Archaeometallurgical Investigation on Historical Sword-Making Techniques in Northern Italy Between the Sixteenth and Seventeenth Centuries

Gabriele Tonelli, Michela Faccoli, Roberto Gotti, and Giovanna Cornacchia

Abstract The history of Brescia (Latin *Brixia*), a city in northern Italy, is characterized by a long manufacturing tradition, in particular the crafting of steel weapons and armor. This was made possible thanks to the availability of iron ore, the great forests from which to obtain charcoal, the numerous streams used as the driving force for power hammers and forges, but most importantly the ingenuity and industry of the people. Beginning in the pre-Roman age, the skills of the masters and craftsmen steadily progressed over the centuries, until Brescia and its vicinity became one of the most important arms production centers in Europe between the sixteenth and eighteenth centuries. This paper presents an overview of the weapon manufacturing region of northern Italy, in particular Brescia. Moreover, a metallurgical study performed on an early seventeenth century north Italian "*storta*" sword has shed light on historical sword-smithing technologies and enabled us to discover the secrets behind the high-quality Italian weapons.

Keywords Archaeometallurgy · Renaissance sword · Metallurgical characterization · Sword-making · Storta · Rapier · Northern Italy · Brescia

1 Introduction: Origins

Many historic sources agree that the Iron Age began in Italy between the ninth and tenth centuries BCE and that it predominantly developed alongside the large and rich iron ore deposits present in the Etruria region (now Tuscany) and on Elba Island (Ridgway 2000). From the eighth century BCE, this contributed to the rise of the Etruscans, who became highly skilled in manufacturing iron products. Numerous

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findings in burial sites dating back to the period between the seventh and fourth centuries BCE serve as evidence of this.

Some historians believe that when the Etruscans expanded toward the north of Italy, they came into contact with the Celtic peoples who inhabited these lands and shared their knowledge of how to extract and work iron (Bartoloni 2012; Sassatelli 2001). Specifically, the engraving on rock no. 35 in the National Park of Rock Engravings in Capo di Ponte, Val Camonica, Province of Brescia, dated between 600 and 400 BCE, illustrates what is likely a blacksmith forging a tool (See Fig. 6.1). This activity is also depicted in other engravings (Anati 1968).

After the Romans annexed the land held by the Etruscans in the early fourth century BCE, Brescia became a colony of the Roman Republic, under the name of *Brixia*. Under Roman influence, the production in Brescia of iron weapons and objects saw its first period of prosperity. This was supported by trade and exchanges in technological innovations that the Romans helped to propagate among the peoples they ruled. Developments in manufacturing also owed much to the rich iron ores and vast forests in the wide valleys north of the city, particularly Val Trompia and Val

Fig. 6.1 Peoples inhabiting the Italian peninsula between the seventh and fourth centuries BCE, before the expansion of Rome. Right: rock engraving from c. fifth century BCE known as the "blacksmith scene." Naquane Park, Capo di Ponte, Brescia

Camonica, which fueled the melting furnaces and forges (Cornacchia et al. 2015). The capacity of Brescia's existing mines and smithies was improved to meet the Roman legions' demand for weapons.

The city of Brescia became an important commercial hub for iron products and weaponry, linking up transalpine peoples with the Po Valley. Specifically, the legion recruited in northern Italy in the first century BCE (consisting largely of Brescians) was the Sixth Legion. It was also known as the *Legio VI* "*Ferrata*" (literally, "iron-clad"), precisely because its soldiers were heavily armed (Abeni 1984; Morandini et al. 1998). After the fall of the Western Roman Empire in the fifth century CE, northern Italy became the theater of numerous wars and Barbarian invasions, until the Longobard occupation in the sixth century CE.

During the Longobard period, Brescia was once again acknowledged as an important center for the manufacture of weapons, iron products, and more (the name *Lombardia*, or Lombardy, is derived from *Longobardia*. This region includes many of northern Italy's large cities, such as Milan, Bergamo, and Brescia) (Cornacchia et al. 2021). Even after Charlemagne defeated the Longobards in the eighth century and the Holy Roman Empire annexed the north of Italy, Brescia continued as a standard-bearer for the production of iron. Weapons from Brescia continued to be appreciated and traded both during the Communal Age (from the year 1000 to the thirteenth century) and under the reign of the Duchy of Milan (from the fourteenth to the fifteenth century) (Jarnut 2002; Fusari 2016).

2 Brescia Under Venetian Rule

Brescian production reached its peak while under the domination of the Republic of Venice, especially between the sixteenth and eighteenth centuries (See Fig. 6.2). The weapons that emerged from Brescia's smithies were sent to the Venetian Lagoon. From there they were sold all across Italy and Europe, where they were highly valued and much sought-after. How the work was coordinated, the availability of raw materials, the suitability of the land for this type of work, and the skill of the artisans were all factors that contributed to this development. The supply chain, which began with the extraction of the raw materials and ended with the sale of the finished product, involved the work of thousands of people, each of whom had a precise task to carry out within a broad and complex system that was very well coordinated.

Chief Magistrate Giovanni Da Lezze's *Catastico Bresciano,* a cadastral report printed in 1610, contains a chapter dedicated to the "*Arte della Spaderia*" (*The Art of Sword-making*), wherein he gives a precise and detailed description of the entire production cycle for iron weapons (Da Lezze 1969). According to his narrative, iron ore extracted from the mines was taken to the foundries. There, the raw iron, which was extracted from the ore, was sent to the many smithies who worked all over the Brescian territory and particularly in the towns close to the main smelters. Depending on its workforce, each smithy could create tools for agriculture, construction, or daily life, as well as swords, spears, armor, and other products (Cornacchia et al. 2020).

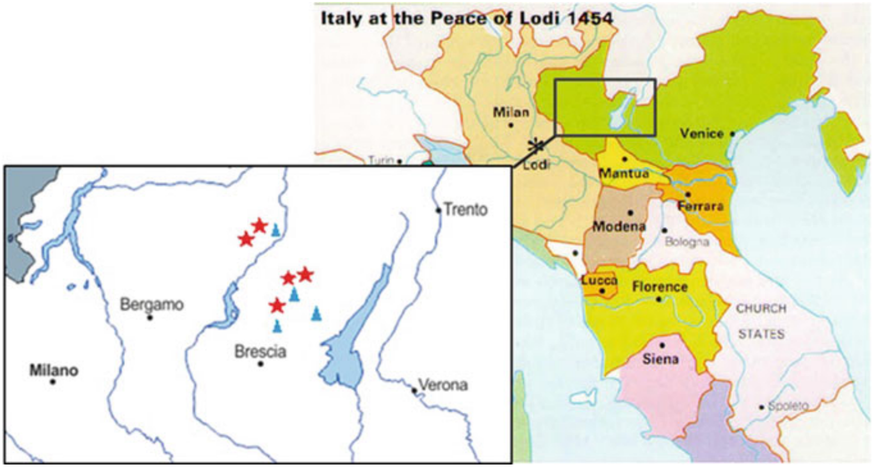


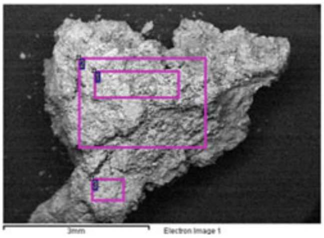
Fig. 6.2 This map depicts the political situation in northern Italy during the Renaissance. The green color indicates the territory ruled by the Venetian Republic. The areas around Brescia are particularly rich in iron deposits (red stars) and smelters (blue triangles)

Though documents indicate that cold weapons could be made entirely by individual smithies (Martinelli 1542), in reality, they tended to specialize in making specific individual components of a weapon, such as the blade, the guard, the pommel, etcetera, in order to optimize mass production (Martinelli, from State Archives of Brescia). All these components would then be sent to the city of Brescia, where artisans assembled them and decorated the swords or pole weapons in their workshops before selling them as finished products.

It is interesting to note how Da Lezze often uses the word "*maestri*" or "masters" in his description as if to underline the importance of the quality of the work done. The skills acquired over centuries of tradition allowed these masters to gain favorable treatment from the Republic of Venice, which protected their business. However, it was precisely because these artisans were so highly valued that they were forbidden from emigrating beyond the Republic or from selling their professional secrets without permission from the authorities (Flangini 2017).

3 Production Process in the Sixteenth-Century Northern Italy and Brescia

Around the sixteenth century, the main iron ore deposits were located in the mountains to the north of Brescia, in Val Trompia and Val Camonica, where siderite and limonite were mined. Analysis of a limonite sample from one of these mines shows a high percentage of manganese typical of its composition (See Fig. 6.3). The presence of this element made this Brescian ore particularly valuable for the production of



Spectrum	O	Al	Si	K	Ca	Mn	Fe	Total
1	34.23	0.63	16.09	0.43	0.89	9.73	38.00	100.00
2	30.56	1.19	12.63	0.48	0.98	8.08	46.07	100.00
3	33.04	0.80	5.37		1.04	7.90	51.85	100.00

Fig. 6.3 SEM/EDS chemical analysis of a sample of Brescian limonite

high-quality steel. Once brought to the surface, the mineral was heated for the first time (roasted) in specific furnaces. The purpose of this operation was to remove the water content (around 25–30% of its weight) and other undesired substances present in the mineral, such as sulfur.

Beginning in the fourteenth century, iron was smelted in blast furnaces (See Fig. 6.4) through a process known as "indirect reduction," which is still used today (Tognarini 1984). By collecting layers of iron ore and of carbon inside a tall tower, and injecting air from underneath, it is possible to reach temperatures of up to 1400 °C. At these temperatures, the iron reduction reactions take place, whereby it passes from an oxidized state to a metallic one. With a large quantity of carbon present, the iron becomes saturated in carbon, turning into pig iron. In its liquid form (≈1250 °C), pig iron gathers at the bottom of the furnace, that is the crucible.

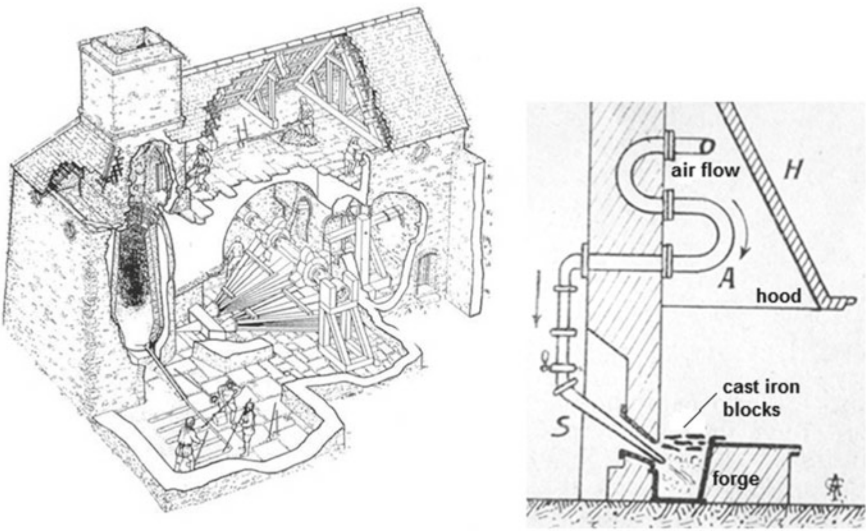


Fig. 6.4 Left: a drawing of a typical pre-industrial blast furnace. Right: a diagram of a "*Brescian forge*" used to transform pig iron into steel (Paoli 1984)

The residual mineral becomes slag with a doughy consistency that floats on top of the liquid pig iron. The presence of the slag is important at this point because it protects the liquid metal from oxidation and holds damaging elements such as phosphorus and sulfur inside it. When loading the furnace, fluxes such as lime were also added along with the iron ore and coal. Their role was to decrease the slag's viscosity thus making it easier to separate it from the metal. The action of loading the smelter took several days, during which the furnace burned continuously, day and night.

When the furnace master believed the moment was right, a clay stopper was broken, and the liquid pig iron would flow out through holes made in the crucible to be cast into ingots. In order to make iron and steel, the pig iron produced by the blast furnace had to undergo a refining process. This took place in a special forge, referred to as a *Brescian forge* or a *Bergamascan forge* (See Fig. 6.4) (Paoli 1984).

The pig iron ingots that came out of the blast furnace were broken up into small pieces using a trip hammer, to obtain what at the time was referred to as "raw iron." This was sold to the smithies that specialized in refining. They were called "*fuochi grossi*" (big forges) and were equipped with Brescian forges. In these ovens, the pig iron fragments were arranged over burning coals and were covered by specific powders, mainly consisting of iron oxide. The iron mass was kept in constant contact with the airflow so that progressive decarburization could be achieved, allowing steel with increasingly lower carbon content to be made (Galassini 1920). Through experience, the master in charge of the refining process could estimate the percentage of carbon and thus recognize the different types of steel being made, by observing the amount of sparks, the color of the flames, and the malleable consistency of the metal mass. Finally, to homogenize the chemical composition and remove slag and carbon residues, steel was made by forging it with a trip hammer into a bar or "*azzale*." The bars could be ductile iron, also known as Ladin iron, or steel, which was categorized according to its carbon content. From the lowest to the highest grade, the categories were: common iron, middle iron, strong iron, or "*azzale rompente*" (breaking iron). The required heat was provided by burning charcoal, which was made by masters who specialized in its production (See Fig. 6.5). Wood was selected and piled into large heaps which were covered with earth and clay. After this, the whole pile was

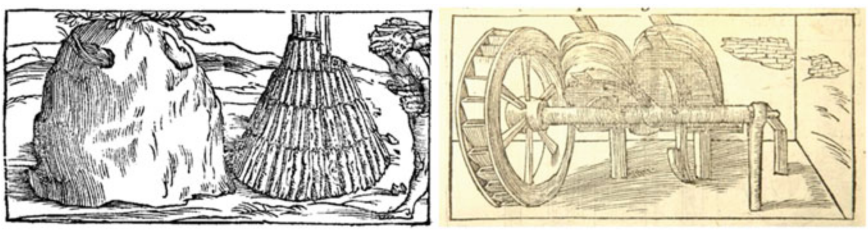


Fig. 6.5 Left: illustration of the process for producing charcoal. Right: bellows for the furnaces in the book *De la Pirotechnia* (*On Fire Techniques*) by Biringuccio (2013, 1977)

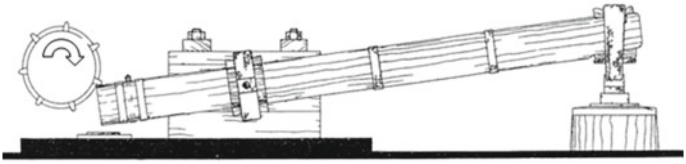


Fig. 6.6 Diagram of how a pre-industrial trip hammer operates (Fauzza 2005)

burned. This had to be done very slowly and with very low quantities of oxygen. The carburization process lasted several days.

When this process was completed, the heap was dismantled and the carbon generated was collected. The carbon was classified in line with its quality as either *strong essence*—denser, at around 250kg/m^3, and with a higher heating value of around 8000 kcal/kg—or as *weak essence*—lighter, at around 200–180kg/m^3, and less effective, at about 7000 kcal/kg.

Strong essence carbon, obtained from beech, oak, and hornbeam, was considered of higher quality, suitable for use in smelting furnaces; weak essence carbon, produced with chestnut, poplar, or larch, worked well for use in smithies (Tizzoni and Tizzoni 1999).

Smithies were typically built to be very tall and dark, with their internal walls blackened by smoke. They were built partly underground to muffle the vibrations and noise. They did not have proper windows, but rather openings arranged at random on the walls and on the roof, to provide a bit of light inside and especially to let the smoke out. All the machinery was installed on the rammed earth floor, which, during the warmest months was sprayed with water to cool it down and lower the surrounding temperature. At the center of the forge work area, there was the trip hammer (See Fig. 6.6), which has been found in several apparently identical examples. These, in reality, had differing features that made them suitable for different processes. The trip hammer was driven by the force of falling water, through a water wheel moved by a stream. Its hammering speed was correlated with the wheel's rotation speed and could be adjusted by changing the amount of water that hit the wheel's blades. The flow was adjusted using a valve, which was controlled by a lever near the work area.

A smithy could employ up to seven workers: the master forger stood at the trip hammer, aided by an apprentice who acted as his assistant. There were also the hearth operator and the finishers who refined the blades that the hammer had roughly forged on the anvil. Depending on the type of smithy, there could also be a grindstone operator or worker who cut away imperfections with shears. Numerous tools, molds, dies, and models used in production were hung on the walls. The color of the metal was used to determine the temperature of the steel blanks when they were taken out of the forge: dark red, around 700 °C; cherry red, around 1000 °C; red-white, around 1200 °C; white-silver melting at 1300 °C (Rotasso 2007). The forges were powered by continuously blowing air onto the burning coals. Until the fifteenth century, the air flow was produced using large bellows which were driven either by using the force

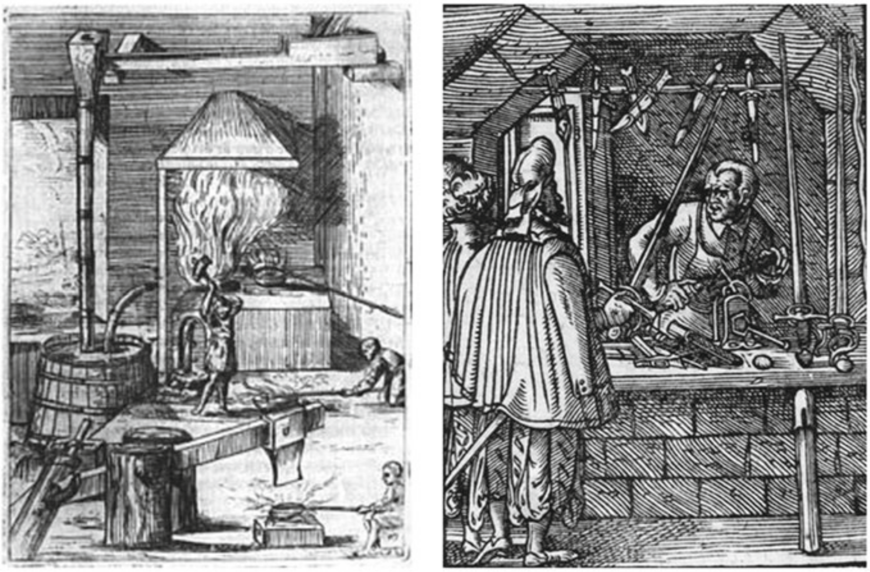


Fig. 6.7 Left: illustration taken from Marco Antonio Della Fratta's book *Pratica Minerale (Working with Minerals)* (1678) depicting a smithy complete with hearth, trompe and trip hammer. Right: a sixteenth century print by Jost Amman depicting a swordsmith's workshop (Fratta and Antonio 1985)

of water or manually. Toward the middle of the sixteenth century, trompes—water-powered air compressors—appeared. This was a new system for producing air jets by using the force of falling water (See Fig. 6.7). A part of the water that was used to drive the wheel was taken and allowed to fall through a pipe into a barrel. As the water dropped, it brought air with it. This came out as a constant jet from the upper part of the barrel, while the water flowed out from the lower part. According to some sources, the Brescians were among the first to adopt this new technology (Marchesi 2003).

Often one or more grindstones were found inside the smithy to provide a rough grinding finish to the products. However, there were also buildings equipped with several grindstones, each with a different grain, which specialized in mirror polishing the weapons. It has also been documented how specific abrasive lime-based pastes were used to further polish the blades (Biringuccio 2013, 67).

Manufacturing in Brescia included a wide range of weapons of war, such as cutlasses, two-handed long swords, infantry swords, and rapiers. Short blades such as daggers could also be produced, as could blades destined for civil or agricultural applications: knives, billhooks, long axes, or scythes. The smithy had to be able to meet market demands and to fulfill client commissions as quickly as possible, while still guaranteeing a reliable, quality product.

4 Techniques for Forging a "*Storta*" (Falchion) in Brescia in the Seventeenth Century

Despite the high number of swords produced in northern Italy and, in particular, in the province of Brescia, not many details are known today concerning the forging techniques. This is because the techniques and materials used were kept secret by the master forgers, who only passed them on to the worthiest apprentices. Furthermore, for the most part, these master artisans were illiterate and did not leave many written records. To discover what sword-making techniques were used in the sixteenth century and understand the reasons why the weapons produced in Brescia gained such status on the market, some "reverse engineering" is therefore necessary. Such a work is referenced below. The authors conducted this recently, on an archaeological finding: an Italian *storta* that dates back to the end of Renaissance (See Fig. 6.8) (Tonelli et al. 2016).

A *storta* is a sword gripped with just one hand. It has a broad and rather short blade, usually, 40–60 mm wide by 500–750 mm long. The *back* is 4–6 mm thick. The blade is *single-edged*—sharpened on just one side—with a curved cutting edge and a straight back that curves only near the tip. The curvature of the tip can be more or less pronounced and can also have a final sharpened section on its back edge. Often there are one or more fullers on the blade. The guard is usually composed of two arms. Depending on the period of history or on its area of origin, these can have different shapes. Among the most common is an "S" shape. The pommel should be quite hefty, to balance the bulk of the blade but without drawing the sword's center of mass too far back, which needs to be more forward to give power to cutting actions.

Between the fifteenth and seventeenth centuries, the *storta* was one of the most commonly used and popular swords, both among soldiers and the common people, such as peasants or merchants (See Fig. 6.9). The key to the success of this type of sword probably lay in how intuitive it was to use and in its versatility.

From the study of the part of the *storta* shown in Fig. 6.8, despite its poor state of preservation, we were able to draw significant information with regard to its forging methods (Biringuccio 2013, 67). The symbols imprinted on the *ricasso* (the letter "I"

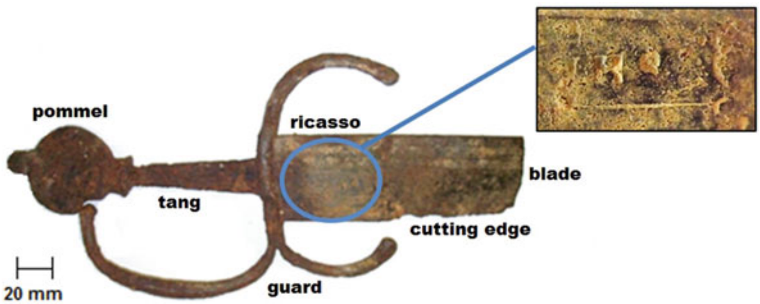


Fig. 6.8 Image of the artifact analyzed by Tonelli et al. (2016)

Fig. 6.9 Examples of *storta* swords made in Caino (Brescia) in the seventeenth century. Top sword is from private collection, center and bottom sword are from Martial Art Museum collection. Right: Image taken from Cesare Vecellio's book (1590), depicting a peasant armed with a *storta*. Printed image from Martial Art Museum collection (Collection of Martial Art Museum (BS), Botticino)

and the loops joined by a crescent) were identified after a careful pickling process. This permitted the object to be dated with some precision. It is very likely that this *storta* was forged in Caino, a village 15km from Brescia, between the sixteenth and seventeenth centuries. During that time, Caino was well known as a center of production of excellent blades. They were forged in four smithies: the *Fucina Scanzi,* the *Ponte Tegolo* smithy (run by the *Sassi* family of master swordsmiths), the *Cartole* smithy, and the *Terminello* smithy (run by the *Desenzani* family of master swordsmiths) (Rossetti 1995).

Once the finding had been dated, a study was made on the dimensions of both the finding itself and on other *storta* swords manufactured in Caino (See Fig. 6.9) which are in good condition. The measurements were initially taken in millimeters and then converted into the units of measurement used in Brescia in the sixteenth century.[1] It emerged that the length of the hilt is almost the same in every sword—34 *punti*, with small variations of just millimeters between different swords. Specifically, the length of the pommel and of the grip is always the same: 13 and 21 *punti,* respectively. The two measurements follow the proportions of the golden ratio ($\varphi = 1.6180339887...$), used since Grecian times for architectural and artistic projects.

As a single smithy could produce up to twenty-five blades in a day, it is reasonable to believe that the masters had developed a system for "standard" production based on the use of models, dies, and dimensional proportions that allowed a good repeatability of the production (Da Lezze 1988).

The study made on the *storta* actually reveals some interesting geometric considerations that confirm these theories (Tonelli et al. 2016). This sword was definitely produced in Caino in the early seventeenth century, as "CAINO" was stamped onto the *ricasso*. Further, the blade also features the words, "F. TOMASO." "F." stands for the Latin "fecit," or "made by"; "Tomaso" is the name of the master who forged

[1] Units of length in use in Brescia in the sixteenth century: 1 *punto* = 4.13 mm; 1 *inch* = 12 *punti* = 49.6 mm; 1 *braccio* = 12 *inches* = *144 punti* = 595 mm.

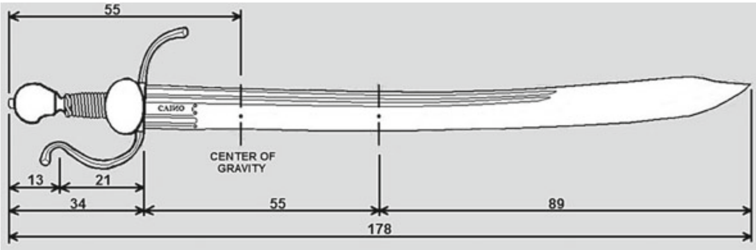


Fig. 6.10 Depiction of the *storta* forged by Tomaso Desenzani (Caino, seventeenth century), with measurements in *punti*

it—Tomaso Desenzani, who owned the *Terminello* smithy (Gotti and Minuzzi 2011, 98 and 158).

As shown in Fig. 6.10, the dimensions of this sword—including the length of the blade (144 *punti* or 1 *braccio*), follow the Fibonacci Sequence (1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, etcetera) which is closely linked to the golden ratio. It is therefore possible that the blade and sword makers followed precise numerical, mathematical, and proportional systems to ensure their products were both beautiful and well balanced.

4.1 Blade

A good blade requires a balance between hard steel that may be sharpened and penetrate the opponent's armor and flexible or resilient steel that does not scratch or break from impact in battle (fracture toughness). The metallographic study below (See Fig. 6.11) shows a pearlite and bainite microstructure (rich in carbon content) on the external surface of the blade. This is much harder than the ferrite-core microstructure, which is more flexible and resilient.

The microhardness tests reveal average values of around 150 HV in the core section and 350–400 HV on the external surface, with peaks of 550–600 HV in some areas very close to the surface. These two areas, having such different microstructures and hardness levels, are separated by lots of elongated non-metallic inclusions, which most likely can be identified as weld lines.

The inclusions on the weld line are formed of vitreous slag entrapments. They are very rich in silicon and calcium oxides. These results are in agreement with the few available written testimonies of forging techniques, according to which glass powder (rich in silicon) was used, mixed with lime and eggshells (rich in calcium), and other unknown ingredients (Biringuccio 2013, 67). The percentage of carbon in the blade varies between the core (around 0.2%) and the surface (around 0.5%). This has also been verified by historical sources where heat treatment using case hardening pastes with clay, carbon, salt, glass powder, animal horn, urine, and other secret ingredients was reported (Petrini 1963, 111–139). These heat treatments probably

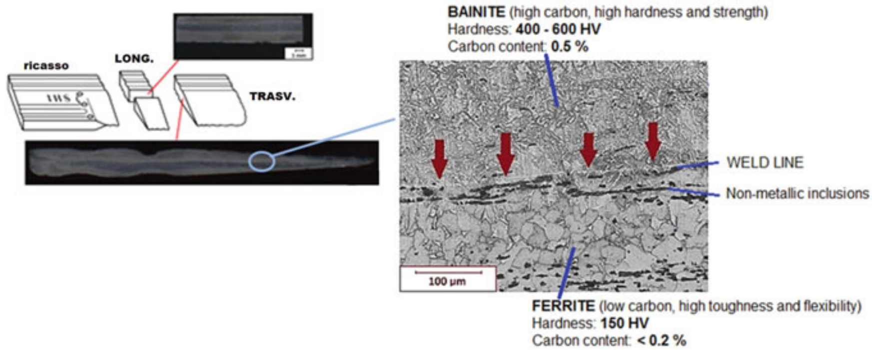


Fig. 6.11 Diagram of the parts of the blade and their metallography after polishing and chemical etching. Note that the central area (the core) is darker than the periphery: the difference in color shows the differing carbon content of the two areas. Right: a micrograph of the blade (200x – Nital2 etching) with indication of the microstructures observed

were used to harden the outer layer of the blade. The study allowed us to establish that it is very likely that the *storta* was produced by welding together two blocks of steel with different carbon content: one low in carbon, and therefore flexible and resilient, inserted into the other, which was rich in carbon, hard and strong, obtained from pattern-welded Damascus steel. To further increase the mechanical properties of the surface, the blade then underwent a carburizing thermochemical treatment (case hardening) and quenching. In this way, a blade that combines the properties of resilience, flexibility, and impact resistance, with an extremely hard, strong, and durable surface, is achieved. Unlike the blade, the tang—which joins the blade to the pommel and guard—was neither case hardened nor quenched.

4.2 Pommel and Guard

The pommel and guard require different characteristics from the blade. Specifically, as the guard was used to block blows, it had to be made using an impact-resistant (resilient) material. The analyses confirmed that both the pommel and the guard were forged using steel with a very low carbon content (<0.1%). Numerous residues of organic material were found inside the pommel. This is likely because animal glue was used in order to assemble the pommel, rather than wood or leather inserts. The grip that enclosed the tang was almost certainly made of wood, coated in strips of leather or braided metal.

5 Comparison of the Techniques for Making the *Storta* and the Rapier

An interesting point to understand is whether the production techniques changed according to the type of sword being made. This question led to the comparison of the structure of the *storta,* which was the focus of this study, summarized above, and the structure of the blade of a rapier (See Fig. 6.12), which also came from Caino and was made between 1575 and 1630 (the *storta* dates to the same period). The imprint on the *ricasso* of a crowned S and the word Caino suggest the blade was produced by the *Sassi* family, who worked at the *Ponte Tegolo* smithy (Gotti 2011).

A rapier is a sword with a long, thin, double-edged blade and a diamond section that tapers toward the tip. It was designed for a type of fencing based on thrusting rather than cutting. This requires a very flexible blade that could withstand the point load without breaking. The *storta* is instead shorter and was mainly used for cutting. That is why the blade is curved, wide, and thick, and just has a single sharp edge (comparison in Fig. 6.13).

The images above show how rapier blades were made in pattern-welded Damascus steel, combining two billets with differing carbon content. Repeated folding of the billets results in the typical layered structure, distributed somewhat at random. Unlike the *storta*, there is no ferrite area in the core. This is probably because of its geometry (long and thin), a rapier blade is fundamentally more flexible than a *storta* blade, thus there is no need for a flexible ferritic core. In addition, the rapier blade does not

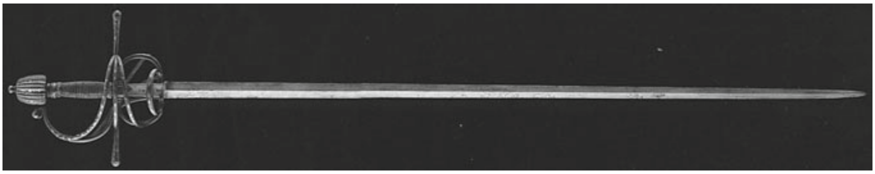


Fig. 6.12 A rapier whose blade was forged in Caino in the sixteenth century (Gotti 2011)

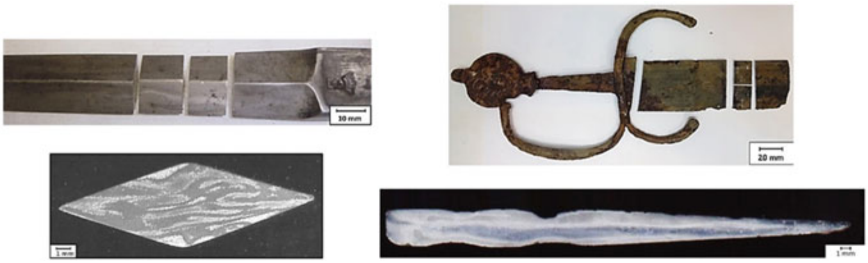


Fig. 6.13 Cross sections, after polishing and chemical etching, of the rapier blade and of the *storta* blade (Gotti 2011). The light areas are those with lower carbon content. Note how the microstructures are distributed differently in the two swords

show carbon-rich areas on the outside surface. This indicates that it was probably not case hardened either, precisely so as not to make the blade too brittle and prevent point load breakage.

In summary, it is reasonable to conclude that blades were produced using different techniques (see Fig. 6.14) for incorporating the steel billets and, depending on the type of sword being made, i.e., the mechanical characteristics required for good use in battle, they might or might not be subjected to thermal/thermochemical treatments.

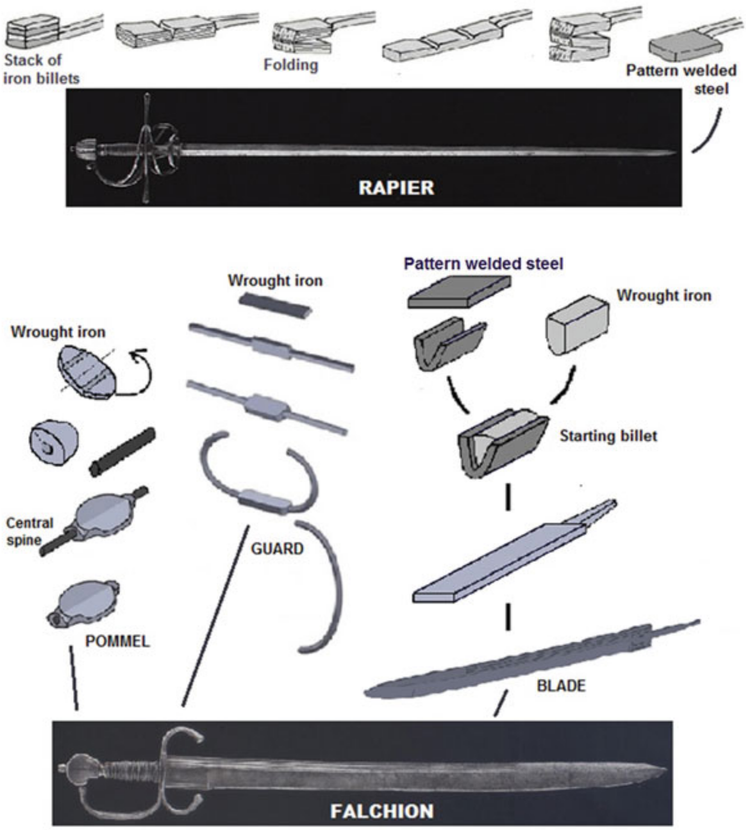


Fig. 6.14 Diagram of the possible methods used for forging the rapier and the *storta*. This hypothesis agrees with the results of the studies undertaken by Gotti (2011) and Tonelli et al. (2016), respectively

Fig. 6.15 Top: the original *storta* (Caino, seventeenth century). Bottom: the finished replica (Sartori 2019)

6 Reconstruction of a *Storta*

A replica of Tomaso Desenzani's *storta* (See Fig. 6.10) was recently reconstructed, following the procedure hypothesized in the metallurgical study described above (Sartori 2019). The replica was forged in a still-operational seventeenth-century smithy in a small Val Camonica town (Bienno, in the province of Brescia). For the blade, steel from a nineteenth-century carriage was used. For the pommel and guard, bars of soft iron from a seventeenth-century balustrade were used.

The blade's starting billet was assembled as shown in Fig. 6.14, by combining an external layer of pattern-welded Damascus steel folded into a "V" around a billet of soft iron in the middle. The polishing stage was performed manually using lime, grindstones, and natural abrasive powders. The result of the project was a faithful copy of the original, made using the same materials. It had the same geometries and the same weight (just a 4g difference between the original and the copy) (Fig. 6.15).

7 Concluding Remarks

This work was intended to be a scientific study of the techniques used by the master swordsmiths in Brescia to better understand what gave the weapons such high value. Prior archaeometallurgical research made it possible to develop theories on the materials and the forging techniques used. In the case of the *storta*, it was possible to reconstruct the entire production process, by identifying the steel utilized for all its components (blade, guard, and pommel) and the method by which the starting billet was probably assembled. The artisans understood that a *storta*—used mainly in combat—had to be hard and durable, but also flexible and resilient so as not to shatter. By combining steels with differing carbon content and therefore with different mechanical properties, and through clever use of heat and thermochemical treatments such as quenching and case hardening, it was possible to obtain a weapon with the characteristics desired for battle. The results of the metallographic analysis and comparison with a rapier from the same period and origins show that different forging techniques were used depending on the type of weapon and its intended use in combat.

This is all fascinating considering that in the sixteenth century, it was not known what carbon or manganese was, nor was the effect of temperature on the microstructure of steels during the forging process fully understood. Furthermore, there were no thermocouples or other measuring devices, which are required today to guarantee the repeatability of processes. The swordsmiths had only their own experience to rely on, which was developed—as described in these pages—thanks to centuries of tradition in working with iron. These conclusions made it possible to manufacture a replica of a *storta*, using the same techniques that were used during that era and seeking also to use the same raw materials. The result was rather encouraging and opens the way for other future studies to analyze and reconstruct various other types of swords.

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