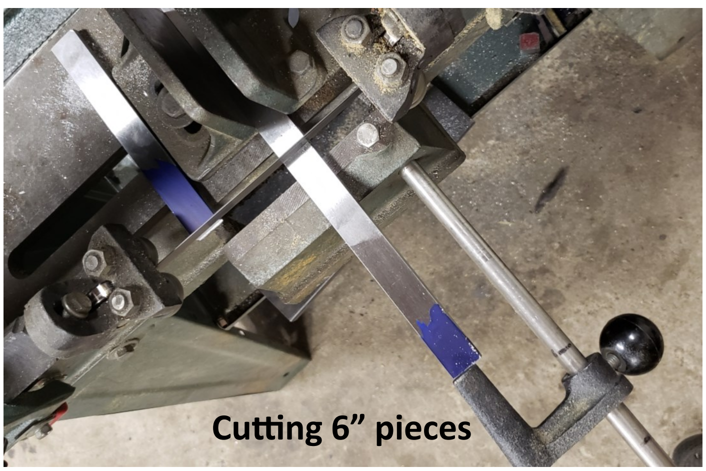
Testing O1 Tool Steel . . . Again

Part 2: Less Heat-treat Variables and More Uniform Test Pieces

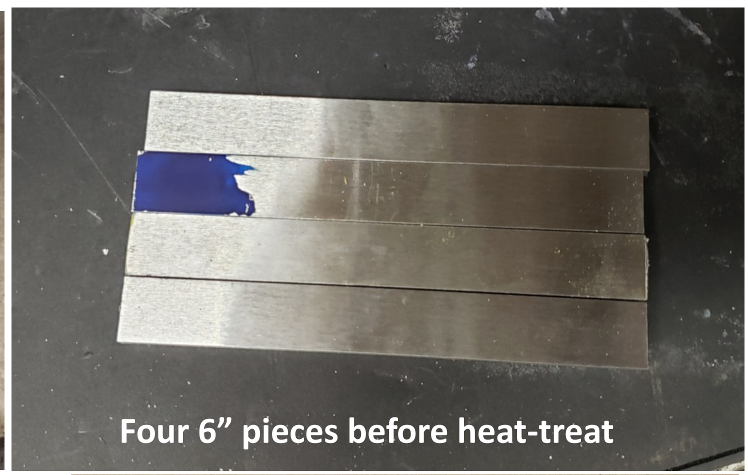
Our preliminary tests provided us with some good information, but not much. The number of variables and the inconsistent size and thickness of the test pieces made drawing any but the most basic conclusions difficult at best.

We could see that allowing a hardened piece to cool to room temperature and rest for an hour before tempering may be a bad idea for a throwing knife. We have always placed the knives in the oven to snap temper while allowing for the furnace to cool to the proper temperature for final tempering after the hardening process. Test pieces #7, #8 and #9 from Part 1 may have verified the efficacy of this practice.

In order to draw any further conclusions, we had to use test pieces of equal size and thickness. To this end we ordered a 36” piece of O1 tool steel measuring 0.750” x 0.250”. This is the typical thickness and width of our knife blades. We then cut them into 6” lengths for testing. We’re keeping two more pieces for verification testing, if needed.



Cutting 6” pieces



Four 6” pieces before heat-treat

We will be using these physically uniform test pieces (labeled **A**, **B**, **C** and **D** stamped top and bottom). We will repeat some of the previous tests. We plan to test hardness on all of them and perform impact testing—bend to break! This time we will record the hammering count.

Cleaned and polished ends for hardness testing

Four pieces after heat-treat

Heat-treating the Pieces: The Process and Resulting Hardness

The heat-treating process was similar to the Part 1 process. Since all of the pieces were larger and had the same proportions, we needed a more aggressive technique for maintaining the quench oil temperature. So, before starting we filled a separate container with extra oil and had another container for depositing the hot oil. After each quench we removed a portion of the hot oil, placed it in the empty container and, while agitating the hot oil in the quenching tower, added the room temperature oil into the quench tower. When the oil reached the proper temperature, we quenched the next piece. This process was repeated for each piece after the first.

As before, when the quenched piece reached 125—150° F (IR thermometer) it was wiped and placed in the oven (piece **A**, **B** and **C**) or left out at room temperature (piece **D**) while lowering the furnace temperature to <750° F for tempering. The furnace actually must be lowered to ~ 600° F or else when power is applied, the residual furnace heat will shoot the temperature above the target temperature.

Since we usually leave the parts in the oven for an hour as the furnace temperature cooled, we experimented with approaches that would reduce this cool-down time. After some experimentation, we found a technique that allowed for proper temperature reduction of the furnace after 35—40 minutes of cooling. This will be our approach in the future!

Piece	oil temp	oven temp	oven time	test	cool rate 1	cool rate 2	Comments
A	129	330	1 hour	Impact	fast	fast	cooled in water after oven and furnace
B	133	330	1 hour	Impact	direct	fast	direct from oven to furnace
C	136	330	1 hour	Impact	direct	slow	allowed to slowly cool after 750° F temper
D	136	--	--	Impact	no oven	slow	tempered 40 minutes after hardening

Notes:

All oven temps: 330° F

All oven times: 1 hour

All furnace temps: 750° F

All furnace times: 2 hours

Cool rate 1: after oven

Cool rate 2: after furnace

Piece	Hardness
A	HRC: 49.6 and 49.9
B	HRC: 50.5 and 50.3
C	HRC: 48.4 and 47.9
D	HRC: 51.1 and 51.4

Each hardness test result is an average of 5 hits.

Testing the Pieces

1. Hardness tests: Hardness was tested using our Leeb portable rebound tester. The pieces were polished in preparation for testing. The results were based on the average of five strikes on each piece. These tests were then performed a second time the next day to verify original results. The following, same as the previous table, are the results in Rockwell C hardness.
   Test piece A: 1st avg = 49.6, 2nd avg = 49.9
   Test piece B: 1st avg = 50.5, 2nd avg = 50.3
   Test piece C: 1st avg = 48.4, 2nd avg = 47.9
   Test piece D: 1st avg = 51.1, 2nd avg = 51.4

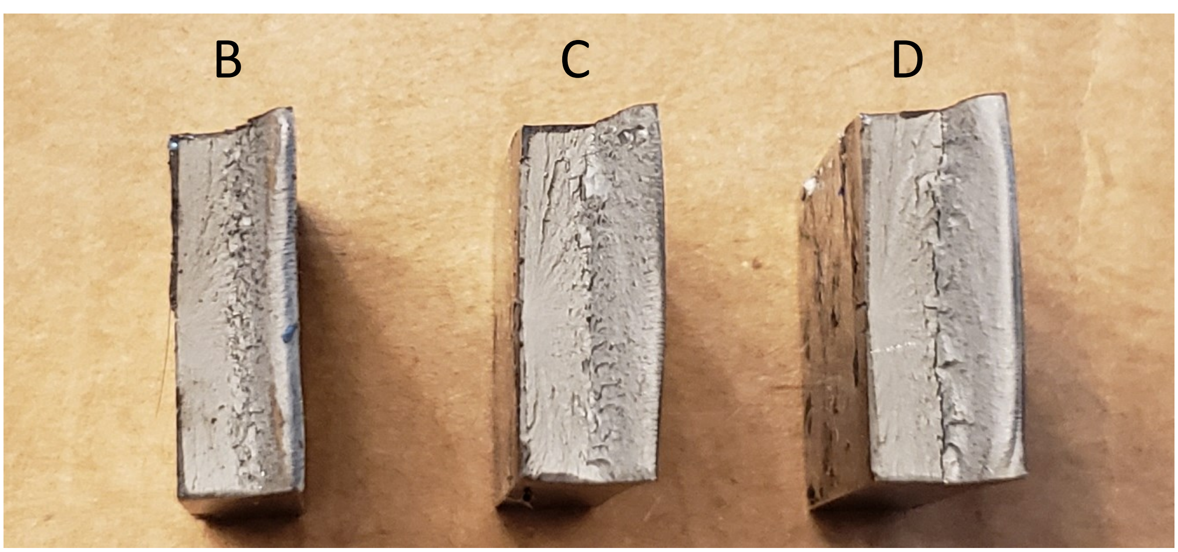
2. Bend/Break tests: Before clamping in the vise for pounding, we placed 1/4-20 bolts in the holes of each piece and used lock nuts to secure them. We did this in order to have a consistent point of contact for the sledge hammer. It would have worked if we could maintain our accuracy, but as the video we up-loaded to our YouTube channel shows, we occasionally miss-hit. Some hits we didn't count since they were partial strikes, other hits were a bit on the low side. Oh well, we tried!

   After a group of five hits, we would measure the deflection with a digital protractor, then clamp it in the vise and go again. We continued this process for each piece until it broke or we gave up as in the case of pieces **A** and **C** on the first attempts at breaking the pieces. We would return another day to finally break piece **C**, but not **A**.

   The table on the following page shows the degree of deflection and possible breaks for the number of hits with a four (4) pound sledge hammer. The Bearded RAT did the bulk of the hammering. This was done for consistency, but I wanted to get in on the fun as well. Being left-handed was beneficial—the vise table was up against my tool box. This minimized the table motion on my hard hits!

   The end grain of the three pieces that we *could* break is shown below. Piece **A** is not shown because after 55 hits and still not breaking, we gave up. You might say that it broke us! Piece **B** was the first to break, followed by **D**. Piece **C** required another session, days later.

   You can see from the fracture points that all of the pieces have a fine grain structure, exhibiting a smooth light gray surface. The fractures looked really rough on **B** and **C**, but rather smooth on **D**.



Summary of Our Greatest Hits

The following table provides the number of hits and angle of deflection per group of hits. As previously mentioned, we tried to make our hits as consistent as possible. If you watch the video, you will see that there were some obvious misses that had to be repeated as well as low hits. The difference in hitters is also a consideration. Oh well, at least we had the 4 lb. sledge hammer to somewhat compensate for our inconsistencies!

As you can see from the following table piece **B**, which was the second hardest, broke after the least number of hits. It was followed by **D** which broke at the shallowest angle. Piece **D** was also the hardest and was left to cool after quenching, before tempering.

The conclusions, so far, would lead one to believe that **A** would break next, since it is next in line for hardness and approximately the same hardness as **B**. Strangely enough, **C**, the softest piece, broke next. Piece **C** was really tough! The rebound when hitting it was incredible! We never did break **A**! After 55 hits we gave up! In terms of hardness, **A** and **B** were less than one Rockwell apart, but in terms of toughness, they were significantly different.

Piece	Hits	Bend angle	Hitters and Comments
A	5	2.5°	Bearded RAT
	5	3.1°	Bearded RAT
	5	4.8°	Bearded RAT
	5	6.8°	Bearded RAT
	5	9.8°	Old RAT
	5	11.5°	Bearded RAT
	5	12.3°	Bearded RAT
	5	16.0°	Bearded RAT
	5	21.0°	Bearded RAT
	5	25.5°	Bearded RAT
	5	32.8°	Bearded RAT--55 hits and still not breaking--we gave up!
B	5	2.9°	Bearded RAT
	5	4.0°	Bearded RAT
	5	5.2°	Bearded RAT
	5	7.5°	Bearded RAT
	5	14.0°	Old RAT--After 25 hits broke at this angle
C	5	2.1°	Bearded RAT
	5	1.7°	measured again--weird
	5	3.6°	Bearded RAT
	5	4.0°	Bearded RAT
	5	10.1°	Intense rebound! Old RAT: Must be "spring tempered"!
	5	10.5°	Bearded RAT
	5	11.2°	Bearded RAT
	5	13.5°	Bearded RAT
	4	17.3°	Bearded RAT--After 44 hits broke at this angle
D	5	2.5°	Bearded RAT
	5	3.3°	Bearded RAT
	5	3.7°	Bearded RAT
	5	4.7°	Bearded RAT
	5	8.4°	Old RAT
	2	8.4°	Old RAT--After only 27 hits broke at this angle--shallowest of all!

Summary and Conclusions

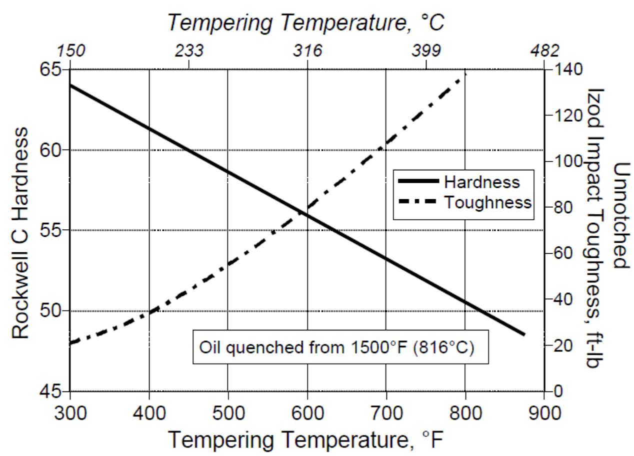
So, the question is "What did we learn?" We learned that hardness does not answer all questions regarding toughness. As the chart below shows, O1 Tool Steel has an inverse relationship between hardness and toughness. So, the softest (**C** at HRC ~48.2) should have bent the furthest and have broken last! It did take a lot of punishment before breaking, but not as much as a harder piece (**A** at HRC ~49.7) that bent further and did not break. Curious! Could it have to do with the process?

None of the test pieces, except piece **D**, have hardness that aligns with the chart below. We had used this chart in a previous experiment regarding flexural strength. At that time, the numbers were in line with expectations according to the chart. One variable that may account for this is the new quench oil.

Until recently, we used canola oil for quenching. When we went to Quenchall 28 second oil, I noticed that it seemed to take longer to bring the knife or test piece down to the proper temperature. While I believe that this is beneficial in reducing possible quench cracking, it may also lower the final hardness of the piece. This is speculation at this time, so we will have to do further testing.

Although these results are not conclusive, they lead me to a narrower focus for further tests. Next things to be considered:

1. Quench oil type as previously mentioned.
2. How consistently we agitate the oil when we plunge the knife (or test piece) into it may be a cause for variability of results.
3. Quench oil temperature.
4. Hardening sequence (Quench sequence: **A, B, C, D**).
5. Oven temperature for holding piece while furnace cools.
6. Cooling rate: oven-to-furnace and post-final temper



So, what's next?

Since repeatability is the measure of a successful test, we will be retesting some of these processes, for consistency with earlier results. Since we are comfortable with the knowledge that **D** was weakened by being allowed to cool to room temperature for a period of time before tempering (as with the pieces 7, 8 and 9 in Part 1), we see no need to retest it at this time.

Currently we plan to use the several more pieces of the same size to repeat the process for **A** and **B** (toughest and weakest with approximately the same hardness) at a minimum. We plan to reverse the quench sequence, **B** first and **A** second, to see if anything changes. Right now, I'm favoring the process used with piece **A**. Strangely, it is the process that we have been using for my knives. I have always wondered if placing a tempered blade (750° F) in water to cool rapidly would cause any stress problems. I guess I now know the answer. **Not likely!**

We will post further results on our website when we finish the next tests. If retesting **A** and **B** have different outcomes we will reevaluate and perform more tests. We may vary parameters such as, oil and oven temperatures. As always, we hope this is somewhat useful to other DIYers out there.