METHODOLOGY - MODERN

Modern *Moire'* damascus rifle barrel manufactured by Zbrojovka Brno

John Bevins published an article "The Forge-Welded Rifle Barrel" in the September-October, 1979 issue of *Rifle Magazine* describing in detail a crolle pattern welded .535" bore rifle barrel forged by Bob Griffith of Montrose, Pennsylvania. An online digital subscription of the issue is available https://www.riflemagazine.com/magazine/index.cfm?magid=324

Forging operation courtesy of Richard Furrer/ Door County Forgeworks
http://doorcountyforgeworks.com/
http://www.youtube.com/user/RicFurrer

Heinz Denig website
http://www.heinz-denig.de/

Steve Culver - Damascus Explained

https://www.culverart.com/Damascus%20Gun%20Barrels.htm

In 1976, *American Rifleman* printed an article by Jean Puraye, "Making Damascus Barrels" which had originally published by *Musee d' Armes de Liege* in 1966. Although Damascus barrels were then believed to be unusable because of intrinsic weakness and degeneration over time, interest in understanding how the incredibly artistic pattern welded barrels were made was stimulated among vintage gun collectors.

More than 10 years ago, Pete Mikalajunas and other researchers began to build on the effort of Dr Oscar Gaddy to classify the many crolle and non-crolle Damascus patterns, and to explain the methodology used to create those patterns. Damascus Demonstration Rods, and illustrations in magazines and sporting catalogs from the late 1800s and early 1900s, now digitized and available on the internet, existed, but the specific techniques used for stacking the lopin, hammer forging and twisting the rods, creating the ribband, and helically welding the ribband into a barrel were not understood.

Sears, Roebuck & Co. Catalogue No. 116 c. 1907

HOW DAMASCUS GUN BARRELS ARE MADE.

The above illustration shows, as nearly as possible, how the Damascus gun barrels are made. The three strips, A, B and C, each consist of from 40 to 60 layers of iron and steel welded together into one square strip, then they are twisted (D) while hot and rewelded into one strip about ⅜ inch wide and ⅛ inch thick; the object being that if any one of these numerous layers of iron or steel has a flaw, the welding process entirely eliminates the flaw. After these numerous layers of iron and steel are twisted and rewelded into one strip the strip is twisted around a mandrel and welded together as shown in the illustration. These barrels are all hand made by skilled mechanics who have spent years in learning this art. They cannot be made by machinery. When a barrel is made from three strips it is called three-blade Damascus, when made from two strips it is called two-blade Damascus, and when made from one strip it is called twist or laminated steel. The more strips used in making the barrel, the finer is the figure of the barrel and the more costly to make.

A major advancement in pattern welded knowledge was made when Pete obtained the 1925 movie *La Fabrication des Canons Damas* in 2008, portions of which appear in Steve's video with permission
https://www.youtube.com/watch?v=AFrZulegvFs

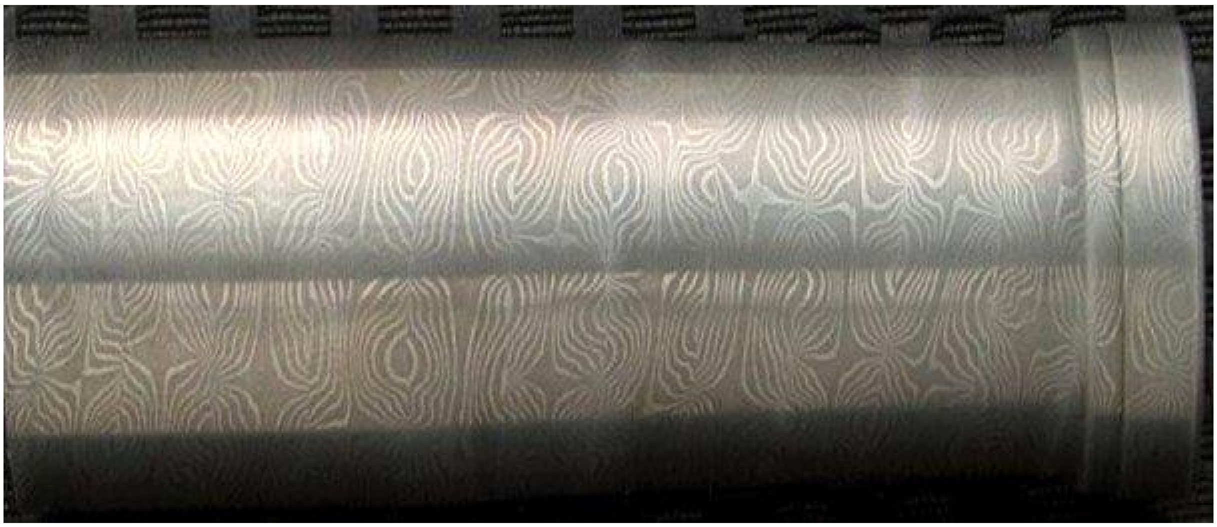
With trial-and-error, and great perseverance, in 2012 Steve Culver fabricated a Two Iron Crolle pistol barrel, and in 2014 a .45 caliber octagonal Bernard pattern barrel. Details of his production process are found here, along with his previously published Youtube videos.

Steve's success speaks to his remarkable abilities as a master forger and bladesmith, and also his aptitude and fortitude in recreating what had been a lost art. We owe Dr. Gaddy and Pete Mikalajunas our gratitude, and Steve our awe, wonder and thanks for his accomplishments!

Two Iron Crolle Damascus Barrel Produced in 2012

by Steve Culver
President-Kansas Custom Knifemaker's Association
www.culverart.com

YouTube of the proof firing sequence
http://www.youtube.com/user/SteveCulverMS1?feature=mhee



I will begin with an explanation of damascus steel and the methods used to create it. The making of pattern welded damascus, is the purposeful manipulation of layers of chemically different materials to create a pattern in the surface of a finished product. The patterns are made by manipulating edges of the layers to the surface of the finished piece where they will form a predefined pattern. As the elements are chemically different, they will be differentially affected by etchant and/or patina solutions to make the pattern visible.

The simplest of damascus begins as a stack of flat materials. Typically, of alternating layers of two chemically different types of steel, or of steel and iron. The stack is forge welded into a solid mass, producing what today in the US, is commonly called a billet. Older terms were faggot and lopin. This billet is then drawn out by forging, pressing and/or rolling, into bar stock.

It is entirely possible, by very controlled dimensional reduction to maintain the layers in their original flat arraignment. The resulting pattern will be of simple straight lines. As there is little aesthetic appeal in a straight line pattern, the material is typically manipulated to displace the layers relative to their original positions in the billet. This is often done by mechanical manipulation, or a combination of stock removal plus mechanical manipulation. In the damascus pattern that we today call “random pattern”, the mechanical manipulation is simply from the impact of the hammer on the layers of material. Each hammer blow displaces the layers and results in a circular pool shape in the surface of the finished piece. Overlapping hammer blows create overlapping pool shapes, the final appearance having what many call a wood-grain effect.

More purposeful manipulation of the layers can be accomplished by twisting, forging at an angle to the arrangement of the layers, stock removal by cutting through the layers and then forging the stock flat to raise the cut-through layers to the surface, or by pressing the layers with pattern dies to raise layers into the die pattern and then grinding of the raised areas to expose the upward turned edges of the layers. The billet can also be cut into angular sections, that are then restacked to organize the layers of material into a specific pattern. The restacked segments are then forge welded into a solid billet. The patterns possible are absolutely endless. Many modern damascus smiths who specialize in very complicated patterns, use “Play-Doh” to plan for the creation of damascus patterns. Using different colors of “Play-Doh” they can formulate a manipulation process to create specific patterns in steel.

Another form of damascus pattern creation is what we today call **mosaic damascus**. In mosaic damascus, elements are stacked in an arrangement to create words or pictures by stacking small square rods of material together, then surrounding them with rods of a different material. This stack then being forge welded into a solid mass. To make assembly and welding easier, these arrangements of materials to create pictures and words are typically much larger than will be desired in the finished product. Once welded together, the stock will be dimensionally reduced as evenly as possible, so as not to introduce distortion in the design. After a degree of size reduction, the design is often stacked into another assembly of elements, to again be forge welded into a solid mass for additional reduction to a dimension suitable for use in the finished product. In this way, a picture or word may be assembled with an original dimension of perhaps 3 inches tall. It can then be dimensionally reduced to the size of a pin head for use in the finished product.

Early mosaic damascus was typically assembled from square rods, or other dimensional stock. Modern mosaic damascus is often made by using water jet or EDM machines to cut out the shapes. Nickel is often used for the primary shape in modern mosaic damascus, as it resists the etchant solution and will display prominently when surrounded by high carbon steel. The primary design shape can be placed into a perfectly fitted hole, cut into a section of high carbon steel by the same water jet or EDM process. This assembly is then forge welded together. Or, the primary shape can be placed into a steel container, such as a piece of pipe, then powdered steel is poured around the primary to fill the container. The container is then sealed and forge welded into a solid mass.

Coloration of the iron and steel elements
The smith will select materials for the elements in the damascus and then also the finishing chemicals that will create the desired appearance in the finished product. The color of the material after etching is determined by the alloys in it. Steel with a manganese content will typically etch black. Iron will etch gray through charcoal. Nickel will produce silver and chromium a light gray. The smith can use several different types of steel for his damascus and create layers in the pattern with varied shades from silver through black in the oxides formed by the etchant. But, there's more. If the damascus is deeply etched, it creates topography (high and low areas) on the surface of the material. Whatever element that is least affected by the

etchant will be proud of the element that was more eaten away by the etchant. When lightly sanded, this higher element will become lighter in color, or silver. Typically, it is the higher carbon content material (steel) that etches quicker. This would leave the iron layers standing above the steel layers. So after sanding, the iron would finish silver. If the damascus is then blackened or browned after etching and sanding, the colors could again change, depending on which element has the greatest affinity for the coloring chemicals. So, it would be a stretch to categorically state that either the iron or steel will always be a certain color. It is all dependant on the finishing process.

In this photo of the defects in the barrel pattern, the condition was caused by decarburization of material that had been exposed to the fire for an extended period of time. **Decarburization** would have occurred over the entire surface of the barrel tube during the forge welding and shaping process of the tube. The decarburized outer material would be ground away during the finishing process on the tube. In the area of the flaw however, the exposed edges of the material extended below what would become the outer surface of the finished tube. Once the welds were closed on the decarburized material, there was no possibility to grind them away in the finishing process.

Surface decarburization is something that is critical for a bladesmith to understand. A blade must be forged with enough material left to remove from the outer surface to eliminate all decarburized steel. This is especially critical at the blade's edge. The thin area of the edge is very susceptible to decarburization. Carbon loss from the steel at the edge will cause a loss in hardenability of the steel and result in inferior edge holding ability. It was long thought that it was possible to increase the carbon content in steel by using a reducing fire in the forge. A reducing fire being one that had insufficient blast to sustain complete combustion of the forge fuel and therefore leave available carbon in the forge atmosphere that the steel could absorb. Metallurgical testing in recent years disproved this concept. Decarburization is especially problematic at the heats required for welding damascus. The high blast rates necessary to bring the fire and steel to a welding heat will certainly cause decarburization.

Another fairly recent metallurgical learning that can affect the appearance of finished damascus is **carbon migration**. It was long believed that forge welding high carbon and low carbon steels together would result in layers with the same carbon content as the original steels. It has been metallurgically observed that carbon will migrate across the weld boundaries from the high carbon steel into the low carbon steel. The carbon is essentially trying to form an equilibrium

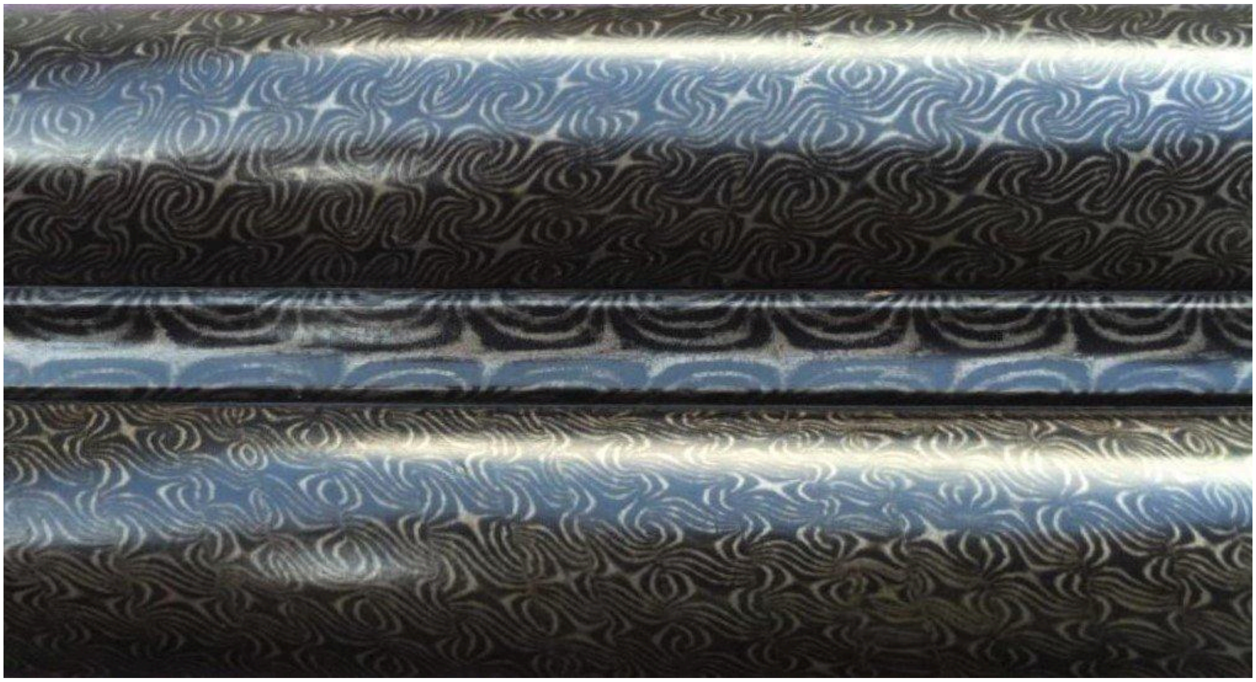
throughout the matrix of steel. This migration happens in a relatively short amount of time and happens quicker at higher temperatures. So if two steels are used that only have different carbon contents and no other alloying difference between them, there is a possibility that carbon migration will render them substantially the same by the end of the forging process. Being nearly the same, they would not be so differentially affected by etchant and coloring chemicals. This could be a plausible explanation for damascus barrels that do not display a distinct pattern.
Carbon migration can be stopped by placing nickel between the layers of steel. This is often done by modern damascus smiths. The result is a very high contrast damascus. The nickel finishes bright silver and will not color if the damascus is blackened. Nickel is not a suitable material for use in a knife blade, as it will not harden, so this combination of materials is only useful for knife fittings or other damascus items that do not require heat treatment for hardness. A question I have concerning old damascus gun barrels is whether the silica content of the wrought iron used for barrel making had the ability to mitigate carbon migration. There is not much wrought iron used in modern damascus, so I know of no testing that has been done in this field. I have sent a piece of an old damascus barrel to a friend and fellow knifemaker, Kevin Cashen. Kevin is arguably one of the most knowledgeable metallurgists on the planet. I have asked Kevin to do some testing on the barrel section, to include carbon migration examination.

I find no mention of **heat treatment** processes performed on the barrel tubes in any writings contemporary to the manufacture of damascus barrels. I suspect that many of these barrels contained a sufficient amount of carbon to have been capable of hardening, if heated to a high temperature and quenched. They likely would have then needed to be tempered, or annealed, to mitigate brittleness. As a brittle gun barrel is highly undesirable, I'm certain that the smiths avoided any rapid cooling of the tube from high temperatures. They were however, doing a type of heat treatment process that I am certain that they did not fully understand. I have read in several writings of the cold hammering of barrel tubes after welding. The tubes were not actually "cold", but in blacksmith terms, at a heat that was too cold to effectively move the steel under the hammer. This would be a low red heat, down to a temperature of about 900 to 1,000 degrees F. Greener states that this hammering "greatly increases the density of the metal". The interesting part is that the actual hammering was totally unnecessary.

In the bladesmithing world, **cold hammering** of a blade edge has been taught for decades; the description of the process was called "edge packing". The concept was that the hammering of the cold steel compressed and refined the grain structure of the steel, creating a smaller and tighter structure. The tighter grain structure would take a keen edge better and retain sharpness longer. Edge packing was taught to knifemakers as an essential part of blade forging until about 20 years ago. Finally, metallurgical testing was done, revealing that the actual hammering of the cold steel had no effect. In fact, it was probably detrimental, risking stress fractures. Too, logic will prevail, in that steel is a solid and solids cannot be compressed. So, no density changes can be made to the material by hammering. Still, changes that were visible to the naked eye occurred to the steel during this process. The surface of the steel looked smoother and actually looked denser. If a blade was heat treated and then broke in two, the grain in the cold hammered blade appeared much tighter and smaller. This was also very apparent in damascus blades. The finish of a damascus blade that was not cold hammered was coarse and grainy looking. So, I am certain that the barrel smiths also realized that their barrels had a better appearance after the cold hammering process. They too would have assumed that the hammering of the steel was making it denser; as that was the look that it had after the process.

The phenomenon of **grain structure changes** is purely the result of the temperatures that the steel is heated to. At high temperature (such as forge welding heat) the crystalline structure of steel becomes very large. As the steel cools, the structure reforms into smaller crystals. However, one cooling cycle is not typically enough to reform all of the crystals. So, the steel is reheated again to a temperature that is low enough not to create large crystals and it is allowed to cool to a black heat again. The lower temperature is sufficient to promote the reformation into smaller crystals, without creating large crystals again. This heating to low red heat and cooling in room air to a black heat is repeated three or more times. The process is called thermal cycling, or normalizing. I am convinced that this is exactly what the barrel smiths were doing during the cold hammering of their barrel tubes.

Addressing the questions about why **stars** in the damascus patterns will transition between white and black, requires an understanding of what the smith is doing and also working with. This is a bit of a generalization, but the layers of iron/steel in a damascus barrel will be around .003 to .010 inches thick. Every hammer blow displaces the material, both downward from what will become the surface of the finished piece, as well as in relation to the material immediately adjacent to the impact of the hammer face. The smith will utilize overlapping hammer blows to attempt to keep the displacement of the layers as even as possible.

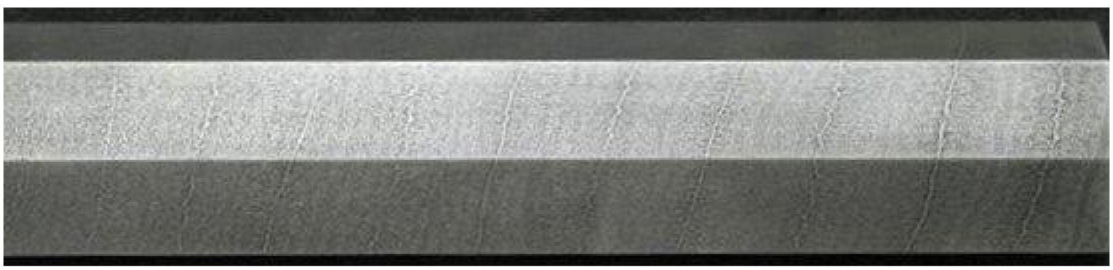


It is important to understand that the smith has no visual reference for what is happening to the pattern, other than the appearance of the workpiece surface and his experienced knowledge of what is happening to the layers inside the material. The pattern cannot be seen at all during forging, as the surface is totally covered in forge scale. Given the hundreds of hammer blows that fall on the material during the welding of the rods into riband and the subsequent welding of the barrel tube, it can be seen that the small margin of a few thousandths of an inch in layer thickness make it impossible for the smith to place all of the layers in an exact position. If when the barrel is sent to the boring room, it does not completely clean out, it is returned to the smith to be forged down in that area to reduce the bore for additional reaming. The effect of this additional forging could easily show up in the pattern. A barrel that displays a short area where the pattern makes a sudden change could have been one that was sent back to the smith.

The barrel grinder has no contribution to the pattern development. During grinding, the pattern cannot be seen. The surface of the barrel is totally in the white. If the bore of the barrel is not concentric with the outside of the tube, the grinder has no choice but to remove the excess material from the thicker side of the tube. Uneven grinding for whatever reason will affect the pattern.

Control of a damascus pattern is something that every damascus smith deals with. You know what you planned for it to be. You forge it as evenly as possible. If you forged well, you will grind an even amount of material away and hopefully preserve the pattern. But, you never know for certain until the etch. Etching is like opening a present for the damascus smith. You hope to get something beautiful and if you have done well you will. If not, you discover you got the ugly necktie.

.45 caliber octagonal Bernard pattern barrel by Steve Culver **2014**



There were 81 steel rods, stacked into the billet used to make all of the damascus used on this pistol. There were 41 rods of 1084 steel and 40 rods of 1018 steel. The rods were stacked in a 9 x 9 checkerboard arrangement in the billet. All of the steel rods were 1/4 inch square and 6 inches long.

This stack of steel rods was forge welded into a solid block. The block was drawn out by forging and then cut into two pieces. These two pieces were additionally drawn out into rods that were 1/2" square. These two rods were then twisted along their entire length, at a rate of 3 1/2 revolutions per inch. The two rods were then forge welded to each other and used to make all of the damascus steel for the pistol.

Thread with links to YouTube of Steve Culver forging a pistol barrel using vintage shotgun tubes
http://www.doublegunshop.com/forums/ubbthreads.php?ubb=showflat&Number=486662#Post486662

“English Two Stripe” fabricated by Aaron Beck

Alec Steele
https://www.youtube.com/playlist?list=PLWx61XgoQmqdpyY3Sv5NDdjWQl-R40mcg

https://www.youtube.com/watch?v=-GHCcwsk_AA

https://www.youtube.com/watch?v=iU5BsbGXHgA

New Shotguns With Vintage Tubes

W.W. Greener produced new shotguns with damascus barrels in 2007-2008.
From the Greener website in 2007:
“Barrels - are made of the highest quality steel and bored to maintain the famous choke boring improvements, made by W W Greener in the 1870s, to optimise shooting performance, and to ensure patterns of shot guaranteed to meet customers' exact requirements whether for game, wildfowl or clay pigeon shooting. A few pairs of guns are being made ***with interchangeable steel and Damascus barrels***.”

Courtesy of Vic Venters (Dec. 2008), who wrote an article in the Sept/Oct '07 issue

of *Shooting Sportsman* regarding the Greener guns:
“They are indeed newly made damascus barrels, built on vintage tubes that David Dryhurst - Greener's master gunmaker - has been collecting since the '60s and '70s. Some are old Greener stock, some are English and no doubt some are Belgian. A few of these sets came from Dyson...They are not lined. The guns are being made in 28-ga up through 12, and maybe in 10-ga. At least 25 of these damascus-barreled guns are made or are under way, and I believe more have been ordered since I last asked. At the time of my writing, none had failed English proof. The guns are proofed under standard CIP pressures per the particular gauge. Most are on sidelocks; some are on reintroduced “G-Guns” - Facile Princeps actions with Boss ejector work. Greeners are a small best maker - but demand has been so great that I am told they have again closed their order books. They were the last British maker to manufacture their own damascus tubes, and are the first to again offer them in commercial quantities.”

New Purdey hammergun with vintage 3 Iron “Oxford” tubes, offered by Griffin & Howe in 2013.
“The Damascus barrels are proofed for 2 3/4” modern smokeless loads.”

Bill Blacker & Sons is manufacturing replacement barrels using vintage damascus tubes
http://www.billblacker.co.uk/

Damasteel

http://www.damasteel.com/

In a 2009 press release **“Purdey's Secret Weapon”**, Purdey announced the production of an all Damasteel shotgun.
“All parts other than springs, tumblers, seers, cams and non-visible screws and pins are fabricated from (Damasteel.) Each visible part of the gun- action, forend iron, triggerplate, bow and guard, rib, fins, etc.- were cut from re-forged billets so as to procure the best display of the pattern available in the steel.”

“If there is sufficient interest, we will produce a limited number of guns as 20-gauge over/unders, 12- and 20- gauge side-by-sides, and 20-gauge hammerguns. We have yet to finalize a price…”

Nigel Beaumont, Chairman James Purdey & Sons
http://www.purdey.com/guns-rifles/damascus-guns/

http://www.shootinguk.co.uk/reviews/shotgun/purdey-damascus-steel-shotgun-review

Damasteel 20g shotgun barrel from http://www.crandart.co.uk/

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