Making Tough No-Spin Throwing Knives: More Lessons Learned

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! Early on in our efforts we experienced these 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 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) after a year of throwing, within a month of each other, 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 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. **Don’t use fire brick!** 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 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 of the harder knife, we decided to figure out what went wrong. We realized 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 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. Just what is should be for a tempering temperature of 650° F. At least we took care of that 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, will have greatest toughness 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 common 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 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.

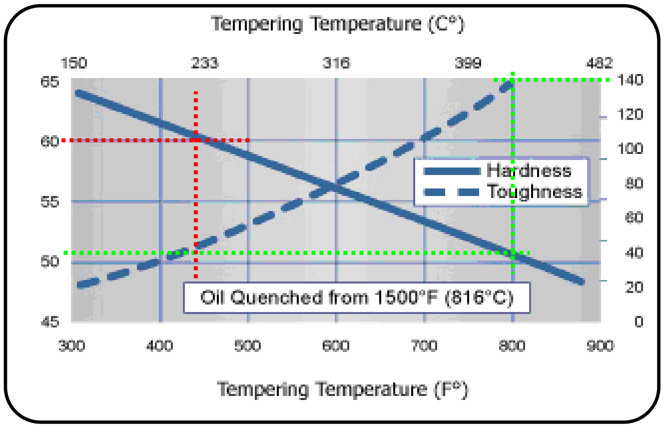

Fig. 1: O1 Tool Steel Toughness vs. Hardness Chart

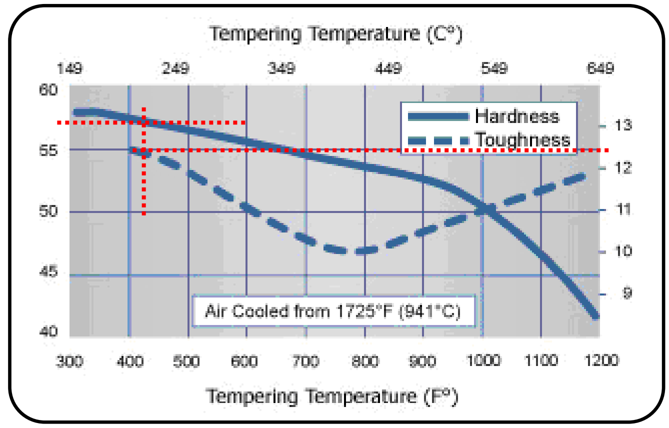

Fig. 2: S7 Tool Steel Toughness vs. Hardness Chart

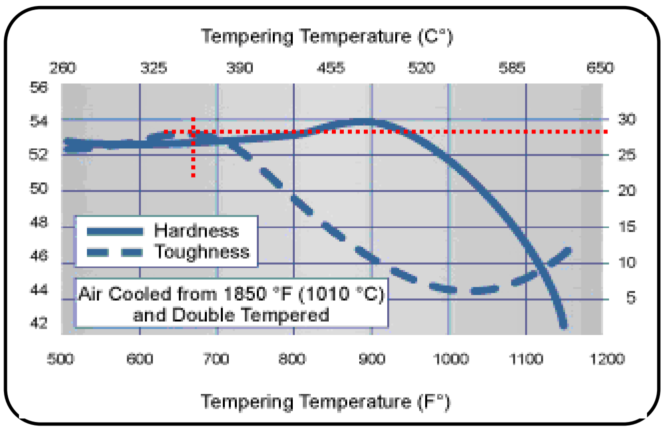

Fig. 3: H13 Tool Steel Toughness vs. Hardness

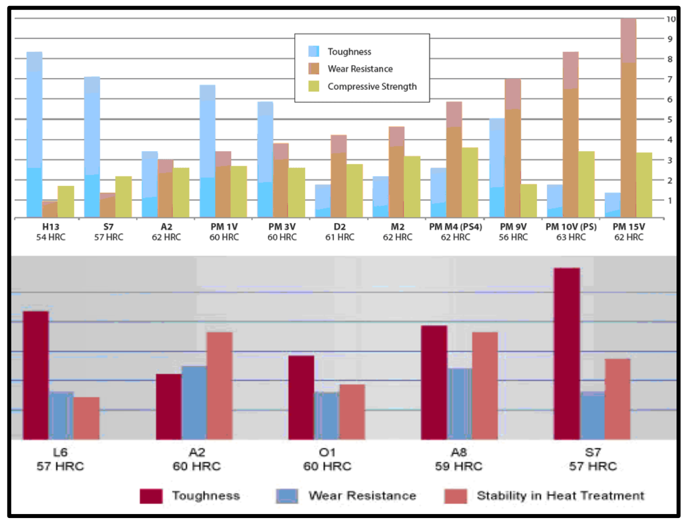

Fig. 4: Toughness Comparisons @ HRC

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) is very high (~140 ft/lbs.) relative to reference used for comparison (HRC 60—red).

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, 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 will change 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. 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. This is what we plan to do in the future. 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!

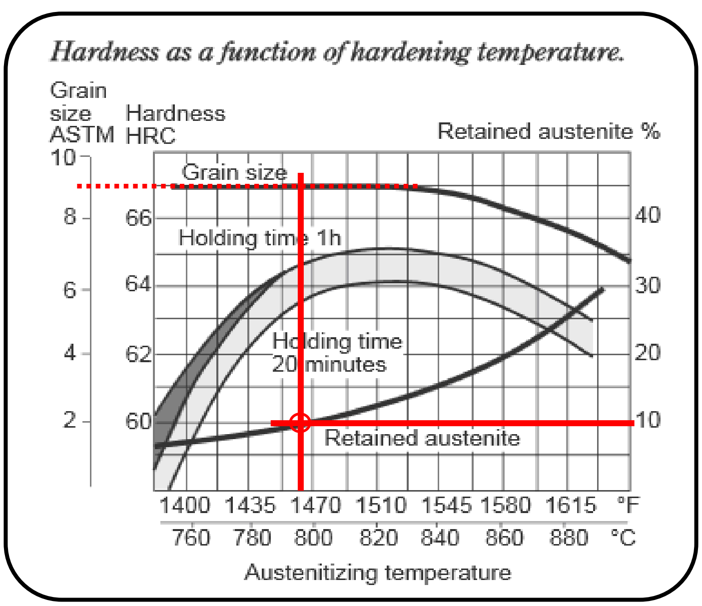

Fig. 5: Grain Size and RA of O1 Tool Steel

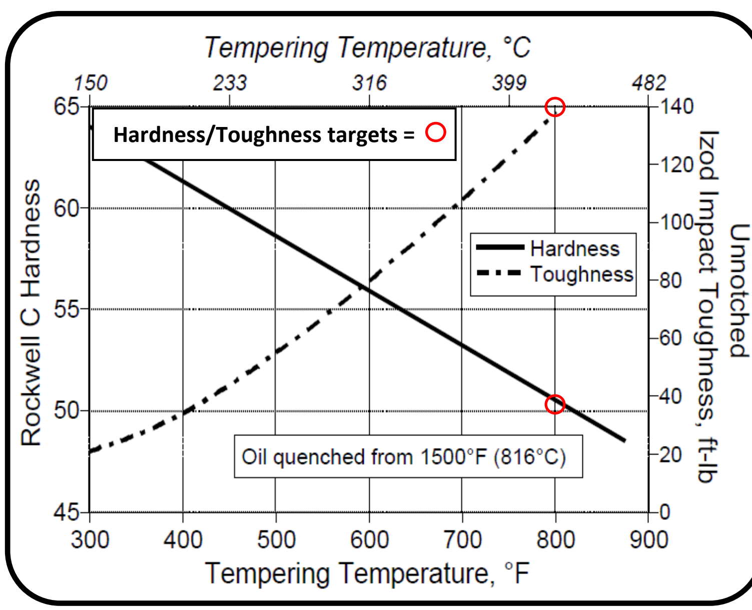

Fig. 6: O1 Tool Steel Toughness vs. Hardness Showing Test Type

Summary (update)
Based on what we have learned, so far, we are definitely staying with O1 tool steel 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 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 shock when using the sub-zero process. We also 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.

We aren't really interested in selling lots of knives! Since there are already several really good no spin throwing knives (and a lot of bad ones), I just want to provide yet another alternative for those who don't make their own. Of course, I think ours are the best, at least for our throwing styles. So, buy 'em, don't buy 'em, who cares! We're still having fun!

We plan to break more test pieces in the name of further research, but so far, so good!

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