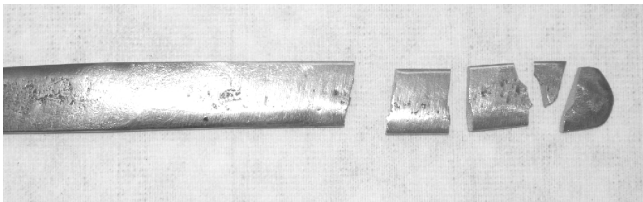


Improving Your Heat-Treating



Rediscovering the Break-Test.



by Dave Smucker

What is a Break-Test ?

The "Break Test" has been around a long, long time. The first reference I find is in discussions of the manufacture of "Blister Steel" in the 15th century.

Blister steel was made by taking the best grades of wrought iron, in the form of bars, and packing them in finely ground charcoal in a large clay box. This was then heated for 6 to 8 days at about 2000 F so that the wrought iron absorbed the carbon from the charcoal and became "steel". (Real wrought iron had almost no carbon, being almost pure iron with several percent of silicon oxide slag.) The clay boxes were about the size of a coffin and

had a small door or opening through which a sample could be removed for testing. This is kind of like testing to see if the cake is done.

The sample which, was well above the critical temperature was removed and quenched in water. It was then broken - hence the name "break test". Pure wrought iron would not break in a similar test, but would instead bend.

I have always assumed that this was just a simple test, with no tempering of the sample, just a quench followed by breaking the sample with a hammer. I also assumed that experience and judgment were then used to guess at the carbon content by looking the fracture. Carbon content could also be judged by testing the sample with a spark test on a grinding wheel. (While they didn't have modern testing methods in those days, they did have natural stone grinding wheels.)

Today I think I was wrong in assuming the test was quite this simple. Instead, I think a progressive temper was made to the sample and it was then tested by repeated breaking of the sample from least temper to most temper. This would add very little time to the testing process but give a much more meaningful test.

Mark Hopper Teaches the Break-Test at Madison

At the Southern Blacksmith Association conference this past May, Mark Hopper was one of the featured demonstrators. Mark grew up in the England and actually started blacksmith when he was 13. He learned blacksmith in a formal British training program and then worked with a number of experienced smiths. He spent four years in Kenya, in East Africa where he taught tool making.

For me one of the outstanding things that Mark demonstrated is how he was taught to perform and used the Break-Test so that you could use the proper heat-treating procedure on almost "any" steel useful for tools. This test is very very useful for a steel that is a "NTS" (Not too Sure what it is steel) but is also very useful to just learn about the best way to heat treat and temper a know steel. It is especially useful to gain experience and confidence in heat-treating and to solve problems you might run into.

Mark taught this test in his 4 years in Kenya where almost 100 percent of the steel used for making tools is material salvaged from junked autos or other industrial scrap.

The Break-Test is for Known as well as Unknown Steels.

The Break-Test is very useful to you even if you know what steel you are using because it lets you do a test heat-treat. Just as you might make a test piece when working out a design the Break-Test is useful for testing a steel even if you know for sure what it is. If you don't know, the steel except by viewing grinder sparks or the kind of thing it came from then the Break-Test is really useful.

It is also a great tool for teaching you how various steel react to heat-treating. It will help you understand if they will be brittle or tough, will you have trouble with cracking etc.

A Quick Review of Heat-Treating Steel.

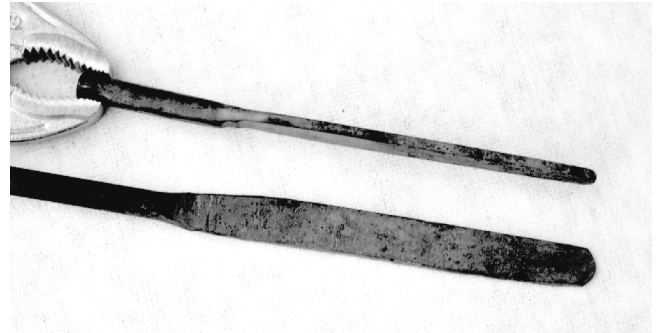
When we heat-treat a steel that contains enough carbon, we are able to change its hardness, strength and toughness. Alloying elements may also help us in this process. It is always some form of a compromise to get the things we desire in the finished product. For example, we can make it very hard, but it will be quite brittle and lack toughness. These and other factors are controlled by carbon content, alloy content, manufacturing history and how we heat-treat the item.

In simple terms, we heat treat by:

- 1.) Heating the steel to above its transformation or critical temperature
- 2.) Quenching the steel, making it very hard but very brittle.
- 3.) Tempering the steel by reheating it to a lower temperature, reducing some hardness but making it less brittle and much tougher.

OK Enough History & Introduction: Just how do you DO a Break-Test anyway?

Step 1.) Forge the stock down to a good working size for the test. I find that you want a flat bar about 1/8 inch thick by about 1/2 to 5/8 inch wide. (A larger cross section may be too hard to break especially in high strength steels.) You will need a working length of about 5 to 6 inches - plus enough additional material to hold for heat treating, quenching and tempering. Extra material on the "handle" end doesn't hurt but isn't necessary.



Here is an example of some typical test pieces after rough forging.

Step 2.) Normalize your test piece. What do you mean "Normalize"? Heat your material to above the critical point - for many steels this is just a little hotter than the point at which it becomes non-magnetic - then set it aside on the coal on the edge of your forge and let it slowly air cool. (If using a gas forge just set it on a firebrick.) This step helps relieve stress in the steel and can give you a smaller grain size.

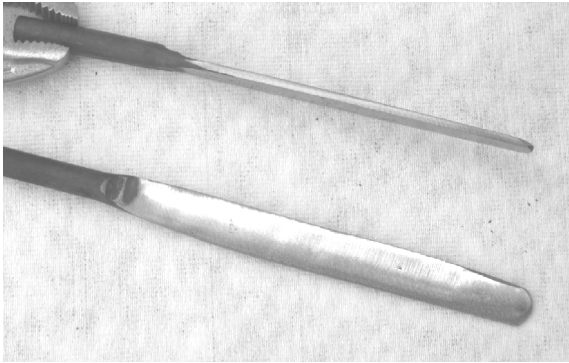
Now Do a File Test

By the way, you can do a little test here and see how hard your sample is. Check it with a file - if shows hardness you very likely will have a good "tool" material. This in itself is not a test for "air hardening steel" because many alloy steels will show quite a bit of hardness when cooled this way if they are of a small enough cross section. This is because they cool quite fast even in still air.

If it is a water-hardening steel, you will still cut it without too much trouble with a new sharp file. If it is an alloy steel with mid range carbon content it will be so hard that while it will still cut with a file it will not be easy. If it is an air hardening

steel it will be so hard at this point a file can't tough it.

Step 3.) Clean up your test piece so that you have a good surface finish. I use a 4 1/2 inch angle grinder for this. Mark Hopper did such a fine job of forging his test piece that he had an almost polished piece coming of the anvil. I have to grind mine.



Test Pieces after clean up with grinder.

Shop Tip. An easy way to hold the test pieces for clean up is to put a welding magnetic holder in your vise jaws. You can then lay flat surface of the test piece on the magnet for grinding. Then flip and do the other side.

Step 4.) Slowly heat the cleaned up test piece. You don't need a very hot, high draft, fire for this. Take it easy. (I think this is one of the major place folks have trouble with cracking in their heat-treating - they heat too fast. This is especially true for W1 or O1 steel. I have been able to reproduce longitudinal crack in W1 drill rod with very rapid heating.) Heat your test piece to a little above the critical temperature. As note above, for most steels this just above the point at which the steel become non-magnetic. If you know that you have a high alloy tool steel such as S7 or H13 then you will need to go to higher temperature for it to be above the critical temperature. Read the article on Heat Treating Tool Steels for more information.

Step 5.) Quench - the 6 inches - of the test piece in water. Keep it moving all of the time, draw a figure 8 in the water, give it some up a down motion too.

Mark Hopper only quenches the test end and then uses the retained heat in the rest of his sample to provide heat for tempering. You can do this too if you know how but I suggest that for you

first attempts at the Break-Test that you completely cool your test piece and use a torch for tempering. See Step 7 below.

What are Temper Colors? Why do they form on steel?

When we heat steel that has a machined, ground or polished surface to temperatures between 400 degrees F and 650 degrees F the surface will take on various colors from a very pale yellow to purple to even a dark blue. These colors are caused by a thin layer of transparent oxide forming on the surface of the steel. Because of the nature of reflected light, we see this as different colors based on the thickness of the oxide layer. This turns out to be very useful to Blacksmiths for judging tempering temperatures. It does take some experience to judge the color but it is a very useful skill. Below are listed a description of the color and temperatures as listed in *Machinery's Handbook*.

Pale yellow	420F
Light yellow	440F
Pale straw yellow	450F
Straw yellow	460F
Deep straw-yellow	470F
Dark Yellow	480F
Yellow Brown	490F
Brown Yellow	500F
Spotted red-brown	510F
Brown-purple	520F
Light purple	530F
Full purple	540F
Dark purple	550F
Full blue	560F
Dark blue	570F
Light blue	640F
Steel gray	650F

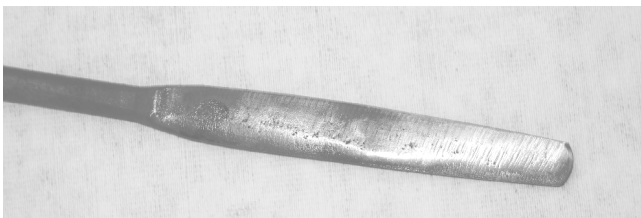


Step 6.) Now re-polish / regrind the surface of "the 6 inches" -Be careful to NOT let your piece become too hot from the grinding. (Warm to the touch is OK) because if you get your piece hot you will be tempering it and messing it up for the progressive temper we are going to add in the next step. Keep fingerprints off the surface too, while not a big deal, oil on the surface will affect the temper colors in the next step.

Step 7.) Now gently reheat your test piece from the "handle" end. I like to do this with a propane torch with the handle held in the vise. You can do this with any torch but use a small tip. Or, you can do this in the forge holding the tip of the test end in vise grips etc. The idea is to produce a progressive temper with the temper colors covering the maximum length of the test section possible. Using the torch, I apply most of the heat back by the handle end, on the bottom side, and watch the colors run towards the tip. I will give the process a little help by quickly playing the torch along the length of the test piece from time to time but put most of the heat in back towards the handle end.

When you have a nice spread of colors from Light Blue to Very Pale Yellow, re-quench your test piece. This stops the tempering process.

Mark does all Steps 5, 6, and 7 in one connected operation. He takes his test piece from the quench with the "handle" end still hot, make a quick polish of the quenched surface with emery cloth and then watch the colors run from heat still in the handle. If necessary, he may add a little more heat from the forge or a torch. He then stops the process by quenching.



OK, close your eyes and imagine the above picture in color. On the center left, you would see steel grey, then light blue. In the center would be dark blue, then purples, then browns, and then as we move to the right dark yellow follow by straw all the way to pale yellow. Isn't Imaginary Color great? 😊

Step 8.) OK, Now we get to use a hammer!! We a test piece that has been the heated above critical, quenched, and has a progressive temper. By progressive temper, I mean one that is almost full hard (un-tempered) at the end to one that has been nearly completely drawn at the other end. In other words, the one end is very hard and brittle the other end softer and tougher. The test piece also has a full range of temper colors.



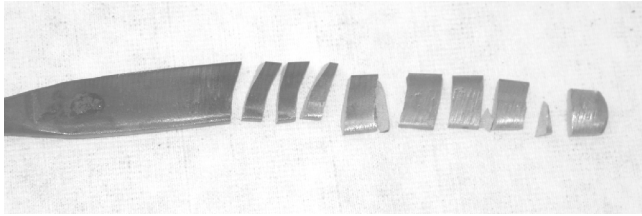
We can now start breaking off small pieces from the very hard end over the edge of the anvil with a hammer. As we progress toward the tougher end, we may reach a point of "bending" rather than "breaking". **Don't use your good forging hammer for this test.** Use a hammer that you don't care about marking up the face. We can now use the colors from the tempering to judge the performance of the steel we are testing. Where does it break, where does it bend. We can also judge the amount of force require to make a break. I start with a lighter blow and then re-strike with a harder blow if it doesn't break.

Mark Hopper uses this test to pick the tempering temperature he wants for a finished tool. In other words, the tempering color he wants. For edged tools, he likes to go back "one break" and use that as his target tempering temperature. He knows it is not the toughest temper, but one that will still hold a good edge and is quite tough.

Results, What I have learned from using the Break-Test.

I have done quite a bit of heat-treating and still have learned a lot from the Break-Test. Especially for me it gives me a way to test one steel against another. It also provides first hand knowledge of how various steels that I have data on perform in my shop using my equipment. It also give me a great way to test the performance of unknown steels like springs, railroad rail, truck axles and things I might pick up at the scrap yard.

Test of W1 (1095)



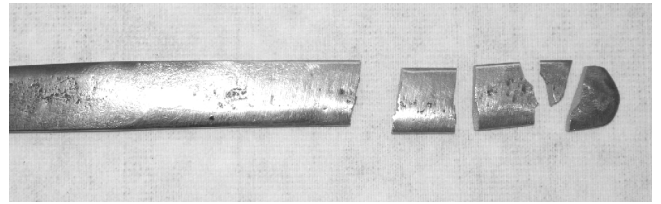
Here is a test piece of W1 (1095) after breaking over the anvil with all of the little bits. There was not much difference in temper color towards the hard end (right side in the photo) so I was not surprise that I could keep breaking it off. It didn't take a lot of force to make these beaks. The steel was quite brittle.

As got farther to the left it took more force (at least it seem like it) but still a rather brittle break some time requiring more one strike. When I got to the full purple, I did get another break but I didn't try breaking in the vise with a really big hammer.

What this test doesn't show for W1 is the effect of a "very hard case" and a tough core. Since my test piece is only about 1/8 inch thick and W1 hardens to a depth of about 1/16 my test piece is through hardened. If I am making tool from W1, a wood chisel for example, on of the advantages with a tool that is about 1/4 inch thick is that I can have a very hard cutting edge and a tool that still has a softer but much tougher center. I need to repeat this test with a test piece made with a long taper to test out this effect.

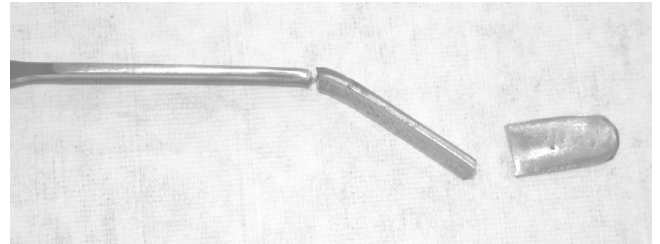
I repeated this with another piece of W1 and got very similar results.

Test of 4340



Here is one of the Break-Tests I ran on a piece of 4340. It was quenched in water, even though I knew that 4340 is considered an oil quench engineering steel. It took a lot of force to break the 4340 sample until, but it still broke with a brittle fracture until I got to the range of 460F temper. At a higher temper temperature, I was not able to break this sample over the anvil. I didn't try breaking it in the vise.

Oil Quenching 4340



Because I knew that 4340 was intended as, oil hardening steel I ran another Break-Test but this time I quenched in oil rather than water. Result, I could not break this test piece over the anvil. I got a small bend, but no break. So, I put the test between the jaws of my vise and hit with a 6-pound striker's hammer. I made the break, on the right seen above.

Then I moved the test piece up in the vise and went at it again. With a series of heavy blows from the 6-pound hammer, I was able to bend the test piece over to about a 45-degree bend. On the last blow, I broke it off. Oil quenched (oil hardened) it is one very tough steel. I was still in the 450F to 480F tempering temperature. Handbook values show 4340 oil quenched and tempered at 500 F with a hardness of Rockwell C in the mid to low 50 with a yield strength of 225,000 psi and a tensile strength of 265,000 psi. In my opinion, a rather good steel for lots of tools, especially if you cool it between uses.

One of the major lesson learned here is that it pays to oil quench 4340. Why? Well I get a just as hard a surface (or nearly so) as the water quench and quite a bit tougher core. The tougher core comes from the type of steel structure that is

formed by the somewhat slower quench in the oil. I have read all about this many times but doing it and then running side-by-side Break-Tests really helps you understand the differences.

Other Steels that I have taken a look at with the Break-Test

I have done similar tests on O1 tool steel, unknown coil spring steel and a chunk of junk - called rebar. I still haven't run the test on some run of the mill A36, railroad rail or some of the high alloy air hardening tool steels such as S7, A2 or H13.

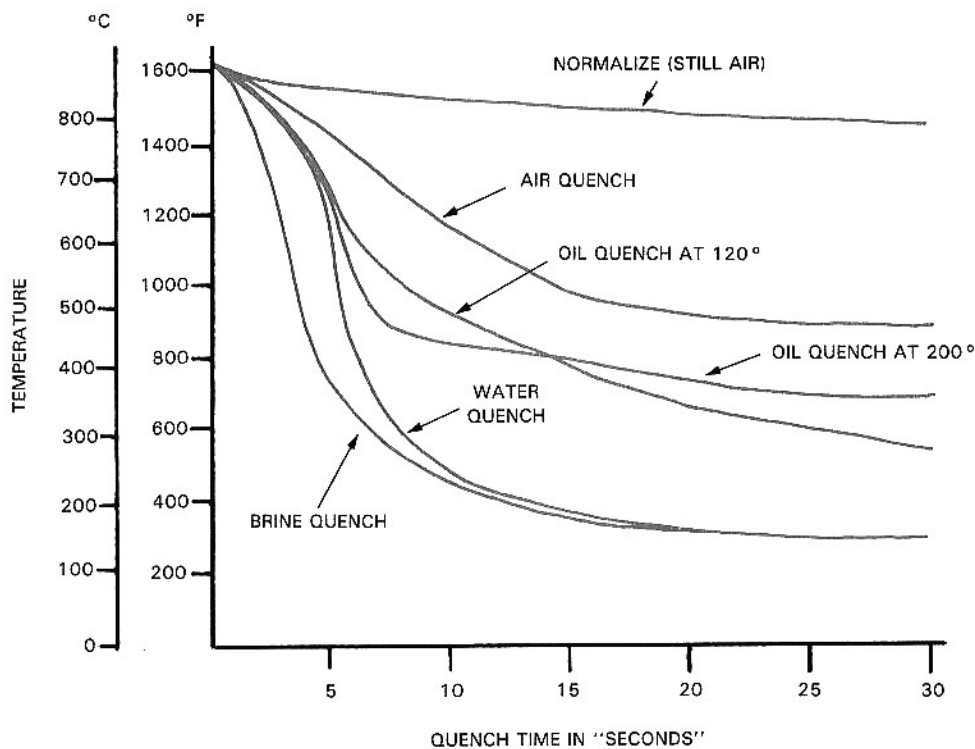
O1 quenched in water looked a lot like W1. I need to run that again and try an oil quench like the one I did with the 4340. The coil spring material looked like it would make good tools based on the

water quenched Break-Test. That too should be looked at with an oil quench.

Now about the rebar. First, I had cracking in the rebar just from forging it. It may have been from forging in a "cold shut" from the rebar surface but still a crack is a crack. Then when doing the break test while the steel is quite tough, it bent to a 90 degree bend before starting to break, but it just didn't have the hardness I saw with the 4340 or coil spring steel. Junk is Junk.

What Quench should I use?

That is a good question on unknown steels. My starting point is to use water because it is easy and fast to do. If from the file test, (at step 2 above) your steel looks quite hard then I would follow with repeating the test with an oil quench. If I have a know steel, that I know should be oil hardening, from what I have learned do an oil quench.



The above set of curves show the quench time in seconds for different types of quench media. While I don't know the size of the test piece used for this data, it is most like about 1 inch in diameter. (Educated guess). The size of the piece has a big effect on the cooling rate, as does the amount of quench media in use.

One additional subject not cover in this article on Break-Testing is the difference between using temper colors for tempering, vs. tempering in an oven (my preferred method). See the article on Heat-Treating Tool Steel for more on this subject.

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