Making Tough No-Spin Throwing Knives: Rev. 3 (some new stuff)

Older Lesson Revisited: Propane Forge vs. Electric Furnace for Hardening
This is not an attack on those who forge knives for throwing. It is an observation, based on our own experience. I consider forging to be an art; therefore, since I have no artistic talent whatsoever, I have great respect for those who can bend metal to their will. The problems that I have encountered using propane have more to do with incomplete heating of the entire knife (hard blade, soft handle) as well as "burning" a **narrow** tip, making it brittle.

Anyone who has watched "Forged in Fire" will notice both tip and blade failures due to improper hardening procedures when using a propane forge. We may also assume heat treating in general, since they never show and barely mention the tempering process or results. I assume it's just too boring for most people.

I still like the show, they have skills that I don't! My issue with forging is the lack of an industrial approach. There seems to be too much guess work involved!

When we harden our knives, we first treat them with an anti-scale compound; I then go through the recommended slow heating process with a ten minute hold @ 1200°F.

Before quenching, we always use a magnet to verify proper temperature. We make sure that the oil is heated to between 130 – 140°F. When we quench, we move the knife in a slicing manner in the hot oil until the temperature is lower than 160°F (infrared thermometer), instead of pulling it out quickly to present an oil fire for the audience. We don't have one to impress.

We also realize that it is TV and anyone who can build a knife under the constraints of six hours with often unknown steel, is quite impressive. I couldn't do it!

Regarding custom knives, we were at a blade show several months ago and saw outrageous prices for many custom knives—not throwers. A fellow thrower (Bearded RAT) commented that he didn't think any of them could hold up to constant throwing. His point was valid for three reasons. First: Who, in their right mind would pay a $1000+ for a knife, only to abuse it by throwing? Second: Many, but not all, custom knives are considered to be art; therefore they are usually displayed rather than used. Third: These knives are tempered to hold an edge. They are hard! It's not a good idea to throw a hard knife.

We learned the valuable lesson regarding hard knives impacting on wood targets when we would buy different knives and throw them. If they stuck it was fine, but after several bad throws, they would inevitably snap. For example, one cheap set of Bowies, obviously made to hang on a wall, broke after one bad hit—all three of them.

Several months after the blade show, I got to watch an episode of "Forged in Fire" when they made throwing knives. As usual, it was a bit unfair because they had the contestants use coal forges, not something that they were used to in their craft. They also had them outdoors, hard to determine by color if they are ready to be quenched—no magnets in sight.

Punchline: When the knives were tested for strength by throwing really badly at a wooden target, the majority of them had severe tip/blade failures. They either made them too hard, or they burned the tips before quenching.

The moral of the story: Only a knife that is designed and heat-treated for throwing can suffer a great amount of abuse and survive over time.

I repeat I couldn't do what they do! I like to start with a known, high quality steel (not scraps), mill away the parts that don't look like a knife, clean up with the belt sander and heat treat. This is how we get repeatable results.

Early on in our knife-making efforts we experienced problems as well. Two tips broke hitting something we assumed to be relatively soft (a knot in the target and an unknown object). We originally considered it to be due to either being tempered too soft and bending first or hitting something harder than we thought. That led us down the road to harder knives—bad idea!

When two of my early Darts broke at the handle/blade interface (hard blade/soft handle boundary) within a month of each other, after a year of throwing, we realized that we had a problem. Since I had only thrown them approximately 16,000 to 20,000 times each, we had to determine what went wrong. We realized that really bad throwers, like us, needed to have a knife that can take the punishment of constantly hitting sideways at the edge of the target as well as hitting knives that are in the target sticking mostly sideways. Like I said, really bad throwers!

Combining the breaking with the constant torn finger tips from snagging on a gouge left from yet another tip/handle collision, caused me to rethink the hardening technique vis-á-vis converting to an electric furnace for full, even knife hardening. This approach seems to take care of finger gouging and knife breaks.

I have a paper on our site for making the electric furnace and a spreadsheet for selecting, sizing and sourcing the required materials for the build. <u>Don't use fire brick, use ceramic board!</u> As I tell my son, learn from the mistakes of others when possible.

Tip geometry: A Design Compromise between Deep Penetration and Strength

Deep penetration requires a thin tip with a narrow point. This should be the weakest part of a well-designed throwing knife. Our early efforts were focused on bolstering the tip strength while still making it a good penetrator. This led to our offset (asymmetrical) tip bevel. Minor chips on hard impacts with other knives, led us to the design of a wider, flattened and rounded tip. We're happy with this design.

More Recent Lessons Regarding Toughness vs. Hardness

When we started making our own knives, we decided to use O1 Tool Steel. It's tough when properly heat treated and it's forgiving. We decided on a hardness of HRC 51 – 53—not too hard and not too soft. This would require a temperature of 650° F. Unfortunately, when we performed our heat treat, we would end up with a test value of HRC 49 – 50. This was lower than we had expected. We would still occasionally get minor tip chipping when striking another knife sideways, or hitting a rock. We thought, at the time that we did not want the hardness to be lower due to our research into this area.

Then we had a catastrophic tip failure (~ 3/8” broke off) of the harder knife, we decided to figure out what went wrong. Our investigation revealed that the tip break was a freak accident (rotating in a gap between two bricks after rebounding from a very bad, hard throw—you should have seen the bricks), but it got us into doing more research regarding heat treating, hardness and steel types.

During our testing, we discovered that the reason for such a low hardness test (~ HRC 50) value was due to our poor prep for testing. We discovered that we were using our rebound tester improperly. We were fooling ourselves!

Our rebound tester requires a highly polished surface for accurate, repeatable results. We usually just sanded and buffed the surface before testing—not well enough. So, we were fooling ourselves about the actual hardness of the knives. The actual hardness was 3 – 4 Rockwell units higher. When we performed our stress tests, we polished the pieces to a mirror finish and found that our results were now within ± 0.5 HRC of the charts (Refer to our paper, “Testing O1 Tool Steel” for further details.) used for the testing.

Later, after our stress testing, we retested the knife with the badly damaged tip, after polishing it heavily, and found it to actually be HRC 53-54. According to our charts, just what it should be for a tempering temperature of 650° F. We now temper at 760° F which gives us a hardness of 52 ± 0.5 HRC. This takes care of the “too hard” problem.

Toughness vs. Hardness for Throwing Knives

Toughness is, or should be, the primary characteristic for a throwing knife! Knife hardness is important for holding an edge—throwing knives don’t have, or shouldn’t have, an edge to hold! While it may be nice to have both, it is not necessary.

Toughness may be considered to be inversely proportional to hardness for some steels (Fig. 1). When comparing toughness among different steels, O1 tool steel @ HRC 60 is the reference hardness, although it is not an optimal value as far as throwing knives are concerned.

Some steels, like S7, toughest when hardest and decrease with hardness to a point (Fig. 2). When comparing toughness, S7 tool steel @ HRC 56 – 58 is the reference hardness range for this steel.

Toughness can also be greatest at low hardness and decrease as hardness continues to be reduced (Fig. 3). When comparing toughness, H13 @ HRC 52 – 54 is the reference hardness range. Confusing, isn’t it?

The scale for S7 (Fig. 2) is possibly Charpy/10 since an HRC of 57 – 58 has a stated toughness on this scale of ~125 ft/lbs. Since scale and notch types are not always stated (Fig. 1 - 3) toughness comparisons among steels are difficult. For example, it appears that O1 tool steel @ HRC 51 has a stated toughness of ~140ft/lbs. This is much tougher than S7 @ HRC 57.

When comparing toughness among different steel types, the specific hardness must be stated (Fig. 4) or the comparison is useless. Aiming for HRC 51 may be great for toughness with O1, but is a bit low for H13 (peak toughness HRC 53 – 54) and a really bad idea for S7. Conversely, an HRC of 57 would be a bad idea for a throwing knife using O1 tool steel, but a reasonable approach using S7.

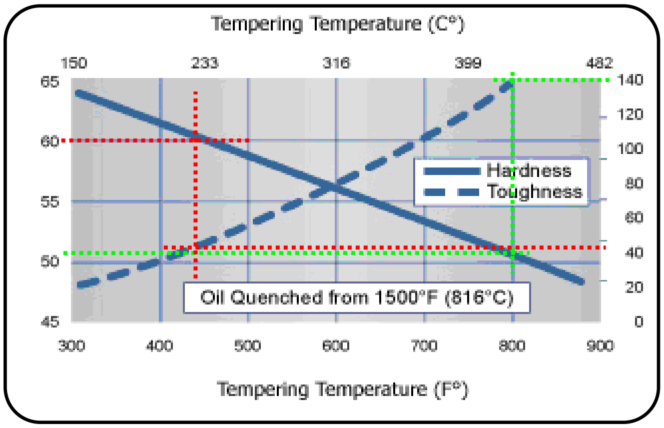


Fig. 1: O1 Tool Steel Toughness vs. Hardness Chart

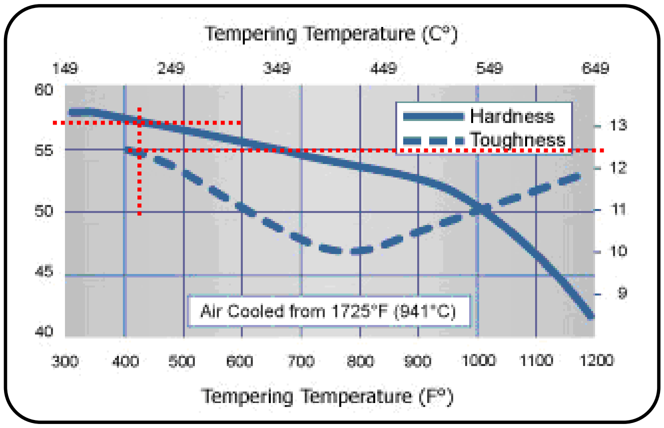


Fig. 2: S7 Tool Steel Toughness vs. Hardness Chart

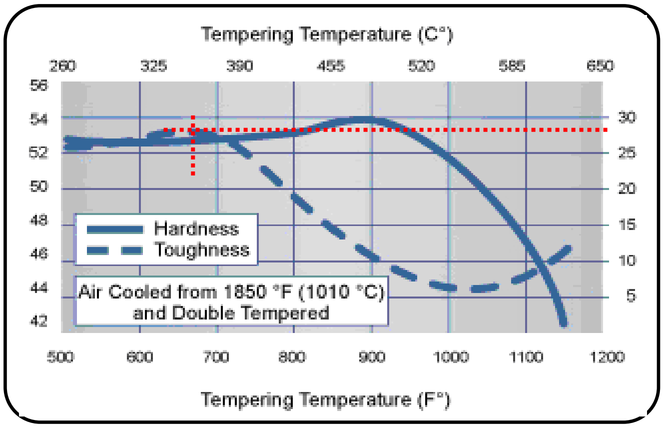


Fig. 3: H13 Tool Steel Toughness vs. Hardness

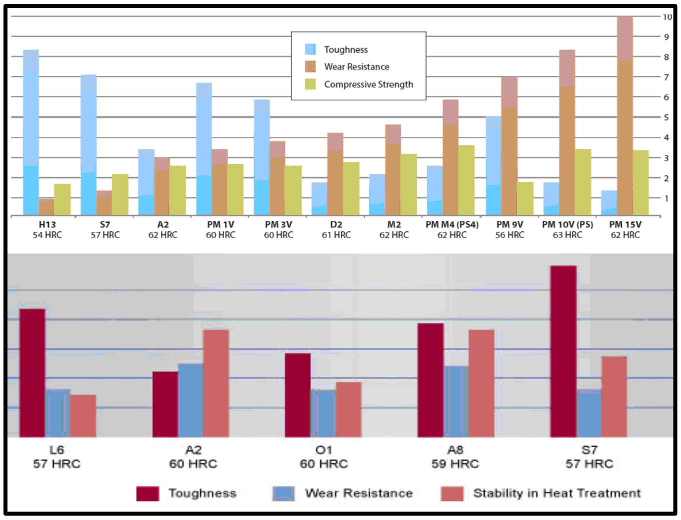


Fig. 4: Toughness Comparisons @ HRC

Toughness as a Function of Primary Purpose

O1 and S7 tool steels are both considered to be cold work steels. This means that they were formulated to work at temperatures up to 400° F. Their hardness is optimized for punches, stamps, molds, etc. This is why you see toughness comparisons stated at optimum hardness for these tasks.

H13, like other H-series (Hot working) tool steels, exhibits toughness at much lower hardness. So, when considering a throwing knife steel, toughness is critical, but must be based on target hardness for the throwing knife.

We can also see that direct toughness comparisons are difficult, not just because of the reference hardness, but because the tests used are not always stated or may be completely different for two steels. The two toughness tests commonly considered are the Izod (notched or un-notched) and the Charpy (same with the notches). Fig. 6 (same as Fig. 1, but shows test type used) refers to toughness of O1 tool steel using an un-notched Izod (notch faces away from impact piont). Notice toughness at HRC 50 - 51 (green in Fig. 1) is very high (~140 ft/lbs.) relative to reference used for comparison (HRC 60—red in Fig. 1).

Other areas for consideration when making a throwing knife are, steel grain size and Residual (Retained) Austenite (RA).

Grain Size, Briefly

Smaller grain size makes steel tougher. My research in this area shows that grain size is a function of the Austenitizing temperature (Fig. 5) and possibly rate of cooling. Since I am using 1460°F (middle the range for fine grain), for O1 Tool Steel, the ASTM grain size number is ~9 (considered to be "Fine").

Residual or Retained Austenite (RA)

RA is controlled by the heat treat process. The chart below (Fig. 5) shows that RA percent is a function of Austenitizing Temperature (AT). At 1460°F, for O1 Tool Steel, RA appears to be ~10% (some charts show higher RA). Per the chart below (Fig. 5), increasing the AT temperature above ~1515° F can begin to significantly increase RA percentage as well as increasing grain size. These two factors can reduce the toughness of a throwing knife.

It is important to remember that, over time, RA changes to Martensite. This is usually referred to as "aging". Unfortunately, it will be untempered (hard, brittle) Martensite. The other problem with RA to Martensite aging is an increase in volume, creating internal stresses, potentially leading to cracking under stress. So, as far as I can tell from my research, reducing RA percent is a really good idea. This is when sub-zero treatment comes into play.

Sub-zero Treatment before Final Temper

Research shows that sub-zero treatment of high-carbon tool steel (~1% Carbon—like O1 tool steel) prior to final temper, reduces RA. This process is often referred to as "rapid aging". So, the sub-zero treatment approach combined with rapid cooling after tempering at proper temperature should add to toughness. We know that the sub-zero process provides less advantage than the cryogenic process, but, from all I've read, it does provide a reduction in RA.

We now perform sub-zero treatment on all of our knives. After all, I'm just a retired engineer and a bit obsessive when designing and implementing my designs (like most engineers). So, I like to tinker and maximize performance of anything I make. I'm getting closer!

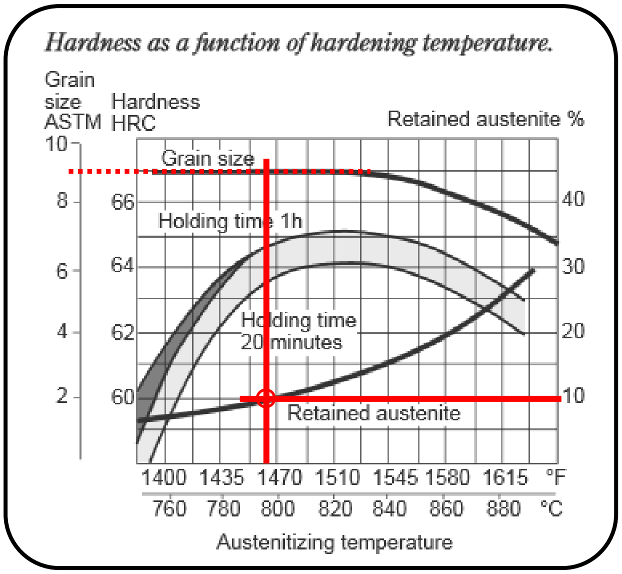


Fig. 5: Grain Size and RA of O1 Tool Steel

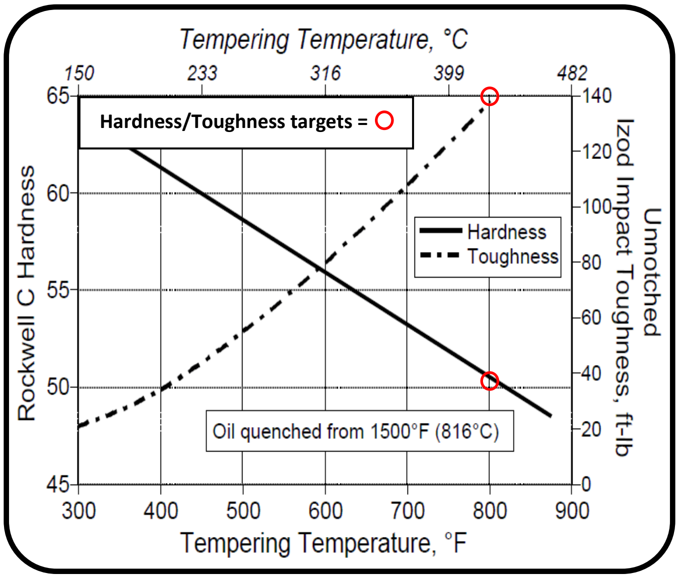


Fig. 6: O1 Tool Steel Toughness vs. Hardness Showing

So, Now What?

Based on what we have learned, so far, we are definitely staying with O1 tool steel, at least for now. It appears to be the toughest stuff we can find at our target hardness! We are currently using the stated approaches and values (Fig. 5 and 6 targets) for heat treating all of our knives.

We aren't experts at this, far from it. We're just amateurs who read, experiment and have fun making and throwing the results of our efforts. We think that anyone who has the equipment and abilities should make or have made for them, their own designs based on their style of throwing!

We have also recently developed a low tech approach to sub-zero cooling (-100 to – 110° F) that allows for a controlled temperature reduction of 4 – 9° F per minute, to avoid thermal shock when using the sub-zero process.

We first perform a "snap" temper, as recommended by several sources, among them Verhoeven*, when using O1 (or O2) steel. I have since performed this process on all of our recently made knives, even Bearded RAT's new Thick Offset Shorties (TOS). I am confident, from our results, that our new approach will make our knives even tougher.

*<u>Metallurgy of Steel for Bladesmiths and Others who Heat Treat and Forge Steel</u> by John D. Verhoeven, March 2005 (page 157, Table 14.5)

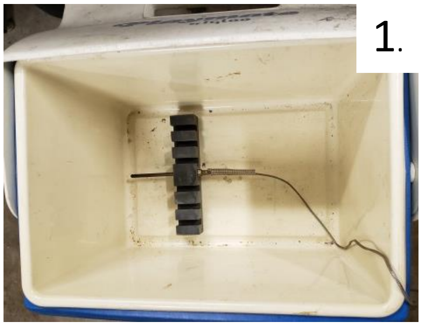
Another Update: Our Low Tech, Sub-zero Process

When we first started with sub-zero treatment, we just poured kerosene over the "snap" tempered knives and dumped dry ice on top. They cooled rather quickly!

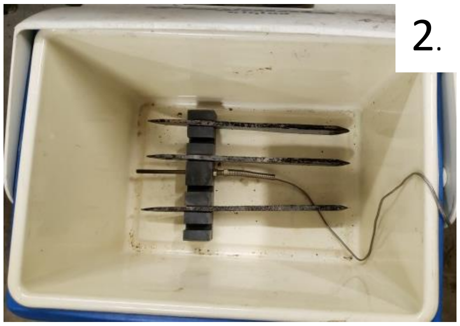
We later researched the process and learned that rapid cooling was not the best approach. According to several sources, one of which we just referenced, the reduction in temperature from ambient to required sub-zero should be at a controlled rate of 4° - 9° per minute.

So, how do you maintain a controlled rate without refrigeration equipment? We designed a process that does just that. The following are the details of the steps and the results of the last treatment we performed:

1. Place temperature probe in bottom in knife support piece (in hole).
2. After "snap" temper, place knives in bottom of cooler, resting on support piece.

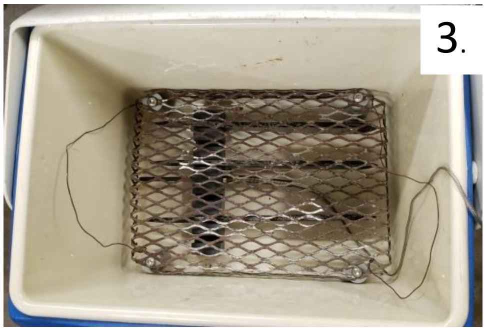


1.

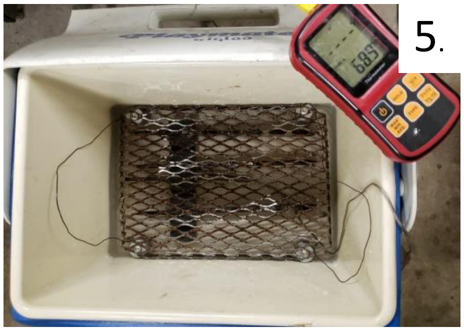


2.

3. Place expanded steel grate over knives.
4. Pour room temperature kerosene over knives to just under top of grate (~ ¼” below).
5. Record temperature of kerosene bath.


3.


4.


5.

6. Place dry ice pan on top of grate.
7. Break up dry ice into smaller pieces (I use a mallet), while still in the bag.
8. Place dry ice pieces in pan and place Styrofoam insulator (not shown) over it. Start timer.


6.


7.


8.

9. Close unit and record temperature drop every 5 minutes until < -90°F.
10. When temp hits ~ 0° F, add kerosene from freezer to make contact with dry ice pan.
11. As temp drop continues to slow, add kerosene from freezer into dry ice in pan.
12. As temp drop slows further, remove dry ice from pan and dump on grate.
13. When temp reaches lowest (~ -100 to -110° F) leave in overnight.


9a.

5 minutes


9b.

10 minutes


9c.

15 minutes


9d.

20 minutes


9e.

25 minutes

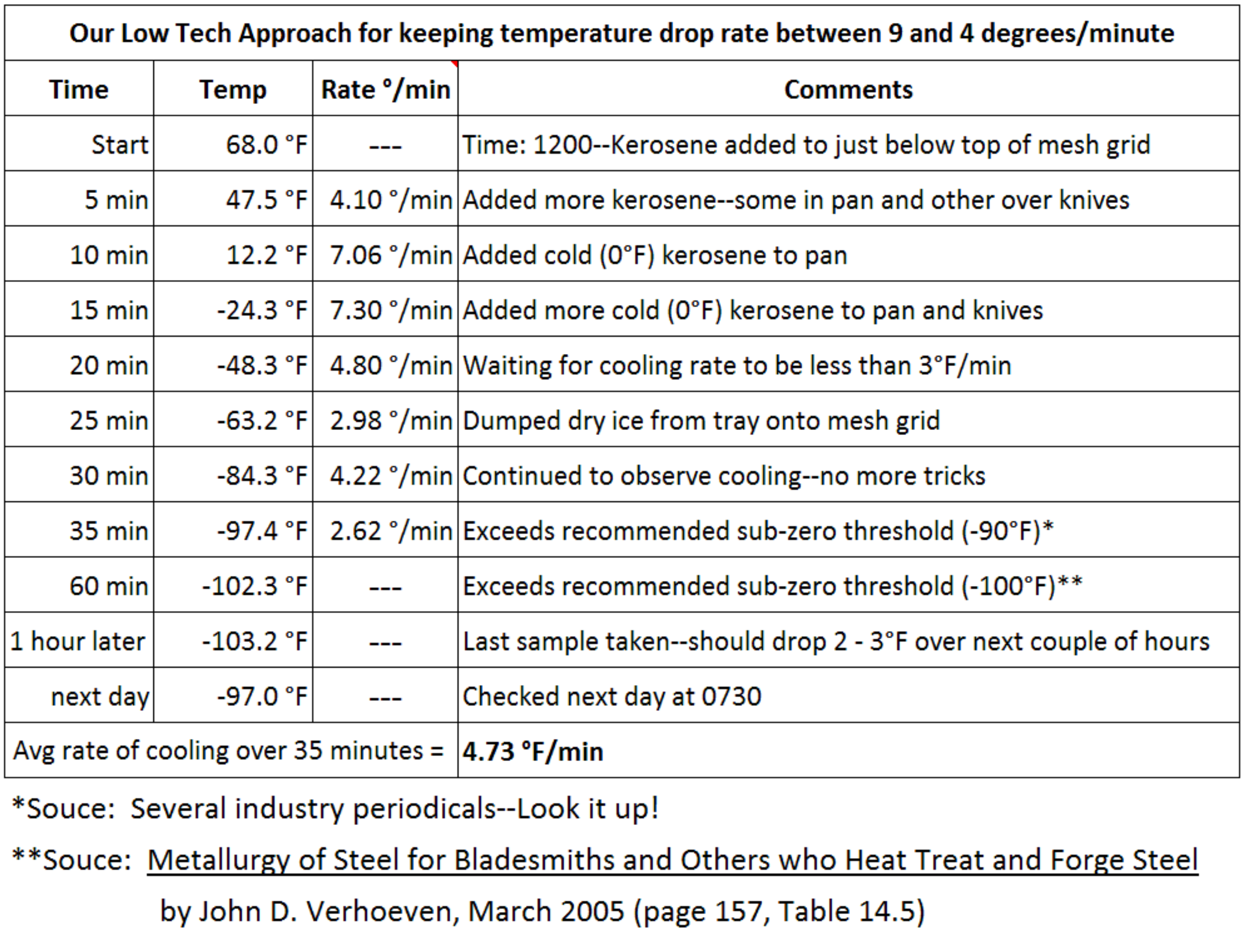

9f.

30 minutes


9g.

35 minutes

Steps 10 – 13, with schedule and cooling rates from our last knife treatment are shown on the next page.



Our Low Tech Approach for keeping temperature drop rate between 9 and 4 degrees/minute

Time	Temp	Rate °/min	Comments
Start	68.0 °F	---	Time: 1200--Kerosene added to just below top of mesh grid
5 min	47.5 °F	4.10 °/min	Added more kerosene--some in pan and other over knives
10 min	12.2 °F	7.06 °/min	Added cold (0°F) kerosene to pan
15 min	-24.3 °F	7.30 °/min	Added more cold (0°F) kerosene to pan and knives
20 min	-48.3 °F	4.80 °/min	Waiting for cooling rate to be less than 3°F/min
25 min	-63.2 °F	2.98 °/min	Dumped dry ice from tray onto mesh grid
30 min	-84.3 °F	4.22 °/min	Continued to observe cooling--no more tricks
35 min	-97.4 °F	2.62 °/min	Exceeds recommended sub-zero threshold (-90°F)*
60 min	-102.3 °F	---	Exceeds recommended sub-zero threshold (-100°F)**
1 hour later	-103.2 °F	---	Last sample taken--should drop 2 - 3°F over next couple of hours
next day	-97.0 °F	---	Checked next day at 0730
Avg rate of cooling over 35 minutes =			**4.73 °F/min**

*Souce: Several industry periodicals--Look it up!

**Souce: Metallurgy of Steel for Bladesmiths and Others who Heat Treat and Forge Steel
by John D. Verhoeven, March 2005 (page 157, Table 14.5)

So, that's it. We can now control our descent to sub-zero to avoid potential thermal shock. At least, that's what the experts say!

NEXT DAY--Tempering after Sub-zero

1. Remove remaining dry ice and allow to warm to >0° F in kerosene, adding small amounts of room temperature kerosene to help the process of warming.
2. Remove some cold kerosene and add more warm kerosene to bath as temperature continues to increase.
3. Allow to warm up to room temperature. This will take several hours and patience.
4. When at room temperature, place in boiling water to remove the remaining decarb powder.
5. Remove from hot water and allow to cool while setting up for tempering process.
6. Set furnace to 760° F.
7. When temperature is reached, place knives in furnace for 1 hour.
8. Remove and cool rapidly by plunging into water.
9. Clean, buff and blast.

Summary

As I have previously stated, we aren't really interested in selling lots of knives! Remember, there are already several really good no spin throwing knives (and a lot of bad ones).

As we go forward, we continue to focus most of our efforts on improving our knives and trying to provide some useful info for those who want to design and, possibly make their own as well. I have seen some nice DIY throwers that have been made without the use of a machine shop. Fortunately, I happen to have one, making my efforts much easier!

We still enjoy providing quality knives to those who don't or can't make their own. So, buy 'em, don't buy 'em, we don't care! We're still having fun!

We keep working on ideas to improve, if possible, our knives. We also continue to post our processes and research that we think can help others. We are always wide open to suggestions from other knife makers and throwers, amateur and professional.

Remember, as our YouTube channels states we are **Really Amateur Throwers (RATs)**!