The Crucible Smelting Method: from Turkey to India then China

In search of the method to create the superior "sword of old," research takes us from Korea to India then to the Middle East. The potential key to unlocking the secret to the sword of old may be in the crucible smelting method, notably utilized and spread during the Ottoman Empire – present day Turkey.

By Tetsutaka Sugawara

1. The Cobalt Colored Sword

In October 2017, I visited the Korean Central Museum. Between September 26 and November 11, the museum had an exhibition called "The Cultural History of Metal, Iron, and Steel." The exhibition included the propagation of iron, rock iron, iron items, and swords from Turkey.

One of the exhibits that drew particular attention was a magnificent Korean sword (picture 1), the metal of

Pict 1. Sword. (Korea Central Museum)

which had a deep blue color. The length exceeded one meter, and the quality and look of the sword were fit for a king. The beauty of this Korean sword moved me in much the same way as the Nihonto of old.

Ordinarily, modern Nihonto made only from iron sand has a whitish color similar to titanium. But the Nihonto of old has a darker, more settled and deeply resonating appearance.

The Korean sword appeared to have the same color as cobalt, and it appeared that either the sword was a type of cobalt alloy or that cobalt was somehow placed on the surface of the metal. The metal's brilliant hue and intense clarity had the phenomenon of drawing the observer into the sword. This effect indicated that the metal had very few impurities and that iron rock of high quality was used during the smelting process, at which time cobalt was possibly added.

2. Glass Items of the Silla Period

I asked John Victorin, a music conductor living in Korea and also one of my students, to look into the source of cobalt in Korea. According to his research, Korea has had a historical relationship with the Middle East, where cobalt was abundant in the fifth century.

Silla (57 B.C. to 935 A.D.) is a Korean civilization that existed for about 1,000 years and is known as the kingdom of gold. In the fifth century, Islamic merchants traveled from the Middle East to Korea on the Silk Road and had direct contact with the Silla civilization.

Pict. 2. Glass items recovered from a tomb in Keishu, Korea, were dated from before the fifth century. These items were part of an exhibition in 2013 and 2014 at the Metropolitan Museum of Art in New York City.

Their brilliant blue hue strongly suggests that the cobalt from the Middle East made its way to Korea, as there are no substantial cobalt deposits in Korea (or China and Japan for that matter). And rather than simply importing cobalt-colored glass items, it is likely that cobalt was integrated into the production of glass items within Korea.

Of course, it was not possible to examine the Korean sword (picture 1) to determine if and how the cobalt was combined with the metal.

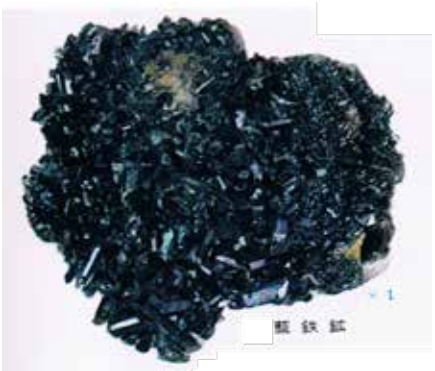
3. Cobalt in Japan

I contacted Tadashi Ozawa, an executive at a ceramic and pottery company, to ask about the use of cobalt in the history of ceramics. I consult with him often about metals.

According to Mr. Ozawa, the method of using cobalt in ceramics came from the Middle East, eventually making its way to Japan around the eighth century. The use of cobalt apparently became very common between the tenth and eleventh centuries, which, incidentally, is about the same timeframe the Nihonto came into being. Mr. Ozawa was also aware that cobalt was used in metal alloys of weapons. When I asked him about this, he said that an analysis of ironware found in archeological digs showed the use of cobalt.

Cobalt likely found its way to Japan from Silla (or possibly China), eventually being applied to ceramics then ironware. Unfortunately, I am not aware of any source that affirms my suspicion that cobalt was also used in swordmaking.

In the book “Michinoku no Tetsu,” a collection of Munechika Kokaji’s swords were presented. Munechika Kokaji is a swordsmith from Kyoto Sanjo, and the swords presented in the book were those made from iron rock containing vanadium. These iron rocks likely came from the Shirayama mine in the Northeast region of Japan, from which high-quality raw materials containing 2.7% vanadium can be sourced. Thus, a swordsmith from Kyoto traveled very far to obtain iron rocks of exceptional quality. Notably, I also went to this now defunct mine, but I could not find any iron rocks to serve my purposes.



Pict. 3. Vivianite (from "Illustrated Book of Ore" published by Hoiku-sha, 1994.

In a book about iron rock, I discovered that a certain type contains cobalt. This type of rock has been found in the Ashio Mine of Tochigi Prefecture. If cobalt can naturally exist in iron rock, then it is not inconceivable to suggest the practice of mixing cobalt during the smelting process.

Furthermore, if cobalt oxide was imported into Japan and used commonly during the Kofun and Heian Periods, then it is quite possible that it was used during the smelting process as well. Of course, this supposition requires further experimentation and examination.

In addition, there is the possibility that some swords were made from iron bars containing cobalt. These bars were imported into Japan.

In March 2018, the Iwate Prefecture Museum published their 35th Research Paper titled "The Circulation of Pre-Modern Ironware in the Northern Region: a Comparative Study of Iron Production in the Japanese Archipelago." The paper compared the content of cobalt, copper, and nickel in the following items: iron pots from the 14th to 19th centuries; iron axes from the 6th to the 13th centuries; iron hoes from the 9th to 10th centuries; sickles from the 8th to 12th centuries; and nails from the 9th to 10th centuries.

Notably, in ironware found at the Kanoko archeological dig site C in Ibaragi Prefecture, most of the items contained amounts of cobalt (1.52~2.45) and copper (0.32~096) that were similar in amounts to those of sickles and nails found in various areas facing the Pacific Ocean. But in area number 5 of Kanoko site C, items were found with substantially higher amounts of cobalt (3.33) and copper (3.5). This variation suggests the possibility that metals were imported from places such as China and Korea.

One point to consider is the mystery of when and why Japanese sword polishers began using cobalt oxide in their craft. Even today, in order to draw out the hamon of a Nihonto, polishers mix iron and cobalt oxides into oils then use those oils to create a contrast between the hamon and the rest of the blade. There must be a specific and practical reason why cobalt oxide is used by sword polishers of the Nihonto tradition.

4. Research in Turkey

After visiting Korea in October 2017, an opportunity arose for me to visit Turkey. The President of the Korean Aikido Federation, Daehyun Yoon, received a request for instruction from Istanbul, Turkey, and he sent his son, Junhwan Yoon to hold a seminar in December of that year. I accompanied Junnan Yoon to Istanbul for the seminar, taking advantage of the opportunity to further my research.

Before arriving in Turkey, I asked my student, Asim Erturk, to introduce me, if possible, to a swordsmith who still makes Islamic blades. I did not have any knowledge of Turkey, and I wanted to talk to someone about the metals used in Islamic swords.

The day after arriving in Turkey, Asim took me to the Military Museum and Cultural Site Command and introduced me to the director of the museum, Lieutenant Colonel Omer Faruk Arslan. When I told the director that I wanted to learn more about swords prevalent during the first half of the Ottoman Empire, he brought several books to me and asked if they were sufficient. The books were published by the museum, and as I looked through them I could see the flowing patterns of the metal but could not determine their exact content or how the blades were

made.

I then asked the director if he could introduce me to a sword smith, but he replied that no such person exists. Unfortunately, such is the current situation in Turkey, where sword making is concerned, and I was disappointed. I later learned that historians generally accept that truly ancient Middle Eastern/Indian crucible-based smelting techniques have been lost for over a century.

pict. 4. from left; Zahari Georgiev, Sugawara, Kayahan Horoz, Asim Erturk, Yoon Junhwan.

The director did, however, mention that there was a researcher who may be able to answer my questions. When he asked if I was interested, I replied affirmatively, and the director immediately picked up the phone and set an appointment for me. We were to meet for lunch in two hours, and I was very grateful.

Meanwhile, I received a call from my student, Zahari Georgiev, who is an instructor in Tenshin Shoden Katori Shinto Ryu. He informed me that he had just arrived from Bulgaria. Despite the adversarial history between Bulgaria and Turkey, I find it quite amazing – and a testament to the power of martial arts to promote peace – that through the study of Katori Shinto Ryu, people from different countries can share respect, friendship, and connect with each other as human beings engaged in a common pursuit.

Tangentially, Sofia, the modern-day capital of Bulgaria, has a history of occupation by Thrace, the Eastern Roman Empire, and Islamic powers. Hence, Bulgaria had a deep relationship with the civilizations that helped develop the use of cobalt in Turkey, as well as the glass items in Silla (Korea).

In any event, the following members assembled at the restaurant for lunch: Asim from Turkey, Zahari from Bulgaria, Junnan from Korea, and me from Japan. This was a strange coincidence, given that the route in which metal traveled to Japan likely traced the same countries, from Turkey, Bulgaria, Korea, and eventually Japan. Together we waited for the researcher to arrive.

5. Crucible Smelting Originated in Turkey

The researcher, Kayahan Horoz, is a computer technician who is interested in smelting and sword making. He has experience smelting metal and plans to produce a sword. Given his background, I felt that this would be a productive meeting.

I had hypothesized that, because the slag found at the Bogazkale site in Turkey contained high quantities of calcium, the smelting process may have involved using animal bones in the furnace. Mr. Horoz's smelting process, however, did not involve a furnace at all. Rather, he smelted Wootz steel using a crucible. I did not expect ancient Islamic swords to be made using such a method, so I was surprised.

According to Mr. Horoz, the crucible method did not originate in India; rather, the technique originated in Uzbekistan and was subsequently spread to India. As he answered my questions, he provided much detail about the smelting process and the production of traditional Islamic swords. He also indicated that the history of the crucible method could easily be confirmed on the internet as well. I was very happy with this meeting.

6. The History of the Crucible Smelting Method

Anthropologist Anna Feuerbach affirms that the crucible smelting method existed in the fifth century in Fargona City, Uzbekistan, and in Merv City, Turkmenistan. In her Youtube video (www.youtube.com/watch?v=GBSh_FFXpgA), she explains that a Yatagan (short sword) made from metal using the crucible smelting method could be bent 90 degrees and would return to its original shape without breaking. She further states that this technology spread to India and China.

As a major city on the Silk Road that was established during the Achaemenid Empire circa 550-330 B.C., an interchange of activity, trade, ideas, and technologies would have connected Merv City with China. Likewise, a continual flow of people, information, and goods between China, Korea, and Japan existed for thousands of years as it does today. Then the possibility is quite reasonable that technology from Merv City would have reached China then migrated to Korea then Japan, including smithing techniques.

Modern Nihonto are heat treated only once using clay. I hypothesize that the ancient Nihonto were heat treated several times.

An ancient Nihonto called Tawara Kuniichi was cut and analyzed, and the results suggested the likelihood that this ancient sword was quenched several times. From Mr. Horoz, I was able to learn how to heat treat a sword using multiple quenches. However, I had not yet thought about the connection between the crucible smelting method and cobalt at that time.

Incredibly, the crucible smelting method creates metal that exhibits microscopic carbon-nanotube structures. The exceptional characteristics of this Wootz steel was further ameliorated with multiple quenches, resulting in swords that cut well yet resisted breaking and bending. This technology gradually spread to other areas of the world.

7. The Making of the Crucible and the Smelting Method

Mr. Horoz provided the following explanation about the smelting method (illustrated explanation on the next page).

Pict. 5. a copy of the crucible, which was excavated in India, made by Prof. Mark Kenoyer of Wisconsin University.

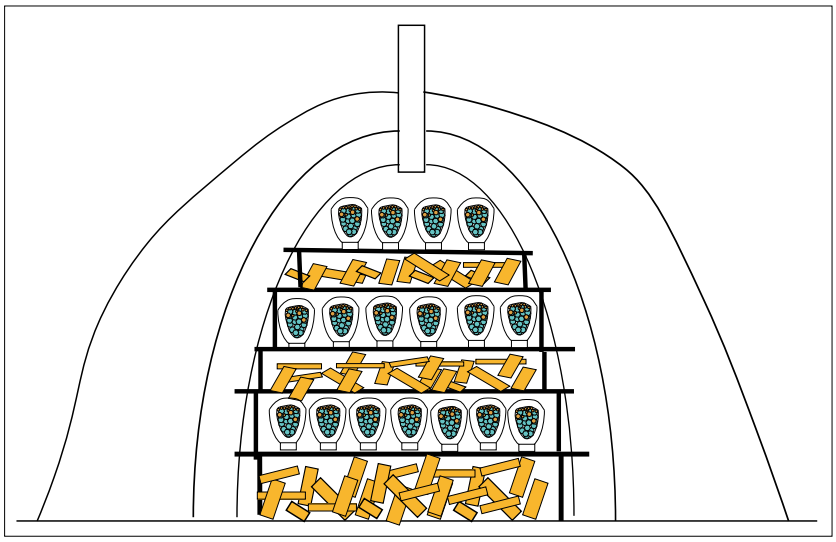
(1) Make a crucible from clay found in the mountains. In Turkey, the crucible is made by adding straw. In India, they add kaolin. According to Mr. Ozawa, kaolin is comprised of silicic acid and alundum. When heated at high temperatures, kaolin combines with sodium and creates glass by-products during the smelting process.

The dimensions of the crucible are unclear, but according to those found in archaeological sites, the inner diameter is about 8 centimeters, the thickness about 1.5 centimeters, and the height about 13 centimeters (see picture 5). To prevent sticking, the outside of the crucible is covered with broken rocks. The crucibles are naturally air-dried.

(2) High quality iron ore is placed in the crucible, sealed with straw then left to dry.

(3) An outer kiln is made with clay then a chimney is attached and the entire apparatus is allowed to dry completely. The size of the kiln needs to be large enough to stack several layers of wood and multiple rows of crucibles.

(4) The crucibles are placed in rows on top of the wood, and the rows are stacked on top of each other in the kiln (illustration 1).



Illust 1. An ouser's image of kiln for the clussible smelting.

(5) The kiln is covered with dirt.

(6) Fire is started from the bottom, and the temperature of the kiln is slowly raised.

(7) The temperature is raised to 1,500~1,600 Celsius by controlling the air.

(8) The kiln is subsequently cooled for an entire day.

(9) Then the kiln is destroyed and the crucibles are taken out.

(10) The crucibles are broken, and the metals are retrieved.

(11) The various metals from the broken crucibles are combined. Because they will have varying high and low carbon content, their combination will create activity and patterns in and on the blade.

(12) The combined metals are heated for 2 hours at 800 Celsius. For the heat treatment, I thought it would be by annealing (slow cooling), but Mr. Horoz said that was not the case.

8. Forging the Blade and Heat Treatment

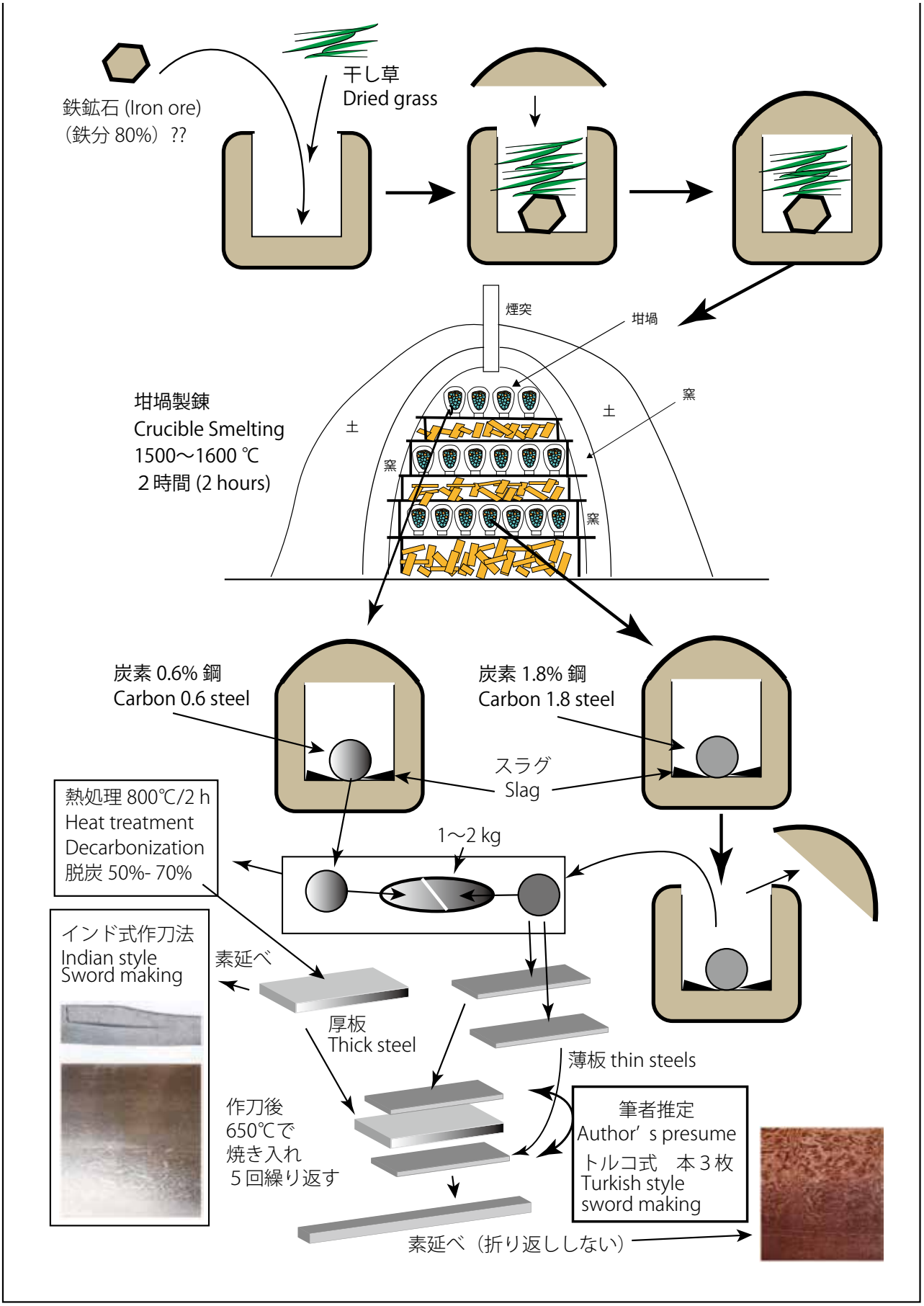
(13) Traditionally, the blade is shaped without folding.

(14) As the blade is shaped, the entire blade is quenched in water 5 to 6 times.

(15) This metal is then heated and flattened without folding.

(16) Once the blade is forged, it is heated to 650 Celsius and then quenched yet again.

9. Using the Crucible to Create Alloys



The mixture of non-iron components affects the quality of the resulting metal itself, and the crucible smelting method appears to facilitate the combination of these different elements. Thus, if cobalt oxide could be combined

into a metal alloy using the crucible smelting method, it may be possible to re-create the Korean sword that was introduced at the beginning of this article.

With the crucible smelting method, the quality of the iron ore is critical. In Japan, it is very difficult to find high-quality iron ore today. This is probably because, during the war, Japan exhausted its natural supply. Still, a type of iron ore (Fe304), which is of higher quality, can still be found in small amounts in Iwate Prefecture. I plan to experiment using this iron ore, which I obtained from someone who was using it as a weight for pickling vegetables.

10. The Sword Exhibited at the Topkapi Palace Museum

Viewing the sword exhibited at the Topkapi Palace Museum in Turkey, I could see the remarkable flowing patterns of the metal. Such qualities have been attributed to the vanadium contained in the sword, but I could not confirm this theory.

I hypothesize that ancient Islamic swords were exceptionally durable due to the combined effects of the crucible smelting method and the multiple quenches of the blade. In my personal experience I have bent an Islamic sword 90 degrees and watched as it reverted back to its true form. Hence, I am convinced of the inherent durability of ancient Islamic swords.

11. Further Study

In summary, I would like to identify areas of further study and recommend the following:

(1) To look for higher quality iron ore in Japan.
(2) Consider combining non-iron elements with the metal (e.g., vanadium, cobalt, calcium, kaolin, sodium).
(3) Fold the blade less.
(4) Experiment with quenching.
(5) Experiment with iron sand where iron ore is unavailable.

The aforementioned is based on my experience in Turkey and proposed as a possible path toward forging the ultimate Nihonto sword of old. That said, even with the right technology, the likelihood of forging the kind of superior sword (such as the Korean sword mentioned earlier in the article) is likely 1 in 10,000.