HEAT TREATING LEAD / ANTIMONY / ARSENIC ALLOYS

By: Rick Kelter

A Perspective From The Metals Industry

Excerpts From Heat Treating of Lead and Lead Alloys "Key To Nonferrous Metals"

[1]*Attempts to strengthen lead by reducing the grain size or by cold working (strain hardening) have proven unsuccessful. Lead-tin alloys, for example, may re-crystallize immediately and completely at room temperature. Lead-silver alloys respond in the same manner within two weeks.*

Transformations that are induced in steel by heat treatment do not occur in lead alloys, and strengthening by ordering phenomena, such as in the formation of lattice superstructures, has no practical significance in typical lead alloys. In one study of possible binary lead alloys it was found that the following elements, in the order listed, provided successively greater amounts of solid-solution hardening: thallium, bismuth, tin, cadmium, antimony, lithium, arsenic, calcium, zinc, copper, and barium.

Unfortunately, these elements have successively decreasing solid-solution solubility's, and therefore the most potent solutes have the most limited solid-solution hardening effects. Within the midrange of this series, however, are elements that, when alloyed with lead, produce useful strengthening.

In most lead alloys, heat treating and rapid cooling (quenching) result in a breakdown of the supersaturated solution during storage (aging). Although this breakdown produces coarse structures in certain alloys (lead-tin alloys, for example), it produces fine structures in others (such as lead-antimony alloys). In alloys of the lead-tin system, the initial hardening produced by alloying is quickly followed by softening as the coarse structure is formed.

Adding sufficient quantities of antimony to produce hypoeutectic lead-antimony alloys can attain useful strengthening of lead. Small amounts of arsenic have particularly strong effects on the age-hardening response of such alloys, and heat treating and rapid quenching prior to aging enhance these effects.

The alloys with 2 and 4% Sb (antimony) harden comparatively slowly, and the alloy containing 6% ***Sb*** *appears to undergo optimum hardening.*

Quenching of castings from arsenical lead-antimony alloys offers an attractive alternative method of effecting improvements in strength. The alloy containing 2% ***Sb*** *clearly does not respond sufficiently to be considered as a possible alternative. The 4%* ***Sb*** *alloy, however, attains a hardness of 18 HV after 30 min, and the alloys that contain 6, 8, and 10%* ***Sb*** *could be handled almost immediately.*

Heat Treating Bullet Alloy

By: Rick Kelter

There is a great deal of information for the bullet caster in the above excerpt from the article "Key To Metals". The article was written mainly pertaining to strengthening lead alloys for the manufacture of lead/acid batteries but the principles are the same for bullet casters that need to strengthen their alloy.

Key Points of The Article

- Lead-tin alloys age soften quickly.
- Antimony is an effective method of strengthening lead.
- Lead-antimony alloy can be strengthened by quenching.
- Small amounts of arsenic have particularly strong effects on the age-hardening response of such alloys.
- Heat treating and rapid quenching prior to aging enhance these effects.
- The percentage of antimony greatly effects the amount of time for strengthening to occur when heat treating or quenching. The alloy containing 2% **Sb** clearly does not respond sufficiently to be considered as a possible alternative. The 4% **Sb** alloy, however, attains a hardness of 18 HV after 30 min.

An interesting point is that the metals industry refers to "strengthening" lead while bullet casters refer to "hardening". Strengthening is precisely what we need as bullet casters, the strength to withstand the pressure of our loads and the strength to take and grip the rifling without stripping and yet, not so "hard" as to not seal the bore.

How Hard (Strong) Do We Need Our Bullets?

Bullets cast of very hard alloys seem to be quite the rage these days, especially with the commercial bullet casters. Ideally bullet strength will match the pressure and velocity of the load in the firearm we are using. Using bullets with a higher BHN than is needed for the load can prevent the bullet from sealing the bore causing gas leakage, gas cutting and leading. Too hard can also cost us velocity and open up groups. Too hard can in some cases be worse than too soft. For interesting, informative articles by Glen E. Fryxell on alloy and bullet obturation use these links: Cast Bullet Alloys and Obturation and A Few Comments On Cast Bullet Alloys.

A note on the Freedom Arms web site states that shooting too soft of an alloy for the pressure/velocity will cause premature forcing cone wear in high pressure rounds. To hard is not good and can cause leading and to soft is bad for the revolver so how do we know how hard is just right?

[2]Excerpt from Cast Bullet Alloys and Obturation: *Extensive experimentation has revealed the empirical correlation of 3 x 480 x Brinell Hardness Number (BHN) (or more simply, 1440 x BHN) as an estimate of the minimum peak pressure required for bullet obturation (the reason for the "3 x 480" format is the number "4 x 480" also has significance, and this format makes it easier to remember both formulae). Thus, a bullet with a BHN of 24 (typical of*

commercial hard-cast bullets) will not undergo plastic deformation and obturate until pressures exceed 34,000 psi.

This formula is a *guide to "minimum" pressure* for a given load. It is not a set in concrete rule, it is a guide, a starting point. In the 24 BHN example of commercial hard cast bullets in Glen's article 34,000 PSI is very nearly full power (maximum) 357 magnum loads (35,000 PSI) but keep in mind we are looking for *minimum not maximum* BHN's. The 38 special, 45 ACP, 45 Colt etc. *maximum* loads are less than half this pressure and 24 BHN is clearly too hard for obturation. Even top end 45-70 loads are max at 28,000 PSI. By multiplying the BHN number of your alloy by 1440 you can get a solid idea of whether or not you need to heat treat your alloy and to what *"starting"* hardness. Its a fairly common misconception that the 1440 formula is a maximum BHN for the load and this is incorrect, we need to know at what pressure the alloy starts to deform (obturate) and seal the bore. This formula *WILL NOT* tell you what the max pressure that will cause leading is as some believe, it is an approximation of a starting point. In a quality bore/chamber with a "properly sized" bullet it is very possible to run the pressure much higher than the formula suggests as a starting BHN without leading, the FA revolver tests mentioned below proved it.

Now that we know a minimum hardness as a starting point what about a maximum hardness? This is a little more complicated and depends on many variables such as the intended purpose of the bullet, bullet type (does a HP need to expand?), cartridge, pressure, action type, rifling twist, chamber & bore condition and dimensions, amount of freebore, velocity, bullet fit etc. Testing different BHN bullets starting at the minimum and checking for leading, velocity gains or losses and improvements in groups is the only real way to know for sure. I did an extensive BHN test in my 9" Freedom Arms Model 83 357 Mag revolver that took over a year and a half and fired hundreds of rounds in five shot groups. Using only virgin WW brass and all powder and primers from the same lot number and all alloy from the same lot, I fired 5 shot groups at 150 meters scoped from the bench (12x Burris). All bullets were sized nose first in a Star Lubrisizer and lubed with LBT Blue. All loads were as identical as I could make them changing only the bullets BHN by heat treating. Best grouping *and* highest velocity was with bullets at 17-18 BHN. Testing started at 11 BHN with air cooled wheel weight + 3% tin, various BHN's were tested up to 30 BHN. Harder than 17-18 cost velocity plus groups opened up, softer than 17-18 and groups opened up. None of the loads caused any leading in the FA but proper bullet fit is as or more important than alloy BHN. This revolver likes it's near max load with 18 BHN bullets. Consider the best groups and highest velocity with 18 BHN bullets and compare this to the 20 to 24 BHN of many commercial cast bullets. 1440 x 18 BHN and a *minimum* pressure of 26,000 PSI is needed. This very near max 357 Mag load (9" barrel, 190 gr. bullet @ 1550 fps) is about 9,000 PSI over the *minimum* 26,000 PSI for 18 BHN and is where it shoots it's best with zero leading. This does not mean that you must be as much as 9,000 PSI over minimum BHN but this revolver with this bullet/load likes it.

An interesting side note of this testing was mixing different BHN bullets within the same 5 shot group. Using a BHN range such as 17-18 or 15-16 didn't effect groups but the worst groups fired throughout the tests were with a wider variation in the BHN. When groups were fired with BHN ranges such as 15-20 BHN or 18 to 25 BHN bullets wouldn't even stay on the

150 meter target much less group. BHN variation opens up groups and the more variation in BHN the larger the groups.

Heat treating lead/antimony/arsenic alloys is a highly useful tool for bullet casters. A BHN range can be selected for any given load/firearm combination we are loading for and BHN variation will be kept to an absolute minimum, *the trick is to not over do it*. Wheel weight alloy with an *average* composition of: $^{1}/2$% tin, 3-4% antimony, $^{1}/4$% arsenic and $95^{1}/4$% lead can be heat treated to well over 30 BHN but it's a rare bullet that needs to be this hard unless your shooting very top end 454 Casull loads at 65,000 PSI.

Conventional wisdom has it that the industry has been reducing the antimony content of wheel weights and my own experiments in heat treating seem to confirm this. The result hasn't "yet" been softer heat treated bullets but rather bullets that took considerably longer to age harden after heat treating. The article by "Key To Metals" confirms this by stating "*The alloy containing 2% **Sb** clearly does not respond sufficiently*" in referring to age strengthening/time curve after heat treating and quenching. Recent batches of heat treated bullets took from 7 to 14 days to reach 18 BHN which is up from 2-3 days of previous batches. According to the manufacturer Lawrence, magnum shot is supposed to contain 4% antimony and $1^{1}/4$% - $1^{1}/2$% arsenic.

*Addendum to the percentage of antimony in wheel weight alloy: I emptied the Magma 40 pound pot and re-filled it with 35 pounds of ingots from the same batch of wheel weight alloy, cast 500 bullets and re-did the heat treating at 420^{o}. The hardening/time curve returned to the predictable 17 BHN in 48 hours. It seems that rather than a major change in wheel weight alloy I deleted some of the antimony with improper fluxing but the results were the same regardless of why the antimony percentage was low, greatly increased time for hardening to occur. I couldn't have planned a better test, the reduced antimony was an error on my part but helped to prove the hardening/time curve of reduced antimony. Yes, that lumpy stuff floating on top of the melt when you first heat up the pot is antimony, do not remove it, flux it back in.

Points for the bullet caster to consider

- The composition of wheel weights is nearly ideal for responding to heat treatment, (lead/antimony/arsenic).
- The higher the tin content of the alloy the less the alloy will respond to heat treating and the faster it will age soften. (2-3% is fine unless your goal is 30+ BHN which is very rarely needed)
- The lower the antimony content the *slower* age hardening from heat treating will occur.
- Antimony is the key to heat treating by providing the fine crystalline structure but antimony is extremely brittle. The industry recommends 4% Sb for an optimum hardening/time curve. Linotype at 12% Sb can be a poor choice for hunting bullets or for use on steel targets. Monotype (19% Sb) and Foundry Type (23% Sb) bullets are so brittle they can actually break in two when chambering the round.
- Arsenic is a catalyst to a greatly improved strength/time curve in heat treating & quenching lead/antimony alloys.

- Magnum shot is a great source of both arsenic and antimony for enriching your alloy. Linotype is a much better source of antimony (12%) but not of arsenic.
- Yes, it's easy to over do it and make your alloy much harder than is required for your loads pressure/time curve and velocity in your firearm.
- The 150 meter revolver group testing was instrumental in determining the effect of BHN on grouping. Detecting differences with groups fired at 50 yards or less would have been difficult or even impossible. The higher the velocity *and* the longer the range the more obvious the differences become.

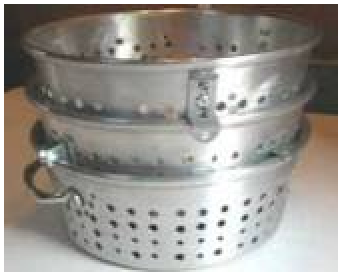
When I first started heat treating wheel weight alloy I used a gas fired conventional cook oven and the results were effective. The precise range of BHN wasn't all that easy to achieve though and it wasn't until I switched to an electric convection oven that I saw a remarkable difference (improvement). For the first bullets heat treated in the convection oven I set the controls to the same setting as the gas conventional oven (460^o) and used the same oven thermometers to help assure that I had the same temperature, but I didn't get the 18 BHN bullets that I needed. In two days they were 25 BHN, much too hard for my application. I repeated the test and the results were the same, 25 BHN. Next the thermometers and more bullets went into the gas conventional oven at 460^o and the predictable 18 BHN was the result. In the convection oven a setting of 440^o achieved a BHN of 20 and was repeatable. 420^o in the convection oven produces the 18 BHN needed for my near max long range revolver load. With a much better temperature control and even heat throughout the oven for the entire time, convection ovens it seems are much more efficient for heat treating. No wonder top chefs insist on using them. Except where noted all of the heat treating results listed in the chart were obtained in a convection oven.

Method For Heat Treating Success

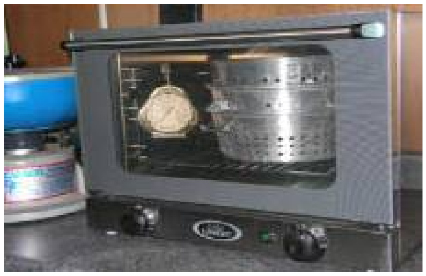
Because the intent here is to strengthen (harden) your bullets, when you process (smelt) your wheel weights into ingots it is important to separate the clip-on weights from the stick-on weights. Stick-on weights are nearly pure lead and by including them in your alloy you are softening the entire batch by diluting the antimony content. Additionally the quantity and size of stick-on weights in each bucket will vary making it impossible to repeat your alloy from lot to lot. Also, it's a bit of a waste of a very good source of quite soft lead (about 6 BHN).

When most steel alloy's are either "*worked*" or "heat treated" they become both harder *and* more brittle, when lead is "*worked*" it becomes softer. Lead does not respond like steel, lead can be heat treated and made harder *without adding any brittleness*. Bullets destined for heat treating should be sized *without lube* and gas checked *before* they are heat treated, not after. Sizing hardened bullets is not only tough on your lubrisizer, tough on the bullets and tough on you, it also will work soften the driving bands of your bullets, the very part you wanted to strengthen. After a day or two for age hardening and to completely dry out they can be run through the lubri-sizer using a die .0005" to .001" larger than the die they were sized with.

Stand your sized and gas checked bullets up on the base in a suitable pan. It's fine if they are touching each other, in fact I group them together to aid in keeping them upright. I use flat bottom spaghetti pans with the holes enlarged for better water flow. Pre-heat your oven to the pre-determined temperature (see chart below) for the BHN you wish to achieve and then place the pan in the center of the oven for one hour. At the end of the hour as quickly as possible remove them and submerse in cool water (they are extremely soft at this point, try not to bang them around). I don't know of any testing done to determine an optimum time to be left in the water but I like to give them 10 minutes or so just to assure they are completely cooled throughout. If nothing else, it's a good excuse to drink a cup of coffee.



Three pans stacked high enough that the tops of the bullets don't touch the bottom of the pan above.



Convection oven, a thermometer and the spaghetti pans. Any bullets too long for bottom or middle pan are done in top pan.

Once out of the water I lay them out on an old terry cloth towel to dry out (completely, even under the gas check) and just let them sit there for a day or so. Now they can be run through the lubri-sizer, pan lubed, tumble lubed etc. to apply your favorite lube. If additional time is needed to reach their final BHN it's fine to go ahead and load them at this point and let them finish age hardening while loaded in the case.

We have all heard that heat treated bullet alloy will age soften over time but how much and how fast does this occur? While cleaning out the cabinet under my loading bench I came across a couple of box's of 35 caliber, RCBS 200 gr. heat treated bullet's properly labeled with the alloy (clip-on weights + 2% tin), the date and a BHN of 30. They were over 10 years old so I figured they would be putty by now but they tested at 26 BHN. 10 years, how is this possible? Taking from the "Key To Metals" article the antimony content of at least 4% and a low tin content controls the age strengthening *and* age softening of the alloy. It seems that if the percentage of tin had been higher or the percentage of antimony lower (or both) age softening would have been faster. With the box of heat treated bullets was a box of 7mm bullets of the same alloy and with the same date but not heat treated, the label said 11 BHN. In 10 years they also age softened and now test at 10 BHN.

There you have it. It's that simple to achieve the BHN that is proper for your load. Sufficient antimony (4%) and only enough tin to aid in mould fill-out, the proper convection oven temp and... exercise constraint. Do you really need or want a 30 BHN bullet? With a little time spent oven & range testing to see at what BHN your cartridge/firearm and load/pressure works it's best, a day at the range with cast bullets can be pure joy, not an evening of scrubbing lead from the bore. The proper BHN alloy for your load/firearm will enable you to get the most velocity and best groups possible with your cast bullets. Even terminal ballistics with hunting bullets can be controlled for proper expansion or no expansion with heat treated alloy's and hollow point designs can be controlled for the amount of expansion desired.

Water quenching (dropping bullets straight from the mould into a bucket of water) will harden your lead, antimony, arsenic alloy but as the lead pot and mould temperature varies so does the final hardness of the bullets. Additionally, you get what you get (about 15-19 BHN with wheel weights). As the revolver tests proved, varying the BHN effects both groups and the velocity extreme spread. With convection oven heat treating a specific BHN range can be attained and variation is held to a minimum.

The melting point of pure lead	621.3°F	327.4° C
The melting Point of antimony	1166.0 °F	630.0° C
The melting Point of tin	449.47° F	231.9° C
The melting Point of linotype	475° F	230° C
The melting Point of clip-on wheel weight alloy	463° F slushy	505° F molten

63/37 (tin/lead) solder melts at 361° F.

Tin lowers the melting point of lead alloys, the higher the percentage of tin the lower the melting point.

Testing Cast Bullet BHN Tester Variability

BHN TESTER EXPERIMENT

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Number of Tests	Oven Temp	Time In Oven	Avg. Water Temp	Avg. Number Bullets	Avg. Starting BHN	BHN In 12 Hrs	BHN In 24 Hrs	BHN In 48 Hrs	BHN In 96 Hrs	BHN In Day 7	BHN In Day 14
3	400°	1 Hour	56	165	10	11	11	14	15	15	
2	415°	1 Hour	60	100	10	13	14			17	
5	420°	1 Hour	58	300	10	12	17	17	18	18	18
2	425°	1 Hour	70	80	9.5			18	18	18	19
1	430°	1 Hour		100	9.5				20	20	
2	440°	1 Hour			11			18	20	20	
2	460°	1 Hour		300	11			25	25	25	
4	485°	1 Hour			11			30	30	30	
**2	460°	1 Hour		300	11	12	14	18	18	18	

About the chart

All BHN tests done with the LBT BHN tester.
All bullets heat treated and tested were with clip-on wheel weights + 3% virgin bar tin.
The oven was pre-heated and for uniformity of the tests the time in the oven didn't start until the oven returned to the set temperature.
**This test done with a gas fired conventional cook oven at 460°. Note difference in final BHN compared with the 460° heat treatment in the convection oven.
Average water temp is the average beginning temperature of all tests done at that temperature.
Average number of bullets is the average number in the oven and placed in the water for all tests at that temperature.
BHN values listed are the average of all bullets tested at that temperature. None varied by more than 1 BHN.
All BHN numbers listed are the average of at least three bullets tested per heat treatment at each temperature.
Thermometers, oven controls and especially BHN testers all vary, you may need to do a little tweaking of the numbers to achieve your desired BHN. The amount of antimony *and* tin in your

alloy *will* affect the time to age harden to the final BHN and the time and amount of age softening.
Additional testing is planned on the results of $^{1}/_{2}$ hour and 45 minutes oven time on the final BHN and hardening/time curve. Everything I have ever seen in print on heat treating says "about one hour" and nothing on the effect of 30 minutes or 1 $^{1}/_{2}$ hours. This could make for interesting/informative experiments.

[1]From the article "Heat Treating of Lead and Lead Alloys" on the web site "Key To Nonferrous Metals"

[2]From the Glen E. Fryxell article "Cast Bullet Alloys and Obturation"

Warning:

All technical data mentioned, especially handloading and bullet casting, reflect the limited experience of individuals using specific tools, products, equipment and components under specific conditions and circumstances not necessarily reported in the article or on this web site and over which The Los Angeles Silhouette Club (LASC), this web site or the author has no control. The above has no control over the condition of your firearms / equipment or your methods, components, tools, techniques or circumstances and disclaims all and any responsibility for any person using any data mentioned.

Warning:

LEAD, ANTIMONY, ARSENIC AND OTHER BULLET CASTING ALLOYS ARE TOXIC. MAKE USE OF ALL APPROVED LEAD HANDLING PRACTICES.

ALWAYS CONSULT RECOGNIZED RELOADING MANUALS