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 The original publication in Muse contains many delightful cartoons and two fanciful drawings that have not been included here in order to reduce the size of the pdf file.

The Mystery of the Damascus Sword

by John Verhoeven and Alfred Pendray

Before atom bombs and chemical warfare, before jet fighters and tanks, even before guns and cannons, people fought with swords. Swords were one of the main weapons of war for centuries. And for that reason, good strong swords were highly valued. A dependable sword could save your life. What would happen if your sword broke in the middle of a fight? Or if it was not sharp enough? You'd probably end up dead. So good swords were highly prized. And just like there are certain types of cars that are known to be very fast (and even brands of sneakers that are supposed to give you an edge), there was one kind of sword everyone wanted. It was made in Damascus, a city in Syria, and so was called a Damascus sword. Western Europeans first saw these swords in the hands of Muslim warriors a thousand years ago. Today you can see examples of Damascus swords hanging in the arms and armor sections of most large museums.

A Damascus sword from 1691. The writing on the blade (detail above) says "O Fulfiller of Needs, the work of Assad Allah."

Damascus swords were prized for their strength and sharpness. They were famous for being so sharp that they could cut a silk scarf in half as it fell to the ground, something European swords couldn't do. They were also known for their beauty. The surface of a Damascus blade has a wavy pattern on it that looks a little like wood grain. Sometimes the wavy pattern would form lines across the sword that looked like the rungs of a ladder; this was called Mohammed's ladder. Some times the waves formed circular swirls called roses. And unless you had the wavy pattern on your blade you didn't have a true Damascus sword.

Blade has a ladder and rose pattern

Not only were Damascus swords sharp and beautiful, they were also objects of mystery. The best European bladesmiths from the Middle Ages on up weren't able to make them, even though they carefully studied examples of blades made in the East. Damascus blades became even *more* mysterious when the art of making them actually died out. The last Damascus swords were made in the early 1800s.

Over the years metallurgists (people who study metals) have suggested many different ways of making the swords, but when they were tested, none of the methods made blades that matched the Damascus swords in the museums. The recipe for a Damascus sword was a puzzle that challenged people for centuries. With all the knowledge and technological advances of the 20th century, people still couldn't figure out how to make these swords. What was the secret? I'm a metallurgist who teaches about metals at Iowa State University. I became interested in Damascus swords when I read an article about them that one of my students gave to me. Alfred Pendray, my coauthor, is a blacksmith in Williston Florida, who also became interested in the swords by reading about them. We worked on the problem independently until a mutual friend put us in touch. For a year, we wrote back and forth, and in 1989 we finally met and decided to try to solve the mystery together. At first, we tried methods for making Damascus swords that had been published in science journals. But those methods didn't give us blades that matched the old blades. So we decided to go back to the very beginning. We would trace step by step how the swords were made in ancient times and see if we could figure out how the ancient craftsmen did it.

According to reports of travelers to the East, the swords were made by forging small cakes of steel that were manufactured in southern India. This steel was called wootz steel. Wootz steel first appeared in India between 300 BC and AD 500. It was more than a thousand years before steel as good was made in the West. Wootz was the first high-quality steel made anywhere in the world.

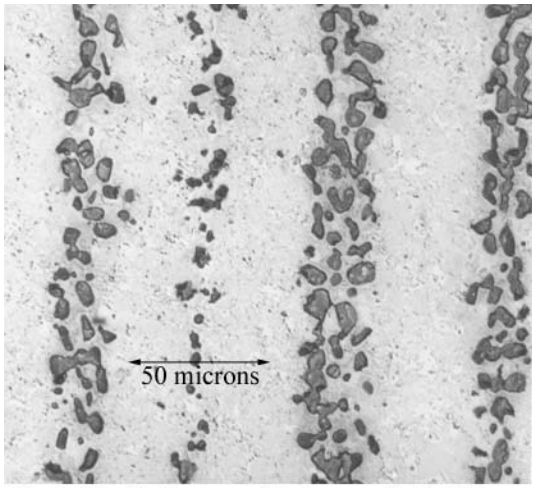
Steel is a mixture of iron and carbon. To make wootz steel, the craftsman melted iron and materials that contain carbon, such as charcoal, wood or leaves. They did this in a sealed crucible, which is simply a melting pot able to withstand high temperatures. When the cooled and hardened steel was taken out of the crucible, it was in the shape of a cake. The wootz cakes (which were about the size of hockey pucks and weighed about four pounds) were then shipped to Damascus, where smiths made them into beautiful blades.

To shape the cake into a blade, the smiths repeatedly heated and hammered it until it was stretched and flattened into a blade shape. As the metal was heated and beaten, the wavy pattern somehow formed on the surface of the blade.

One of the major problems we faced in making a Damascus sword was to get the right pattern on the surface. And in order to get the right pattern on the *outside* of the sword, you had to have the right structure *inside* the sword. In steel, some carbon chemically combines with iron to form a new kind of chemical called iron carbide. These iron carbide particles are surrounded by metal that is almost pure iron. But it is the *arrangement* of these carbide particles that cause the famous Damascus pattern.

The interesting thing is that the carbide particles aren't scattered randomly throughout the Damascus blade. If you sawed the sword blade in half and looked at the cut surface under a microscope, you'd see how the carbide particles arrange themselves in rows. This is called banding.

These bands of carbide particles form the pattern you see on Damascus swords. When the steel is beaten with a rounded hammer, the bands of carbides near the surface are



The inside of a Damascus blade, magnified 370times, showing the carbide particles aligned as rows.

pushed up and down until they look like waves instead of bands.

The wavy pattern in true Damascus blades only turns up in the beating and hammering of the steel cake into a blade. No one could figure out how this pattern was formed. People tried to create the pattern in many ways. Smiths tried to copy the pattern by etching or carving the metal. They also tired welding different types of steels together to create a patterned look. And some of the patterns they created were beautiful. But if you looked closely, you could see the surfaces of these objects didn't really look like the surfaces of true Damascus blades. And since they didn't have the right pattern, they didn't have the right structure on the inside either.

So what caused the pattern to appear? We guessed that impurities in the steel might have something to do the carbide banding. In plain steel, any element that isn't carbon or iron is an impurity. By today's standards cooking steel in a crucible is a dirty process; the finished steel is likely to contain small amounts of many different impurities from the iron ore or from the walls of the crucible. Perhaps there was a special impurity in Damascus steel that made the pattern.

But what kind of impurities did Damascus steel have? In the past 100 years, scientists have analyzed the ingredients of 10 Damascus blades, and these analyses have shown that wootz steel contains small amounts of four impurity elements, sulfur, phosphorous, silicon and manganese. So why couldn't people recreate a Damascus blade if they had the recipe and knew how the blade was prepared? Well, we guessed that there might have been other impurity elements in the steel that people missed. The impurities could have been present in such small amounts that they were undetectable. Nowadays we can analyze elements at lower levels than before, so we thought there was a chance that we might not have all the right ingredients.

Was our guess about impurities right? Only trying to make a blade would tell. Although our early attempts to make Damascus steel mostly failed, once in a while we succeeded in making a presentable Damascus blade. Like cooks perfecting a recipe, we started to experiment with our ingredients, adding different amounts of impurities and carefully watching and controlling the heating of the metal.

Our big break came when we started to make our steel using a type of commercial iron called Sorel iron, which is refined from a special ore deposit in Canada. Once we started using this iron we began to obtain much better results. We analyzed it and found very small amounts of two carbide forming elements called titanium and vanadium. When these two elements were present we got improved results. Eventually we got to the point where we could make Damascus steel that could be forged into good blades on nearly every try. So to get an internal structure consisting of bands of carbide particles, the steel had to contain small amounts of vanadium and titanium--but as we found out particularly vanadium.

Genuine Damascus blades are considered treasures, so their owners usually don't allow metallurgists to cut them up.

You can imagine how excited we were when a museum in Switzerland recently gave us small pieces of several original blades for study. We found that they *all* contained very small amounts of vanadium. This agrees with our discovery that vanadium is a key impurity element for making Damascus steel.

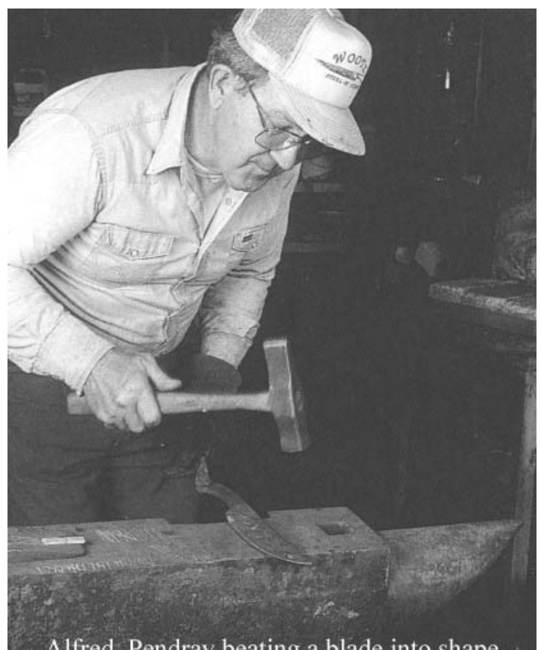
There are still things we don't understand about Damascus steel. For example, despite all our science, we still don't know why vanadium makes the carbide particles line up in rows when other impurities do not. But our method has passed the crucial practical test: we are now consistently able to make blades that have both the external surface patterns and the internal structure of ancient Damascus blades. And, yes, our blades can cut a silk scarf in half as it falls to the ground.

Our solution to the puzzle also suggests an answer to an interesting question: why was this art lost in the first place? The answer may be that only certain deposits of iron ore in India contained the necessary impurities. When these ore deposits were used up, and when bladesmiths began to use steel from other areas of India, the secret ingredients were missing, the magic was lost, and with it, the secret of Damascus steel.

MEET THE MAN WHO BEATS DAMASCUS STEEL

I am a horseshoer by trade. My dad was a blacksmith, and I started helping him when I was very small. I've always enjoyed working with the old traditions. That's one of the reasons I became interested in Damascus steel. The old bladesmiths didn't have fancy foundries or equipment; Damascus blades were made in a backyard-shop atmosphere. Yet these swords were tremendously sharp and strong. They were better quality than anything else that was around at that time. I was fascinated by the fact that the method for making them was lost. And in my ignorance, I thought I could solve the problem on my own.

I worked by myself on Damascus steel for almost five years. Then a friend told me that John Verhoeven, a metallurgy professor, was working on the same problem. In 1987, we started writing to each other. Then I visited his lab. John and I made a good match because I knew forging and he knew metallurgy. We had a lot to teach each other, and we weren't ashamed or embarrassed to ask each other questions.


Alfred Pendray beating a blade into shape.

To make Damascus steel, I take charcoal and mix it with an iron that has the impurities we need to form the Damascus pattern. I also use green leaves, just like the old bladesmiths did. Hydrogen (which comes from the water in the leaves) helps the carbon from the charcoal mix better with the iron.

I try to do everything as close to the original procedures as possible, but I do use some modern technology when I know it won't make a difference in the steel. For example, I use power hammers that can hit hard or soft. I also use a modern gas forge that can control temperature very accurately. The original bladesmiths didn't have any fancy instruments to tell them what to do—they had to look at the color and feel the metal to figure out what was happening. And I had to teach myself to do the same, because there were no records of how the early smiths broke down the steel cake into a blade. I would have loved to have been a fly on the wall of one of those early shops so I could have seen how early smiths worked. It took a lot of trial and error to figure out how the blade should be forged: we had to figure out the right temperatures, and how the metal was hammered and beaten.

As far as I know, I'm the only bladesmith who makes Damascus steel. When you compare my blades to original blades, pretty much everything's the same. I make so many blades today that I often forget how many years it took to figure out. All I can say is that it been a really fun experiment.

HOW TO MAKE A DAMASCUS BLADE IN 22 EASY STEPS

You've just finished reading how the mystery of Damascus steel was solved. But now you're probably wondering: How exactly does somebody make a Damascus blade? It's not that easy. Alfred Pendray, the co-discoverer of the method, shows us some of the steps in the process.

You'll need iron, charcoal, and fresh-picked tree leaves, among other things. And don't forget a clamp to hold the crucible.

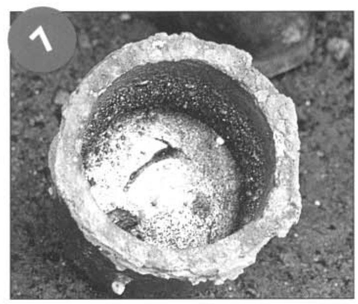
Load the ingredients into a crucible.

Seal the loaded crucible with putty.

Put the crucible into the kiln.

Fire the crucible for several hours.

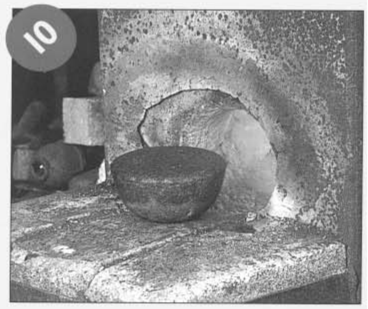
Take the crucible out of the kiln.



Take the lid off the crucible. You'll see a whitish crust covering the top of the steel.

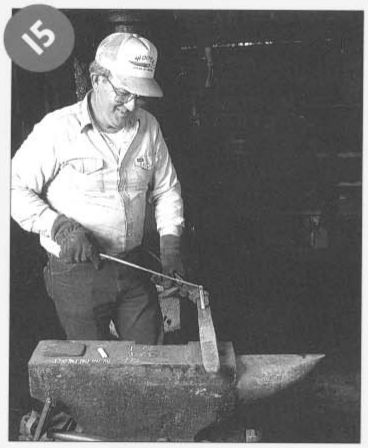
Remove the crust to reveal the steel cake.

The de-crusted steel cake.

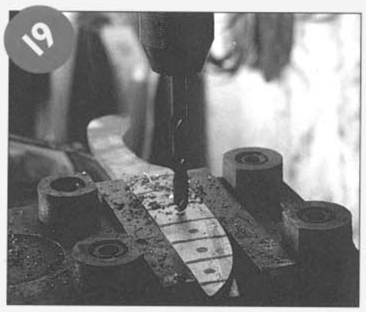


Preheat your cake (to avoid cracks in the metal).

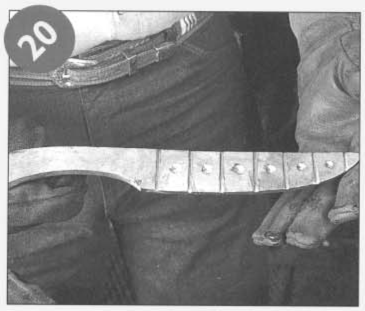
Use an infrared pyrometer to check the temperature of the steel. As the steel cools, the color of the metal changes, too.



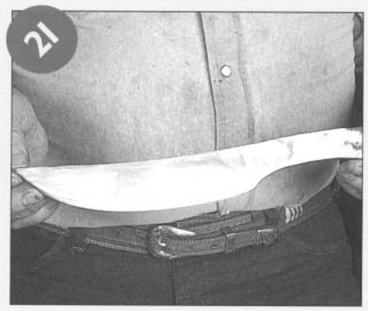
Use a magnet to test the steel. The metal's magnetic field changes as it cools. It won't attract the magnet when red-hot. Make chalk marks on the anvil to keep track of how many times the steel's been hammered and returned to the fire.



Use a drill to make one-tenth-of-an-inch-deep holes on both sides of the blade. This is where the rose pattern will appear.



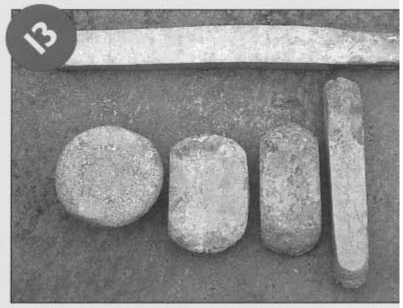
The drilled and cut blade. (The cuts are where the ladder pattern will appear.)



Reheat, rehammer, and regrind your blade. No cuts or holes should show.

Remove the heated cake from the fire.

Stretch and shape your cake with an air hammer.

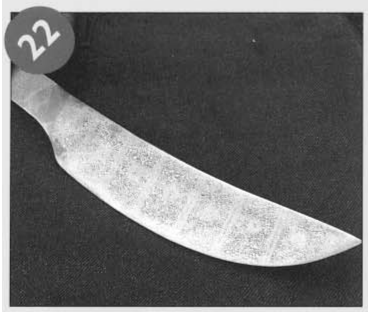


The different shapes the steel cake takes after it's been heated, stretched, and hammered for a blade.

Shape the steel some more.

Cut the steel short to form a knife blade.

Shape the blade with a grinder.



The completed blade showing the pattern.

An example of a completed blade set into a handle.