Part 3: Re-retesting Knife Steel with New Agitator System

A Brief Review or Here We Go Again:

If you have read our recent knife steel tests (Part 1 and 2), you may remember that our initial reason for testing O1 tool steel for hardness and toughness was based on changing our quench oil from Canola oil to Quenchall 28 Second oil (McMaster-Carr). We wanted to evaluate the performance of our new quenchant before making any knives with it.

During our testing, we discovered some other areas to consider for improvement. Initially, we improved our approach to getting the quench oil temperature down after quenching a knife (or test piece in this case). This was done with a ladle to remove oil and a pan to transfer room temperature oil back into the quenching tower while mixing the oil with a paint mixer on the end of a drill. Although it was an improvement on the old cold aluminum rod for keeping the oil temperature approximately where we wanted it, it involved several steps and was messy, .

After the previous set of break tests (Parts 1 and 2), we began to research quench oil systems. This led us to develop our overhead agitator system with baffles. A good DIY project for knife makes to check out!

Once we had the new quench system in place, we decided to perform tests on another set of pieces. We wanted to focus on two variables from the previous test:

1. <u>Quench time and temperature</u>, based on how long it took to reach < 150° F during the quench. We assumed that the new quench system would allow for faster, more uniform quench times. It did!
2. <u>Quench sequence</u>, based on the time between quenches for each piece of steel. If the quench oil temperature was the same for each piece, (~130° F) the only variable under consideration would be the extra time spent in the furnace before quenching.

Before going forward, lets take a quick look at the results from "Testing Steel—Part 2". Remember, the only component of the system that changed since Part 2 was the new agitator system with baffles. Below is a summary of findings from the **previous** set of tests (Part 2). Notice that piece "A" was the toughest of the group, so it was the basis for the next set of tests. It is important to remember that the heat-treat process for piece "A" was the same process that we have always used for making our knives.

Piece	oil temp	oven temp	oven time	test	cool rate 1	cool rate 2	Comments
A	129	330	1 hour	Impact	fast	fast	Did not break after 55 hits--bend angle 32.8°
B	133	330	1 hour	Impact	direct	fast	Broke after 25 hits--break angle 14.0°
C	136	330	1 hour	Impact	direct	slow	Broke after 44 hits--break angle 17.3°
D	136	--	--	Impact	no oven	slow	Broke after 27 hits--break angle 8.5°

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--Combined average HRC: **49.8**
B	HRC: 50.5 and 50.3--Combined average HRC: 50.4
C	HRC: 48.4 and 47.9--Combined average HRC: 48.2
D	HRC: 51.1 and 51.4--Combined average HRC: 51.3

Each hardness test result is an average of 5 hits.

Testing Part 3 Process:

Using test pieces with the same dimensions as the previous test pieces, we decided to use only the parameters of test piece “A”. So, all three of the pieces used those parameters.

Since the new quench system allowed for maintaining consistent oil temperature for quenching each piece while providing a consistent bottom-to-top agitation of the oil during the quench, the only variable was how long each piece was in the furnace before quenching.

As the chart below shows, each piece was quenched for two minutes to reach below 150° F (132—140 ° F). Using the new system, it took less than a minute to pump out some hot oil and replace it with room temperature oil to bring the oil temperature back to ~131° F. The digital thermometer with the 12” probe (bottom temp) and the IR thermometer (top temp) converged quickly when adding the room temperature oil after each quench as the agitator continued to run.

Each piece was then placed into the 330° F oven for one hour before final temper in the furnace at 750° F for two hours.

Repeating Original "A" Parameters for Consistency							
Piece	**oil temp**	**oven temp**	**oven time**	**test**	**cool rate 1**	**cool rate 2**	**Comments**
A	129	330	1 hour	Impact	fast	fast	**Original "A" from previous tests**
1	131	330	1 hour	Impact	fast	fast	1st to quench--same as original "A"
2	132	330	1 hour	Impact	fast	fast	Same as 1, but second to quench
3	131	330	1 hour	Impact	fast	fast	Same as 1, but last to quench

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 (two averages of five hits)
A	**HRC: 49.8--Original "A" from previous tests--toughest tested**
1	HRC: 49.7 and 49.5--Approx. **0.2** Rockwells lower than original "A" when combined
2	HRC: 50.2 and 50.6--Approx. **0.6** Rockwells higher than original "A" when combined
3	HRC: 49.3 and 49.6--Approx. **0.3** Rockwells lower than original "A" when combined

Time between quenches ~ 3 minutes (2 minutes to quench and 1 minute to restore oil temperature)

The variations in hardness across al three pieces was less than 1 Rockwell. Relative to the original “A”, the worst-case variation (piece 2) was 0.6 Rockwell. So, essentially they were the same hardness. We learned from the previous tests that, even though charts show a correlation between hardness and toughness, the hardness didn’t seem to be much of an indicator of toughness for each piece. Remember, for O1 tool steel, hardness and toughness are inversely proportional.

When we once again started impact testing with the old reliable four pound sledge-hammer, we were expecting to see tough steel bending rather than breaking. We were expecting to see results similar to the original piece “A” from the previous tests (Part 2). Our results far exceeded our expectations, as you can see in the chart on the following page.

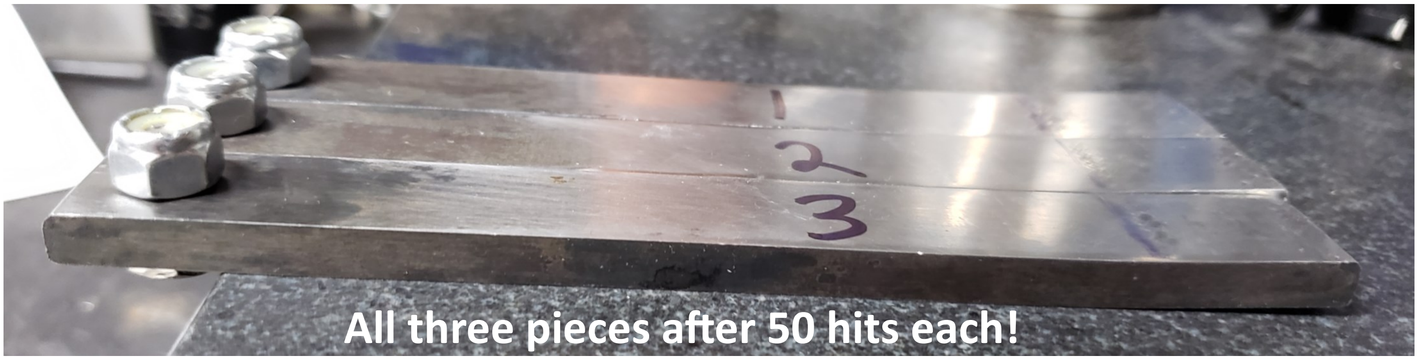
The chart also provides the amount of deflection of the original piece “A” for comparison. The circled areas on the chart, show little or no change in deflection angle towards the end on the pounding! The previous tests showed an increase in deflection angle towards the end of the pounding. At the bottom of the next page, there is also picture of all three test pieces showing the small amount of deflection after 50 hits each.

Testing toughness:

The order of quenching didn't seem to affect the hardness of the test pieces by any real degree. So, the impact tests were next to determine if the toughness was affected. As usual, The Bearded RAT would do the hammering, for consistency. After 50 hard hits on each piece we gave up; the Bearded RAT was happy with this turn of events.

Results of pounding, including picture, are shown below with a comparison of the bend angle of piece "A":

Piece	Hits	Bend angle	Comments
1	5	2.6°	Bearded RAT--Previoous "A" bend angle: 2.5°
	5	3.4°	Bearded RAT--Previoous "A" bend angle: 3.1°
	5	3.6°	Bearded RAT--Previoous "A" bend angle: 4.8°
	5	3.8°	Bearded RAT--Previoous "A" bend angle: 6.8°
	5	3.9°	Bearded RAT--Previoous "A" bend angle: 9.8°
	5	4.5°	Bearded RAT--Previoous "A" bend angle: 11.5°
	5	5.0°	Bearded RAT--Previoous "A" bend angle: 12.3°
	5	5.0°	Bearded RAT--Previoous "A" bend angle: 16.0°
	5	5.0°	Bearded RAT--Previoous "A" bend angle: 21.0°
	5	5.0°	Bearded RAT--Gave up at 50 hits--no breaks--Previoous "A" bend angle: 25.5°
2	5	2.0°	Bearded RAT--Previoous "A" bend angle: 2.5°
	5	3.3°	Bearded RAT--Previoous "A" bend angle: 3.1°
	5	3.6°	Bearded RAT--Previoous "A" bend angle: 4.8°
	5	4.3°	Bearded RAT--Previoous "A" bend angle: 6.8°
	5	4.4°	Bearded RAT--Previoous "A" bend angle: 9.8°
	5	4.9°	Bearded RAT--Previoous "A" bend angle: 11.5°
	5	5.0°	Bearded RAT--Previoous "A" bend angle: 12.3°
	5	5.2°	Bearded RAT--Previoous "A" bend angle: 16.0°
	5	5.3°	Bearded RAT--Previoous "A" bend angle: 21.0°
	5	5.3°	Bearded RAT--Gave up at 50 hits--no breaks--Previoous "A" bend angle: 25.5°
3	5	2.0°	Bearded RAT--Previoous "A" bend angle: 2.5°
	5	2.2°	Bearded RAT--Previoous "A" bend angle: 3.1°
	5	2.8°	Bearded RAT--Previoous "A" bend angle: 4.8°
	5	3.1°	Bearded RAT--Previoous "A" bend angle: 6.8°
	5	3.2°	Bearded RAT--Previoous "A" bend angle: 9.8°
	5	3.2°	Bearded RAT--Reversed order for next 25 hits--3, 2, 1--Previoous "A" bend angle: 11.5°
	5	3.3°	Bearded RAT--Previoous "A" bend angle: 12.3°
	5	3.4°	Bearded RAT--Previoous "A" bend angle: 16.0°
	5	3.6°	Bearded RAT--Previoous "A" bend angle: 21.0°
	5	3.7°	Bearded RAT--Gave up at 50 hits--no breaks--Previoous "A" bend angle: 25.5°



All three pieces after 50 hits each!

Conclusions and Summary:

The approach used for piece "A" was the approach that we have been using for making our knives in the past. Test pieces 1, 2 and 3 were the same approach except for the new agitator system So we were pleased to observe that our throwing knives are even tougher due to the new agitator system.

When we began to make our own knives, before ever considered occasionally offering them for sale, we focused on approaches and techniques that allowed for strong, tough knives. After all, we planned to throw them for a long time!

A quick chronology of process changes since we began to make our own knives:

1. Abandoning using a propane forge for hardening due to potential tip burning and difficulty in hardening the complete knife, not just the blade portion. Moved to an electric furnace.
2. Reducing the target hardness from HRC 52-53 to HRC 51 ± 0.5 to reduce chipping on hard objects. Due to results of our recent tests, we have decided to reduce to HRC 50 ±0.5. Not a big change, but we decided that this is a better hardness target, given our results with the new agitator system.
3. Experimenting with sub-zero treatment to reduce retained Austenite. We abandoned it as a practice since we only saw a slight increase in hardness, (not the goal) but the potential for reduced toughness. We still play with this and may try more tests in the future.
4. Changing from decarb powder to decarb clay. Easier and less messy application (fumes) and cleaning. Also no need to heat knives first for application of decarb. Quench oil accumulates debris from the clay and we occasionally have minor scale issues—still debating this issue.
5. Changing from a long piece of heated steel, to bring up the quench oil temperature, to a submersible electric element. Initially disastrous! Using only the IR thermometer, we were fooled into believing that the quench oil was at temperature with little agitation. We discovered that it was stratified—room temp on bottom and high temp on top. Fortunately for us, only one set of knives was sold before we learned of our mistake—broken tips after little use. Immediately replaced and apologized! We still use the electric heating element, but with constant agitation.
6. Changing from Canola oil to Quenchall 28 Second mineral oil (McMaster-Carr). Two reasons for this: 1. decarb left a sticky mess on the knife with Canola oil. 2. Reduce quench stress with a slower oil.
7. Combining the IR thermometer and a digital thermometer with a 12" probe to verify homogenous temperature throughout the quench column. This is when we also started using a paint stirrer to mix the oil while replacing hot oil with room temp oil.
8. Developed a quench agitator system with baffles to provide consistent, strong bottom-to-top agitation during the quench as well as when replacing hot oil with room temp oil.

Among all of the improvements over time, #1 and #8 have shown to be the most important to date.

After this set of tests, we did further research on quench oil agitation to determine why the knives were so much stronger than the previous "A" test piece. We found several papers addressing this issue. Apparently, heavy agitation of quench oil, instead of manual agitation, plays a more significant role in through-hardening of the carbon steels tested than the quench oil temperature. For now, we are happy with the system and the results. This will be our new improved approach, but we will continue to test and refine what we can.

Some reference links:

http://www.scielo.br/scielo.php?script=sci_arttext&pid=S1516-14392005000400018

https://pdfs.semanticscholar.org/295d/9d6f65364347de2ef6b86bf5d05f999ed1ac.pdf