Testing O1 Tool Steel . . . Again

Part 1: Using Some Scrap Pieces to Test Several Heat-Treat Variables

We recently changed from Canola oil for quenching to Quenchall 28 second oil. We also modified our quenching process by using an electric heater to get the oil temp up for quenching. Due to an earlier failure of some knife tips, we also decided to add a mixing process to maintain the oil temperature constant from top to bottom. This required a mixer attached to a drill combined with thermal probes top and bottom.

The new quench oil system approach allows us maintain constant oil temp over the entire quench oil column. In order to keep the oil temperature below the maximum temperature (< 140° F) for our testing, we used a frozen aluminum bar, plunging it into the oil when the oil exceeded maximum temperature. Since most of the pieces were small, the frozen aluminum bar did the trick.

Since we have a bunch of scrap pieces of O1 tool steel (artifacts of the knife making process, some shown below), we decided to test some other process variables to determine their effect on toughness.

We started with nine (9) pieces of scrap O1 tool steel, shown below after coating with anti-scale paint. We focused on impact testing, instead of just bending as we had done in previous tests. Because the pieces vary in thickness and length, we considered this first set of tests to be preliminary.

We hardened all of the pieces at 1460° F and tempered all of them at 750° F. Most of them we snap tempered at 330° F while waiting for the furnace to cool to tempering temperature. Others we allowed to rest at room temperature while the furnace cooled for tempering (~1 hour). We varied how fast we cooled them from snap temper and final temper. "Fast" cooling means cooled in water. "Direct" means no cooling from snap temper to final temper. "Slow" applied to post-final temper, allowing them to air cool slowly. These variables and results are presented on the following table.

Some scrap pieces from knife making
(We have a lot more!)

Nine pieces of scrap O1 tool steel used for testing different variables

Test Parameters and Preliminary Results

Piece #	Quench seq	Oil temp	Oven	Test	Cool rate 1	Cool rate 2	Comments	Dim (inches)
1	1	107	Yes	Impact	fast	fast	thick piece relative to 7 - 9--strong tip	0.25 x 0.375 x 6.3
2	2	114	Yes	Impact	direct	fast	thick piece relative to 7 - 9	0.25 x 0.375 x 6.3
3	8	128	Yes	hardness	direct	slow	thick and wide piece--removed 2nd to last	0.312 x 1.25 x 5.0
4	9	141	Yes	hardness	direct	fast	thick and wide piece--removed last	0.312 x 1.50 x 5.1
5	3	121	Yes	Impact	fast	slow	handled pounding better than other pieces	0.281 x 0.281 x 4.8
6	4	123	Yes	Impact	fast	fast	handled pounding better than other pieces	0.281 x 0.281 x 4.8
7	5	127	No	Impact	no oven	slow	Cooled for 1 hour after quench before temper	0.211 x 0.312 x 5.4
8	6	124	No	Impact	no oven	slow	Cooled for 1 hour after quench before temper	0.211 x 0.312 x 5.4
9	7	127	No	Impact	no oven	fast	Cooled for 1 hour after quench before temper	0.211 x 0.312 x 5.4

Notes:

All oven temps: 330° F

All oven times: 1 hour

All furnace temps: 750° F

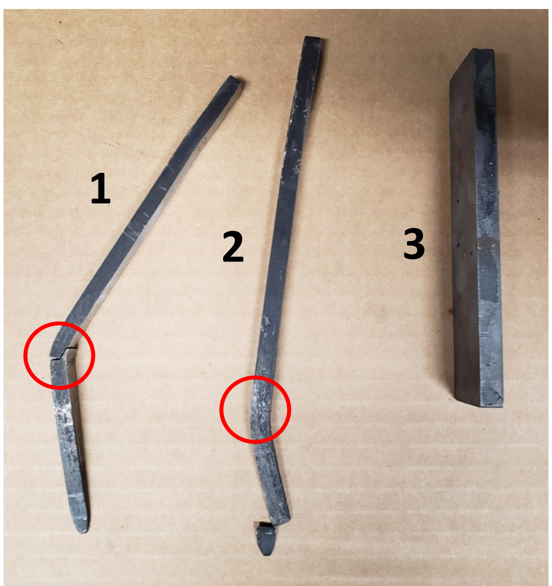
All furnace times: 2 hours

Cool rate 1: after oven

Cool rate 2: after furnace

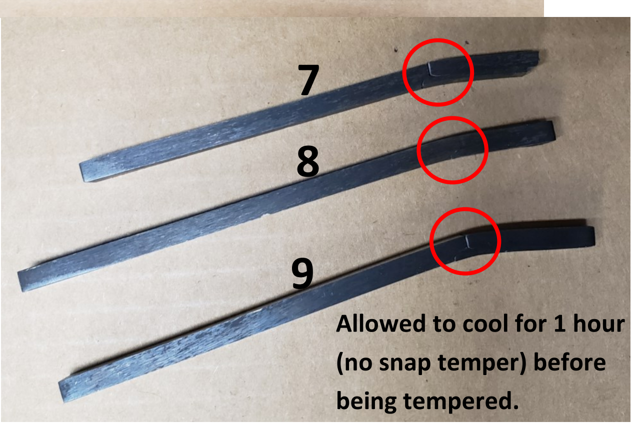
All pieces: break tests done on thin side

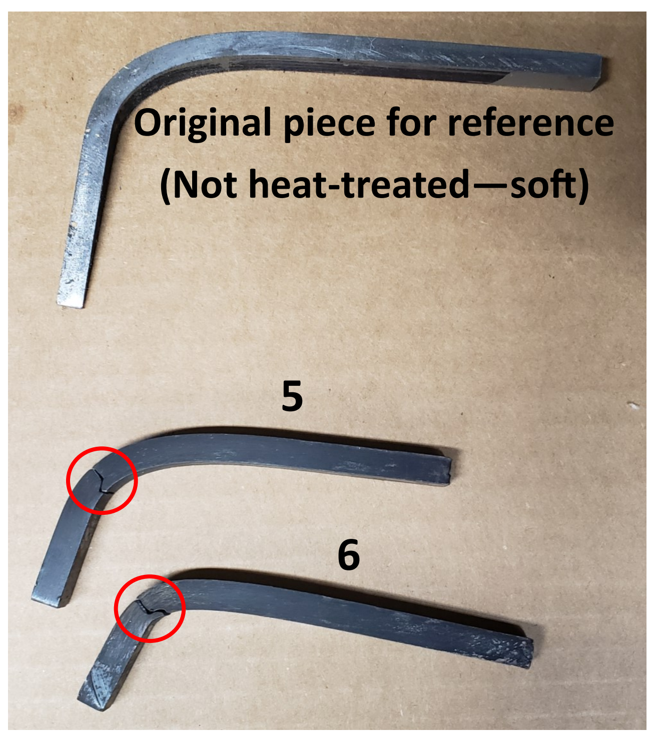
Piece #	Preliminary Results
1	Severely pounded--Broke at ~ 36°
2	Severely pounded--Broke at ~ 30°
3	HRC 50.4--Severely pounded--no discernable deflection--gave up!
4	HRC 50.8--Severely pounded--no discernable deflection--gave up! Then lost it somewhere!
5	Severely pounded--bent to breaking at ~ 77°
6	Severely pounded--bent to breaking at ~ 70°
7	Severely pounded--bent then broke at ~ 4° Sitting out for 1 hour before tempering is a bad idea
8	Severely pounded--bent then broke at ~ 10° Sitting out for 1 hour before tempering is a bad idea
9	Severely pounded--bent then broke at ~ 15° Sitting out for 1 hour before tempering is a bad idea



Notes:

- Break points are circled in red.
- Lost (as in misplaced) piece #4—no idea how! It's out there somewhere!
- Piece #2 was clamped by the tip and took several hits before snapping.
- Piece #5 had more hits close to the top than #6.
- Pieces #7, 8 and 9 were as hard to bend as others, but broke at shallow angles.





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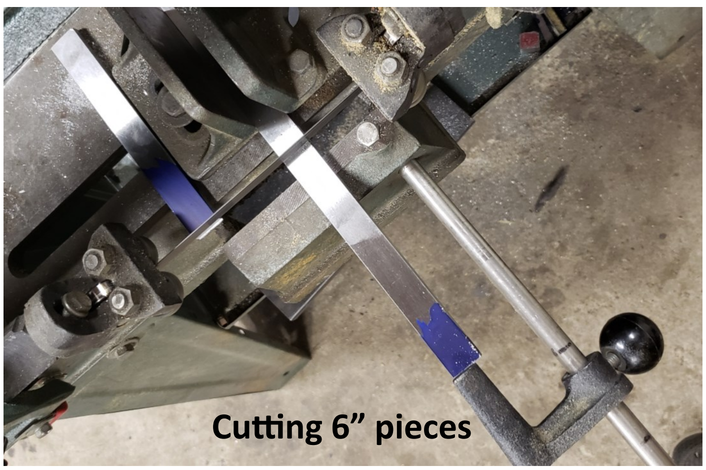
Part 2: Less Heat-treat Variables and More Uniform Test Pieces

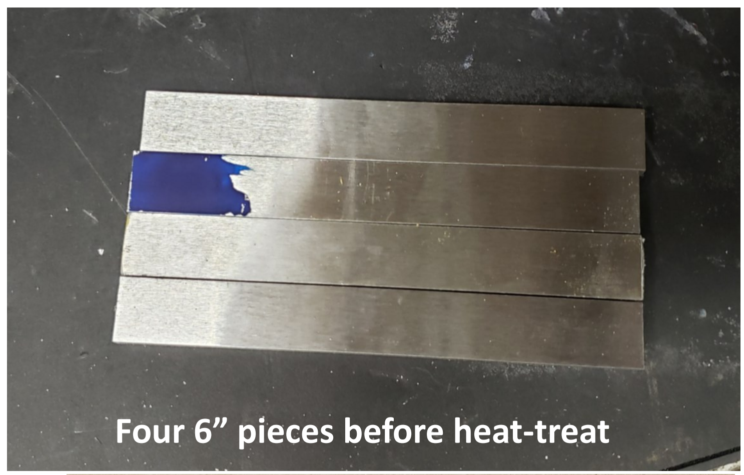
Our preliminary tests provided us with some good information, but not much. The number of variables and the inconsistent size and thickness of the test pieces made drawing any but the most basic conclusions difficult at best.

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

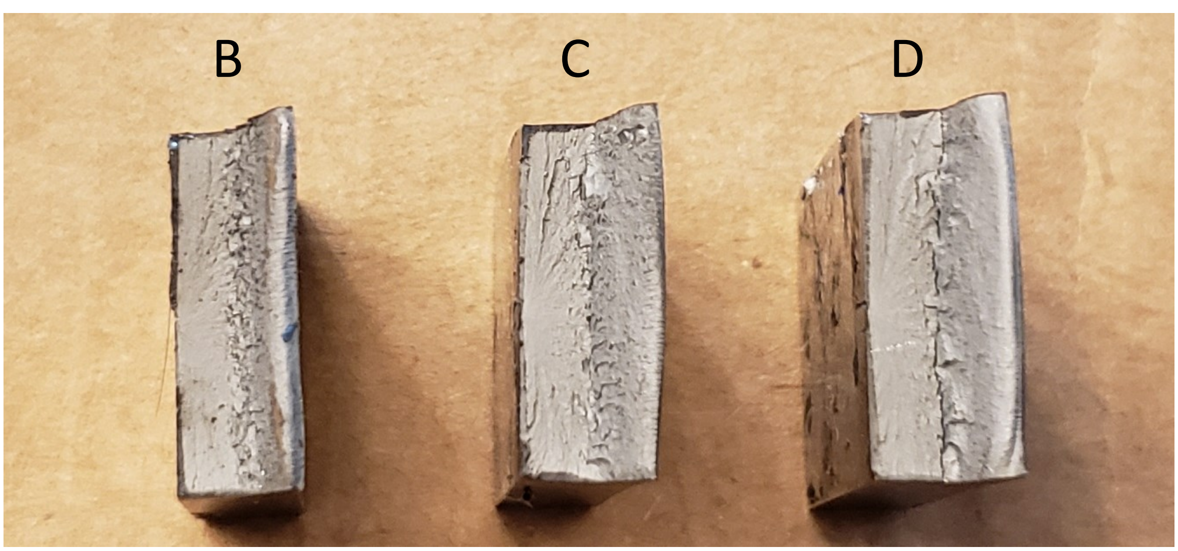
2. Bend/Break tests: Before clamping in the vise for pounding, we placed 1/4-20 bolts in the holes of each piece and used lock nuts to secure them. We did this in order to have a consistent point of contact for the sledge hammer. It would have worked if we could maintain our accuracy, but as the video 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!