Heat Treating for the Muzzle-Loader

“Heat Treating” in the broad sense is a process of modifying the properties of a piece of metal by heating it to some temperature, and then cooling it down again at a certain rate. It might be cooled rapidly, as by quenching in water or oil, which is done to harden steel. Or it might be cooled very slowly, as by burying in lime or ashes, which is called “annealing”, and softens steel.

Heat treating of steel has been done since ancient times—the Greek poet Homer refers to steel heat treat procedures in the Odyssey. You might want to read what Homer has to say about Ulysses’ treatment of the Cyclops. Also, the contest that Ulysses won when he finally returned home. Homer does have a couple of things to say about metals. In spite of your high school English teacher’s best efforts, he can be interesting.

To harden a piece of plain carbon steel one heats it until it glows red, and then cools it very quickly by quenching it in water (reference—the Cyclops). If you try that with a 20d nail, nothing will happen, it will be just as soft and bendable as it was when you got it at the hardware store. It won’t even be hard enough to measure on the Rockwell C scale. It will be somewhere below C20, where this “C” hardness scale doesn’t work, somewhere high on the “B” scale.

The nail remained soft, because for steel to harden, not only must it be heat treated, but also that steel must contain a certain amount of carbon. Nails have maybe 1/10% carbon in them, and that is not enough to permit them to harden very much at all. At least 0.2% carbon is needed. Some examples: Modern rifle barrels and revolver frames commonly have about 0.4% carbon in them. That is, roughly 6 ounces of black carbon, or soot, dissolved in 99 pounds 10 ounces of the element iron. A metal file, such as the Nicholson file in your hardware, is made of high carbon steel. This metal has about 1% carbon (99 pounds of iron, alloyed with 1 pound of carbon dissolved in that iron).

Carbon, carbon, carbon—any time steel is being heat treated, there is some amount of carbon involved. It might be in the surrounding atmosphere, as well as in the steel. Sometimes carbon is added to the steel during heat treatment, which is “carburization”. Sometimes the opposite happens, and a little bit of it burns out, leaving the surface soft and depleted in carbon. Called “decarburization”, this is normally a bad thing, causing distortion and cracking in heat treatment.

Back to that file. When Nicholson buys their high carbon steel, called AISI 1095, it is in the annealed condition, which is reasonably soft. They blank out the shape of a file, and then have a machine chisel those tiny little teeth in the file blank. Then it is heated to 1440°F (782°C), which is a nice red color, and quenched straight down into cool salt water. When it comes out of the water it is very hard—you might even say, “file-hard”.

Notice that they quenched in salt water. Water with about 13 ounces of table salt per gallon (10 grams per litre) dissolved in it quenches faster, with less distortion & less chance of cracking, than does just plain tap water. That is trued for knives, springs, chisels—anything made of plain carbon steel, which will be water quenched. Perhaps not a good idea for case colors, though.

If you were to make a nail out of that same steel, 1095, and harden it the same way, it would break the first time you hit it with a hammer. Likewise, if you drop your new file on concrete you may find yourself picking up two pieces. The metal is very hard, which is good for a file, but it is not tough, not ductile.

To make that hardened piece of steel a little tougher, we reheat it just a few hundred degrees. That reheat, or “temper”, might be anywhere from 350°F/177°C (the temperature Mom bakes her apple pie) up to 1100°F (around 600°C) or so, hotter than her self-cleaning oven. The old word for temper was “draw”, and you will still hear heat treaters use this term, such as when referring to the “draw furnace”. The higher the tempering temperature, the softer the metal. We really don’t want the metal to be softer, but we have to accept it being softer if we want it tough enough to be useful for anything other than a file.

One may also make truck springs of 1095. These are tempered close to 800°F (427°C), or until the hardness drops to about Rockwell C 40 to 45. That is a good “spring temper”.

Springs can be too hard. I have known of more than one beautifully finished mainspring to break while the lock was just setting on the bench. Those springs were about Rockwell C50, which is far too hard for such a spring. I’d guess they were tempered somewhere around the melting point of lead. Which brings up the point that it is difficult to judge the right tempering temperature for a water-quenched spring.

For thousands of years people have used “temper colors” to judged if the steel has been at the right temperature (ref Homer for “blue steel”). A temper color chart is in *Modern Steels*, Sixth Edition or earlier. Straw, or light tan, color means that a clean piece of steel has seen about 380°F (193°C). Brown is 460°C (238°C), purple 500°F (260°C) blue maybe 580°F (304°C). By 700°F (371°C) these colors washed out to a dull blue-gray. Some of us still do judge temper by these colors.

Water quenched 1095 springs should be tempered at least 700°F and preferably 800°F (371—427°C). This is well beyond where temper colors will be of any use at all. In the absence of a well-controlled tempering furnace there are other ways. One of the temperature indicating crayons, brand name Tempilstik®, have been around for years. Your local welding supply house may have hand-held laser temperature-indicating devices which work just dandy.

If temperature control could be a problem, then an oil quench, rather than water, may be the way to go. 1095 will be a little softer, as-quenched, if oil is used rather than water. Lead just melts at 621°F (327°C), which still may not be hot enough.

In my personal opinion the ideal spring steel for the small shop is the 1074/1075 available from McMaster-Carr up through 1/4” (6.35mm) thick. This is a more forgiving steel. Oil quenched 1074 is less likely than is 1095 to end up too hard.

Appropriate materials for gunlock springs include 1074/1075, 1095, and W1 tool steel. If you have access to good temperature control for tempering around 700-900°F (371-482°C), then it is appropriate to water (salt water) quench these steels for the very best properties.

Given access to temperature control, W1 tool steel is a good and available choice, followed by the carbon steel 1095. The difference between tool steel and carbon steel is quality. The chemistries of W1 and 1095 are close together but W1 is a higher quality metal. W1 quenched in salt water may come out file-hard, Rockwell C65 or greater. Tempering two hours at 900°F (482°C) drops the hardness to Rockwell C40-42 typical, good for a spring. An 800°F (427°C) may leave it around RC46-48, which is just a little too hard for a mainspring. For O1 tool steel add 100°F (56°C) to those temperatures.

To this point it appears that we have two choices. Either the steel can be hard as a file, and brittle, or it can be tough, but not so hard. One can’t have it both ways. Except . . .

There is one means by which you really can have it both ways. Take a pinion gear, for example, or the square shank on an air impact wrench. Or sears, tumblers & percussion hammers. All need to be very hard so they don’t wear out. But all may take something of a beating, so they must be tough enough not to snap.

Say you made an impact tool, or gunlock sear, of some soft, tough, low carbon steel. If there were a way to put a “case”, or surface layer, of high carbon steel on it, then the surface would be hard, so it wouldn’t wear out. But underneath that thin, hard case the metal would be soft and tough, so it wouldn’t break.

The way this has been done, for a thousand years or so, is to make the part out of low carbon, soft steel (or wrought iron). Then put it into a box packed with charcoal, broken up to about the size of peas. Usually something is added to the charcoal as an “energizer” to speed up the process. Wood ash, animal charcoal and pigeon dung have all been used. Cover the box, and put the whole thing in a furnace at a good red heat, maybe 1750°F (950°C). At that temperature carbon from the charcoal will slowly diffuse into the low carbon iron.

For those who care, the mechanism by which this happens is the formation of carbon monoxide from the charcoal. Carbon monoxide, in the presence of an excess of carbon, forms iron carbide on the surface of the steel. This iron carbide dissolves in the red-hot steel and slowly diffuses inwards.

After about four hours at 1750°F/950°C there will be a high carbon "case" or surface layer 1/32" (0.8mm) deep all over the part. If you turn that box over & dump the contents into a tub of water, the gear will come out hard as a file on the surface. But the inside remains soft, tough low carbon steel.

In modern practice one tempers the carburized part about 350°F (177°C) to make it a little tougher, without much loss in hardness.

This process is most correctly called "carburizing", though it is also called "case-hardening". Industrially it is now done in a furnace with a protective atmosphere of hydrogen, nitrogen, carbon monoxide and perhaps 2—4% methane (or other hydrocarbon) as the source of carbon.

About 1973 I saw a video promoting a new method of carburizing. It first showed the old method, with the heat treater at Smith & Wesson dumping a box full of forged AISI 1022 hammers & charcoal into a tank of water. Very messy, water and charcoal all over. With the new method the heat treater got to stay clean, which no doubt pleased him.

The type of charcoal has some effect. "Charcoal" means something made from wood, leather, ox hooves or bone. That is not necessarily true of the charcoal briquettes used for summertime barbeques. In the U.S.A. these little black lumps are made with a little pitch coke, which means they include some sulphur. Maybe not so good for those who want to make beautifully finished gun parts.

In Western Europe by the 18th Century the most common method of making steel was to deeply carburize flat bars of wrought iron. Wrought iron contains maybe 3% by volume of slag stringers.

This slag is a glass-like mixture of calcium—aluminum silicates and iron oxide. As the carbon diffused into the iron it reduced the iron oxide back to metallic iron, and carbon monoxide gas. The gas raised large holes blisters throughout the bar, and blisters on the surface. This product, not surprisingly, was known as blister steel, and sold as such even in the 19th Century. To use it, it first needed to be forged to hammer down & weld up the blisters. A better grade of steel, known as shear steel, was made by shearing bars of blister steel, bundling them together and forge welding that bundle into a new bar. This had a little more even distribution of carbon, the high and low carbon layers being thinner. And, of course, the blisters had all been forge-welded shut.

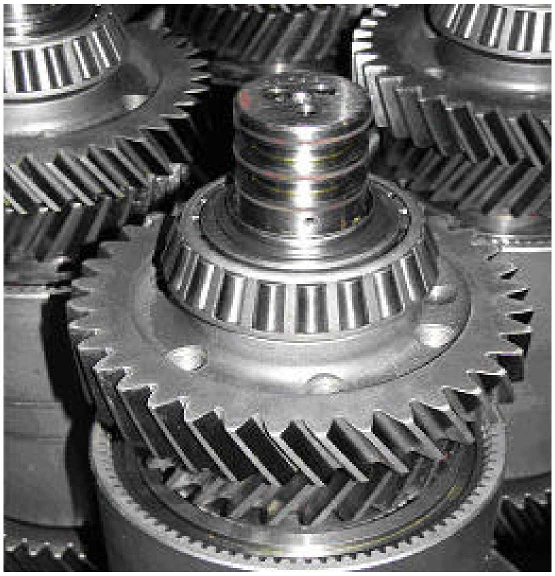
The frizzens (hammers, more correctly) of flintlocks were “steeled” by forge welding or brazing a piece of blister steel onto a wrought iron part. When that steel wore out it could be replaced by another piece, brazed on. I examined two original American flintlock rifles and a Ryan & Watson brass barreled pistol, all three with a flat piece of steel brazed to the iron hammer. On the Ryan & Watson the steel is about 40/1000” (1 mm) thick. Military arms and better English pistols show no braze line, so it seems reasonable to assume the steel was forge-welded to the wrought iron back. The whole thing might have been lightly case hardened when finished. It would have been very impractical to case carburize the whole frizzen deeply enough to be useful. On wrought iron, deep carburizing raises blisters of carbon monoxide, distorting the metal & requiring forging to weld them up.

American flintlock rifle, late style, with a piece of steel nearly 1/16” (1.5mm) thick brazed onto the frizzen. The rifle itself shows very little signs of use, so this was might have been done when the lock was made. Capt. John G.W. Dillin illustrates this rifle, from the Clarence St John collection, as No. 3, Plates 93 & 94.

In the mid-18th Century a Frenchman named Reaumur experimented with ways of speeding up the carburizing process. Eventually he found that adding some amount of sea salt and pigeon dung to the charcoal gave a deeper case, or the same case depth quicker. Today we would say that these additions acted as “energizers”, to help make more carbon monoxide to do the carburizing. Apparently the calcium phosphate in bone charcoal also acts as an energizer, which is perhaps why bone charcoal was used in the first place.

Industrial carburizing is done largely on alloy steels, such as 8620. The case depth ranges from perhaps 0.010—0.040” (0.25—1.0mm) for most machine parts up to, for gears on large earthmoving equipment, as much as 1/4” (6.4mm). This carburizing is usually done in range of 1650—1750°F (900—955°C).

In normal industrial practice, when an engineering alloy steel is carburized and oil quenched, the core has some reasonable degree of strength. Gears require to be carburized to maximize the bearing loads the teeth can withstand.



Clutch pack. These gears which have been carburized by the most modern contemporary method, known as “Vacuum Carburizing”, more accurately Low Pressure Carburizing.

WHITWORTH RIFLE C○ MANCHESTER

Color case hardening, as done to firearms of the mid-19th Century through the first half of the 20th Century, was done at lower temperature, and to extremely shallow depths, perhaps only 0.002" (0.05mm).

The plain carbon, mild steels (or wrought iron) used for classic old firearms ended up pretty much dead soft underneath that case. One cannot expect the same result when old methods are used with modern alloy steels.

Those who are interested in colors & good pack carburizing practice as it applies to guns really ought to read the articles by Oscar L. Gaddy in *The Double Gun Journal,* Vol 7, Issue 4, 1996 and Vol 8, Issue 1, 1997. Part I may be found at **www.gunshop.com**. This is a practical and professional discussion, by a man with knowledge of fine guns. It might be helpful to read these articles over a couple of times to get the full impact.

The reason bone charcoal is used is for the calcium phosphate present in that type of charcoal. Calcium phosphate does not itself harden the steel, but it is necessary for the most durable colors. Mr. Gaddy got his bone charcoal from Ebonex Corp, in Michigan, **www.ebonex.com .** Their web site lists distributors in the U.K., Spain, Germany, Italy, Australia, Mexico and Singapore, which ought to suffice. His wood charcoal came from Berger Brothers, Inc., Chicago, Illinois +1-312-642-4238.

Most of Gaddy's case-hardening was done in the temperature range 1320—1337°F (715—725°C), for about 1 to 2 hours, giving a case depth no more than 0.002" (0.05mm). This is fine for resisting scratches & keeping the engraving sharp, but not deep enough to embrittle the thing.

Gaddy varied time and temperature to get the color patterns he wanted. The quench was plain tap water, kept cool, about 45-55°F (7-13 °C). He aerated the water for some time before quenching in it, to increase the oxygen content. No aeration was used during the quench. The pack, charcoal, parts and all, was dumped into the water in a way to avoid air contacting the parts.

This is not a complete recipe for color case hardening. For that, see Part 2 of Gaddy's article.

In the old days, the metals to be case hardened were all low carbon wrought iron or mild steel. They had no chromium, nickel or molybdenum added. They were quenched in water because they had to be cooled that quickly in order to harden.

Modern alloy steels meant for carburizing do not have to be cooled so fast for the case to harden. The slower cooling rate of oil suffices. If you water quench AISI 8620 from 1550°F (843°C) it can reach the hardness of a spring. For a patent breech this is not a good thing to have underneath a file-hard case.

To color case-harden an investment cast 8620 patent breech, it should be done at the lowest temperature. That is 1320—1337°F (715—725°C) in Gaddy's article. Consider letting the pack cool a bit lower, perhaps to 1200°F (650°C). before dumping into the quench. Quenching from a lower temperature helps keep the 8620 core from getting too hard.

Personally, I would prefer a breech filed out of annealed 1018 mild steel to any casting.

It would be good for life & limb to reserve color case hardening for plain, low-carbon steels only, and not ever for modern breech-loading rifle actions or revolver frames. It is not only to make their lawyers happy that firearms manufacturers attempt to discourage re-heat treating their products.

One may debate the merits of various steels, but one of the most important properties is—availability! I know a little about this here in North America. Here are some of the steels which are available in the U.S. A. in small quantities from **www.mcmaster.com**. They have other grades. One would do well to avoid any resulphurized grade, such as one of the 11xx series. The 12xx series, in particular 12L14, have no place a firearm. The stringers of manganese sulphide which are great for machinability reduce the metal's toughness & ductility across the grain.

Plain Carbon Steels

AISI	UNS No.	Specified Chemistry Range (minimum and maximum levels)							
Grade		C	Mn	Si	Cr	Mo	Ni	W	V
1018	G10180	0.15	0.60	--	--	--	--	--	--
		0.20	0.90	--	--	--	--	--	--
1045	G10450	0.43	0.60	--	--	--	--	--	--
		0.50	0.90	--	--	--	--	--	--
1095	G10950	0.90	0.30	--	--	--	--	--	--
		1.03	0.50	--	--	--	--	--	--
Engineering Alloy Steels									
8620	G86200	0.18	0.70	0.20	0.40	0.15	0.40	--	--
		0.23	0.90	0.35	0.60	0.25	0.70	--	--
4130	G41300	0.28	0.40	0.20	0.80	0.15	--	--	--
		0.33	0.60	0.35	1.10	0.25	0.12	--	--
4140	G41400	0.38	0.75	0.20	0.80	0.15	--	--	--
		0.43	1.00	0.35	1.10	0.25	0.11	--	--

Tool Steels

W1	T72301	0.95	0.10	0.10	--	--	--	--	--
		1.05	0.40	0.40	--	--	--	--	--
O1	T31501	0.85	1.00	0.10	0.40	--	--	0.40	--
		1.00	1.40	0.50	0.70	--	--	0.60	0.30

Similar European Grades, Availability Unknown

W.Nr.	DIN (Euronorm)	C	Mn	Si	Cr	Mo	Ni	W	V
1.1141	Ck 15 (C 15E)	0.12	0.30	--	--	--	--	--	--
(similar to 1018)		0.18	0.60	0.40	--	--	--	--	--
1.1291	Mk 97 (C 97 E)	0.95	0.25	--	--	--	--	--	--
(similar to 1095)		0.99	0.45	--	--	--	--	--	--
1.6523	21NiCrNiMo2	0.17	0.65	--	0.35	0.15	0.40	--	--
(similar to 8620)		0.23	0.95	0.40	0.70	0.25	0.70	--	--
1.7325	25Mo4	0.23	0.60	0.15	0.40	0.40	--	--	--
(similar 4130, higher Mo)		0.29	0.90	0.40	0.60	0.50	--	--	--
1.3563	43CrMo4	0.40	0.60	--	0.90	0.15	--	--	--
(similar to 4140)		0.46	0.90	0.40	1.20	0.30	--	--	--
1.1545	(CT 105)	1.00	0.10	0.10	--	--	--	--	--
(equivalent to W1)		1.10	0.40	0.30	--	--	--	--	--
1.2510	95 MnWCr5	0.90	1.05	0.10	0.35	--	--	0.40	0.05
(equivalent to O1)		1.00	1.35	0.40	0.65	--	--	0.70	0.25

Suggested Reading

The Modern Gunsmith, James Virgil Howe, two volumes, ©1941

Modern Steels and their properties, Bethlehem Steel, 6th Edition ©1967 or earlier

The Double Gun Journal, Vol. Seven, Issue 4, 1996 & Vol., Eight, Issue 1, 1997.

C=Carbon Mn=Manganese Si=Silicon Cr=Chromium Mo=Molybdenum Ni=Nickel W=Tungsten(Wolfram) V=Vanadium

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