475 although the internal mill target I have been told is 430 to 470 Brinell. And, from the steel certifications we get for this material the actual range is more like 440 to 460 Brinell – a true reflection of a quality driven process.

2. Impact Properties – the impact test consists of freezing a coupon of the steel to 40° Centigrade (which also happens to be 40° Fahrenheit) and letting a weight swing against the coupon and see how much energy the coupon can absorb before it breaks. SSAB 450 at 40° Centigrade absorbs 40 joules of energy.

3. Temper Temperature – SSAB Hardox tempering temperature is 250° Centigrade or 480° Fahrenheit

4. Weldability / Carbon Equivalence – which is a measure of how careful one must be in welding the steel, (is preheating or post heating required to weld on the material) there is CEV and CET. SSAB Hardox CEV is .47 and CET is .34 as long as the number is below .50 the material is fairly easily welded.

5. Fatigue Strength – Most steel producers do not test their High Strength Quenched and Tempered Plate for fatigue strength, SSAB Hardox has tested their 450 product and the fatigue strength is approximately 52,000 psi yield. In other words this steel can be repeated stressed to 52,000 psi yield and never fail. In fact if you want to know how good a steel that a

particular producer is producing ask if the steel has been tested for fatigue strength. Most steel mills never test their quenched and tempered steel plate for fatigue strength.

So how do some typical steels stack up?

Steel Type	Carbon. .75" Thick	Brinell Range	Brinell Range	Impact Properties	Weldability		Temper Temperature
					CEV	CET	
Hardox 450	.21	425-475	50	-40°C 40J	.47	.34	480°F
Dillidur 450V	.25	420-480	60	-20°C 30J	.43	.33	570-750°
Algo Tuf 450F	.21	410-477	67	-40°C 20J	.54	.50	480°F
ThyssenKrupp XAR 450	.22	410-490	80	-40°C 30J	.55	..35	480°F

As an added benefit the SSAB Hardox mill in Sweden recently underwent a major improvement and today is using some of the most modern plate rolling and processing equipment in the world. In fact the SSAB Hardox product carries a precision thickness guarantee, they call it Accurolitech! See attached SSAB Hardox data sheet on this precision thickness guarantee.

To maintain the high level of thickness consistency in product production the SSAB Hardox plate rolls are changed out at least once every shift. These rolls are then micro ground to remove any and all imperfections that might have developed in these rolls since the last roll change out.

Well the one and only common denominator of IRON / Steel is the weight per square foot, a one inch thick piece of any of these three types of steel is always going to weigh 40.84 +/- pounds per square foot!

It is only IRON?

Absolutely NOT

Again, the writer is not a metallurgist and does not claim to be rather the preceding document is drawn from a lot of practical experience. And the writer has a degree from the "College of Hard Knox" to prove it.