BRASS IN CENTRAL EUROPEAN INSTRUMENT-MAKING FROM THE 16th THROUGH THE 18th CENTURIES

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Specialist literature on metals used in the construction of brass instruments—and the influence of these metals on the quality of the instruments—contains many contradictory statements. Bowsher and Watkinson noted this in their article "Manufacturers' Opinions about Brass Instruments," in which they spoke of a "harmonic mixture" of facts, folklore, exalted opinion, myth and mystery.[2] Many ambiguous statements have been made about the quality of brass and its effects on the sound of "historically" constructed instruments. In this context, the fundamental facts of early brass production, and the characteristic features of the resultant metals, are very often left out of consideration.

The purpose of this paper is to clarify some of the questions raised by providing a description of the production and processing of brass in the three centuries under discussion, and a consideration of the quality of the material from the technicians' point of view. In general, I have adopted a non-technical approach for this article, thereby omitting detailed discussion of more complex matters.

2. Brass as a material from the 16th to the 18th centuries

Nowadays it is self-evident to consider brass as an alloy of the metals copper and zinc, but this was not the case until at least the middle of the 18th century. Knowledge about metals was very limited, and until the beginning of the 18th century only iron, copper, lead, tin, antimony, bismuth, silver, mercury and gold could have been produced as metals; that is, could have been extracted from their respective ores.[3] Zinc, required for brass production, was practically unknown. Zinc was first identified as a metal in the 17th century, and was not produced industrially until about 1740. Only then was it used in its metallic form for brass production. For this reason, during the period under discussion brass was understood not as an alloy of two metals but as "colored copper."[4]

More than 5,000 years ago it was discovered that copper turned yellow when it was melted with a special "stone," nowadays known as calamine. The "yellow copper" produced by this melting process had a number of advantages in processing, as well as in production, over normal copper.[5] It was easier to cast, to work cold, to solder, and to surface-finish, and it did not develop a toxic oxide film when it came in contact with food. In addition, it was of special importance that the copper in the melting process miraculously increased in volume and weight, so that in the end one could command a higher price for the final product. It was this feature alone that made the process economical.[6]

3. The origin and quality of the raw materials needed for brass production

Copper, calamine and scrap metal were necessary for the production of brass, in addition to coal (usually charcoal). These materials will be described in more detail below.

3.1. Copper as a raw material

Copper production usually took place in copper works, which were located close to the source of the copper. During the period under discussion there were several centers of copper production in Europe, including Kuttenberg in Bohemia, Schwaz in Tyrol, Neusohl in Hungary, Freiberg in Saxony, Goslar near the Harz Mountains, Mansfeld/Eisleben in Thuringia, and Falun in Sweden. Mansfeld and Falun were by far the most important copper mines. Bi-annual production was 40,000 to 60,000 cwt. (1 European lb.= 500 grams), and they out-produced all their competitors several times over.[7] In addition to the mines mentioned above there were, of course, a large number of smaller copper mines and copper works, which however had only a more or less local importance.

The ores used for copper production contained different kinds and amounts of impurities, depending upon the place where they were found, and these could not(or only partially) be removed by the smelting processes of the time. For this reason the copper produced was never entirely pure, but always showed traces of lead, tin, zinc, iron, nickel, arsenic, silver and so on.[8] Because of its value silver had a special position. As early as the 15th century it was known how to extract silver from copper by a special and additional smelting process called *liquation* (Ger., *Seigerung*). To do so one had to first smelt the copper with large amounts of lead or lead ore. The resultant lead-silver mixture had to be extracted from the copper by a separating process. This method was relatively long and expensive and a comparatively high lead content remained in some copper treated in this way. In some quality-conscious brass works copper produced in this way was not used at all,[9] or only with limitations;[10] but most of the copper produced and subsequently used in brass production from the beginning of the 16th century was produced by this method, and therefore contained lead.[11]

It is interesting to compare the following values for Mansfeld and Swedish copper.[12]

	Mansfeld Copper	Swedish Copper
CU%	98.25	98.65
Pb%	1.09	0.75
Ag%	0.13	0.23
Fe%	0.13	0.05
Ni%	0.23	0.00
Al%	0.05	0.02
Mg%	0.00	0.03
Ca%	0.10	0.09
Si%	0.00	0.12
O%	0.00	0.05
	99.99	99.99

These two types of copper actually show minor differences in their respective analyses, but from a technical viewpoint they can be considered equal. Incidentally, one should not attach too much importance to trace elements in copper because, as we will see later, they contribute only slightly to trace elements in brass. It should also be pointed out that occasionally lead was added to copper with intent to defraud.[13]

3.2. Calamine as a raw material

The production of brass from calamine and copper is described fully in section 5. At this point it is sufficient to say that calamine was mixed with granulated copper in crucibles and, when heated, zinc was released from the calamine and diffused into the copper, increasing the weight of the metal. This process is known as *cementation*. The following types of calamine were used in brass production.

3.2.1. Natural Calamine

Natural calamine is a zinc ore (zinc carbonate, $ZnCO_3$). During the period under examination it was mined at different locations in Europe, such as the area around Aachen/Stolberg/Limburg, near Tarnowitz in Poland, in the Rheinisches Schiefergebirge, in Westphalia, in the Black Forest, and in Carinthia.[14] The mines around Aachen/Stolberg/Limburg were the most productive and were of significance for brass production at that time.[15]

The type and quality of calamine had a special influence on the resultant quality of brass. Usually it was contaminated to a high degree with other ores, such as iron ore, galena (lead sulfide) and so on.[16] Even with the most careful sorting it was not possible to remove these other ores from the calamine. A further important factor was the zinc content of the calamine, which accounted for the increase of weight during the cementation process. The brass producers were always interested in calamine that not only had a high degree of purity, but also resulted in a great increase of weight. But calamine of this kind was very expensive and not always available everywhere. For this reason brass producers were often forced to mix higher and lower qualities of calamine in order to achieve a brass of useable quality and justifiable price.[17]

If it is assumed that during cementation 50 lbs. of copper should increase in weight by 16 lbs. due to absorption of zinc, then this would result in 66 lbs. of brass. However, if the inevitable vaporization of zinc during the process is assumed to be 10%, then 17.6 lbs. of zinc would actually have to be added. Therefore, because in addition to zinc, calamine contains carbon and oxygen together with impurities, the 17.6 lbs. of zinc would require the following quantites of calamine:

— 44.0 lbs. of best-quality calamine from Altenberg (see section 4) with a zinc content of 40%,

— 58.7 lbs. of calamine,[18] of medium quality with a zinc content of 30%,

— 88.0 lbs. of calamine of poor quality with a zinc content of 20%.[19]

As these examples show, the large quantities of calamine necessary for making brass posed a severe problem of transportation. It is also easy to understand that with an increasing demand for calamine the quantity of the unwanted impurities in brass became greater. In some isolated cases the quantity of calamine required to give the requisite increase in weight could be more than twice the amount of copper.

3.2.2. Furnace Calamine

Furnace calamine came from deposits that formed in the upper parts of furnaces during the smelting of lead ore. The lead ore contained a certain amount of zinc ore as well, and during smelting the zinc vaporized, then oxidized and was deposited in the cooler parts of the furnace. Initially these deposits were simply discarded until it was discovered that, like natural calamine, they could be used in brass production.[20] In chemical terms furnace calamine was a mixture of zinc oxide and zinc carbonate and had a zinc content of more than 50%. The zinc content was actually higher than in natural calamine and consequently the increase in weight was greater.[21] However, furnace calamine contained high levels of impurities, particularly lead, so that it also had to be carefully sorted before it was used.[22]

As mentioned previously, the essential nature of both kinds of calamine was not understood for a long time and it was not discovered until relatively late that both were compounds of zinc. Also, because of the relatively high quantities of impurities in both sorts of calamine, the impurities introduced during the making of brass far outweighed those already present in the copper.

3.3. Scrap metal as a raw material

In almost all brass works a considerable amount of copper and especially brass scrap was melted, in addition to the aforementioned raw materials copper and calamine. This scrap accounted for up to 30% of the final melting weight. As long as brass scrap was a by-product of its own production (melting and casting mistakes, waste and so on from the brass foundry) the standard of quality was hardly influenced. However, it was a different matter when purchased scrap was used. This scrap could contain impurities in unknown amounts, such as tin, silver and lead, which came from the metallic plating and/or soldering joints on the scrap objects, or were alloy parts of them.

Metals were of great value and all metal objects no longer needed were remelted. This procedure was practiced quite rigorously so that even precious works of art were sent for scrap.[23] Under these circumstances a high "analytical purity" of the scrap could not be expected.

4. Brass works: Location and their sources of raw materials

In Central Europe there were a wealth of brass works at widely spaced locations and with different sources of raw materials. Of special importance in choosing the location of a brass works were, apart from the existence of water power to work bellows and hammers, the proximity to a source of raw material and/or access to an important market. As we have seen in section 3.2, brass production required a greater bulk of calamine than copper. It is therefore no coincidence that the world center of brass production was in the area of Aachen/Stolberg. The most productive calamine mines were here. From them came the famous "Altenberg calamine," which contained a high zinc content and was also quite pure.[24] When used with Mansfeld or Eisleben copper, this calamine produced the best quality brass.[25] In the area around Aachen/Stolberg up to 60,000 cwt.(3,000 tons) of brass were produced in the best years.[26] About 200 furnaces were working in the area, producing semi-finished products such as ingots (for remelting), sheet brass and wire, as well as finished products, such as kettles, needles, thimbles and so on. One of the main customers for the brass ingots was the Nuremberg brass industry,[27] which will be described later.

Aachen/Stolberg dwarfed all other production sites. There were also large brass works located directly at the copperworks, or connected contractually with them. Examples of such production sites were the brass works in Goslar in the Harz Mountains, Neustadt-Eberwald in Prussia, Rodewisch in Saxony, and Graslitz in Bohemia. The capacity of these works was up to 2,600 cwt.(130 tons) a year.[28] At these works it can be assumed that at least one of the raw materials used had a fairly predictable purity. Therefore, under favorable circumstances a specific quality of material could often be developed and maintained. But this was true if a certain consistency over a period of time could be achieved, even with other purchased raw materials.

The ability to develop a specific quality of material with a narrow analysis tolerance was very low because the brass works did not have their own sources of raw materials, and had to buy everything. Typical examples were the brass works in and around Nuremberg. The metal trade in Nuremberg in the period under study was in the hands of a few *Montanherrn* (metal merchants), who decided what kinds of metal were sold and worked on in the city.[29]

In Nuremberg copper from Bohemia, Hungary, Tyrol, Mansfeld and Sweden was used at various times.[30] Calamine sources were similarly widespread.[31] Brass ingots (for remelting) and sheet brass (for sheet metal or wire production) were bought in Aachen.[32] One can assume that the brass works were limited in their choice of materials and were often forced to work with those raw materials that happened to be on the market or that were provided by distributors.[33] This type of distribution was customary for metal works and hammer works in Nuremberg.[34]

5. The production of brass and its processing into semi-finished products

Production in all European brass works was uniform according to a process that had been known for over 2,000 years, and which had hardly changed during that period.[35] This process, known as *cementation*, employed up to eight small clay crucibles, in which small copper pieces, brass scrap and/or brass pieces were mixed in layers with finely ground calamine and coal dust. The crucibles were then covered with more coal dust and heated for about twelve hours. Zinc from the calamine diffused into the hot, but still solid copper. After twelve hours the heating was increased to melt the metal, and the contents of the eight crucibles were then poured into a central crucible. The melt was stirred, the slag removed from the surface, and the liquid metal then poured between two stone slabs, which were kept apart by metal spacers (Figures 1 and 2). Brass sheets produced in this way were cut into strips or pieces with big lever cutters after they had cooled down. Then the pieces were hammered, usually into rectangular sheets or long strips (for wire production), in a water-powered trip hammer which was usually connected to the brass works.

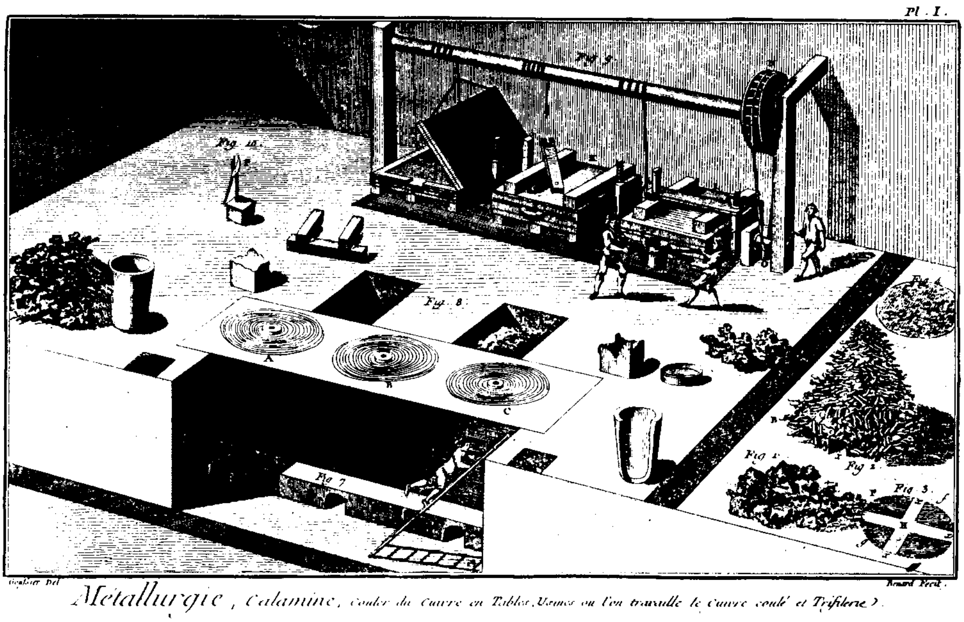
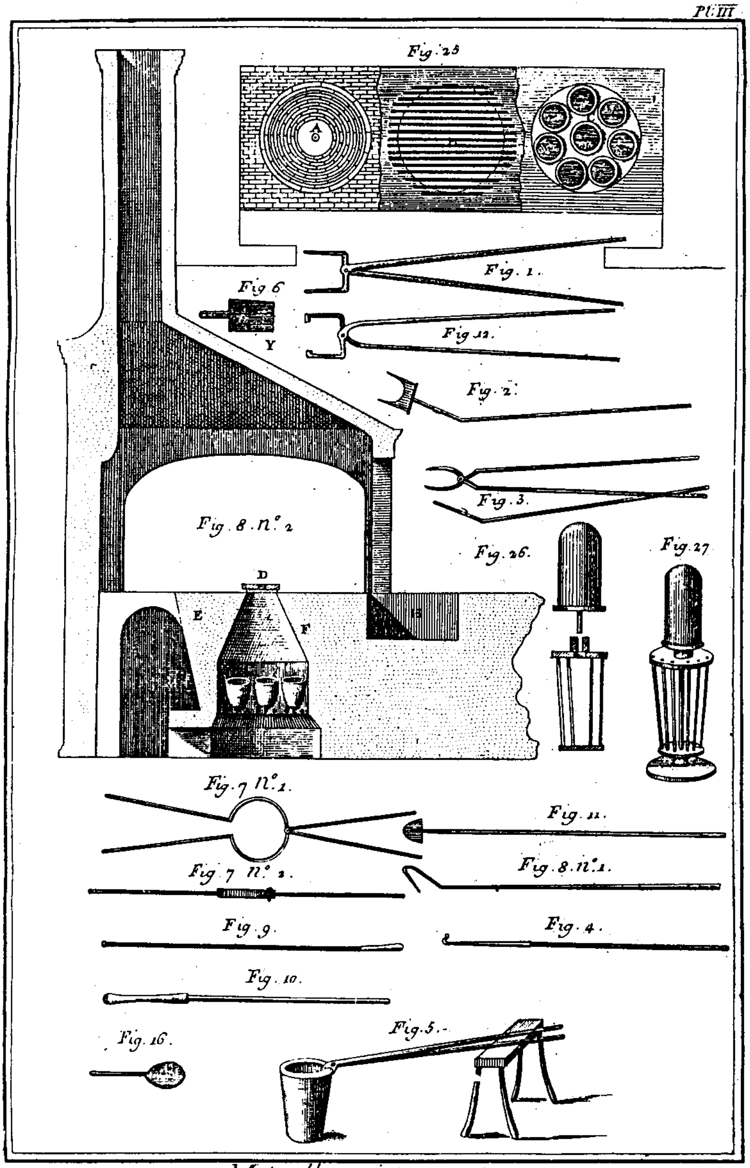


Figure 1
View of the cementation and casting shed of an 18th-century works producing sheet brass (Diderot and d'Alembert, *Encyclopédie,* 1751-80)



Métallurgie, Calamine,

194 Couler du Cuivre en Tables, Usines où l'on travaille le Cuivre coulé et Trifilerie.

Figure 2

Cross-section of a cementation furnace (no. 8), the shape of the melting pots (no. 25), and the tools necessary for making and casting brass (Diderot and d'Alembert, *Encyclopédie*)

Since the material hardened as it was hammered, the sheets and strips had to be heated repeatedly to anneal them. For example, in order to obtain a brass sheet with a thickness of approximately 0.20 mm, approximately 25 reheatings were necessary (Figure 3).[36]

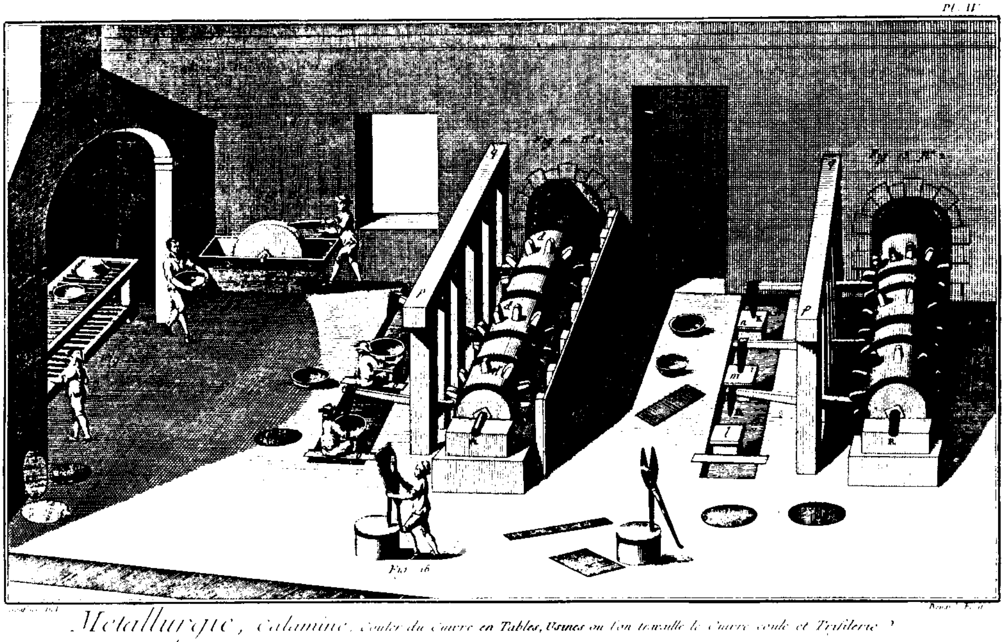


Figure 3
View of a characteristic 18th-century hammer works for brass processing. The illustration shows the production of utensels made of brass. The production of brass sheets required different hammer heads. (Diderot and d'Alembert, *Encyclopédie*)

The amount of raw material used in the various brass works was not always the same (Figure 4). The primary reason for this, as mentioned earlier, was the quality and the availability of the raw material, and was therefore a matter of economy.[37] Production weight was between 60 and 92 lbs, depending on the location. For example, the increase in weight during cementation was approximately 32% in Rodewisch, where natural calamine was used, and depending on the amount of copper used, this corresponded to a zinc content of approximately 24%.[38] When furnace calamine was used a zinc content of up to 32% was obtainable.[39]

Production Center	Copper	Galmei	Brass Scrap	Piece Brass
Stolberg[a]	20	55-60	20	30
Goslar[b]	30	45	NA	53
Kassel[c]	30	60	34	–
Namur/France[d]	35	60	35	–
England[e]	28	30-35	14	28
Sweden[f]	40	60	–	30

a K. Schleicher, *Geschichte der Stolberger Messingindustrie* (Stolberg: Stolberger Metallwerke KG, 1975), p. 51.
b F.L. Cancrinus, *Beschreibung der vorzügleiche Bergwerke usw...* (Frankfurt, 1767; rpt. Kassel, 1981), p. 126.
c J.G. Krünitz, "Messing," *Ökonomisch-technologische Encyklopädie* (Berlin, 1802), p. 317.
d Gallon and Duhamel, "Die Kunst Messing zu machen, es in Tafeln zu giessen, auszuschmieden und zu Draht zu ziehen usw...," *Schauplatz der Künste und Handwerke* (Leipzig: J. Kanter, 1766), p. 18.
e Ibid., p. 66.
f Krünitz, "Messing," p. 373.

Figure 4
Amounts of raw material used in the production of brass sheet and wire in the 18th century

With regard to the quality available from the brass works the following points should be made. As previously mentioned, economy played a decisive role in brass production. The principal economic factors were the supply and the resultant product, as they are today. The supply was essentially determined by the quantity and quality of the raw materials, while the result was the increase of weight achieved. This meant that compromises were always made between technical possibilities and economic justification. The brass producers knew very well that the best brass was a "pure" brass, free of other elements.[40] To achieve this the use of a high-quality pure copper with Altenberg calamine, but without scrap, and an intensive and costly cementation process were necessary. These measures, however, would have raised brass prices considerably. For this reason a "standard quality," which contained substantial amounts of impurities but which nevertheless still met the requirements of the brass processors, was agreed upon.[41] Normally no distinction was made between brass for sheet metal or wire production, but in individual cases a lower quality of brass for wire production was tolerated.[42] Beyond this, it seems that no special brasses were produced for specific purposes, and especially not for the very low demand of the instrument-makers. In summary, it can be said that under the circumstances described above an absolutely pure brass was never achieved from the elements copper and zinc; it always contained some impurities. Today it is not possible to determine from which raw materials the trace elements in old brass came. For the same reason it is not possible today to determine the origin of the brass used in the construction of brass instruments.

6. Source of supply for instrument makers.

Between the 16th and 18th centuries, Central Europe, and especially Germany, consisted of a multitude of independent countries, principalities, free cities and so on. The authorities of the day also mandated that, wherever possible, economic dependency was maintained. All producers, and thus also all metal-working guilds, were required to use only those raw materials which were produced in their own territories. Importation from other territories was often prohibited or subject to high duties, or was allowed only by special permission from the authorities. This meant that brass instrument makers were often forced to use local brass. This was especially true for the trumpet and trombone makers in Nuremberg. The production, trade and processing of brass were regulated in detail by the city council. The melting of brass, was restricted to brass foundries, rod-smiths and bowl-makers, who were the real producers of brass for sheet and wire production.[43] The town council ensured that brass dealers sold only local brass, and that the brass workers used only Nuremberg brass.[44] But as there was always a lack of raw material in Nuremberg[45] and their own brass works could not meet the demand, illegal foreign brass and wire *(frembder Mössing und Drot)* always appeared on the market.[46] Council regulations which were constantly renewed, confirm and repeatedly indicate how successfully and continuously the regulations were broken. As many Nuremberg trumpet- and trombone-makers lived under difficult economic conditions, at least from the beginning of the 17th century onwards,[47] they undoubtedly reacted economically when buying material, and were certainly open to "special offers." There is also no indication that for the production of a standard trumpet or trombone a brass sheet made in Nuremberg was absolutely necessary.

Whether or not the trumpet- and trombone-makers used materials from Nuremberg or elsewhere, the source is hardly relevant with regard to the quality of the brass actually used. Thus, no special position can be given to the brass made in Nuremberg; rather it must have corresponded to the customary standard. In this context a relatively broad spectrum of quality can be assumed.

The flow chart in Figure 5 illustrates the stages from copper ore to a production-ready material. (The raw material and the intermediate trade has not been taken into consideration.) It is important to note that the brass works, hammer works and wire production usually took place at the same location, which might also house a brass scraper who would prepare the sheets for buyers' inspection by scraping the oxide film off one side.[48] A trumpet-maker did not always buy his material from an independent scraper.

7. Brass quality from the point of view of instrument makers of the 16th - 18th centuries

Brass producers and processors agreed that "good" brass was, first and foremost, "pure" brass. Purity was understood as freedom from impurities, even if the identity of the foreign materials was uncertain. It was their conviction that using pure material was necessary to achieve a good "craft quality." This belief was based on the knowledge that impure materials were difficult to work and therefore could interfere with optimal production processes. This would result not only in higher costs, but also in a final product of lesser quality. Unfortunately there are only a few clues as to how the brass-instrument makers evaluated the quality of brass. However, we can assume that they did not differ from other metalworking trades in this respect, as the following examples show.

In connection with measurement and tuning of instruments, Johann Christian Hinrichs writes, "Too much still depends on the thickness and quality of the metal, and in terms of manufacturing horns much remains to do."[49] The term "quality" (*Güte*) can be understood for this period only to mean "qualitatively improved;" that is, "pure" material.

Johann Ernst Altenberg is more precise. In his book *Versuch einer Anleitung zu heroisch musikalischen Trompeten- und Paukenkunst,* he says,"A craftsman must be sure to select a good and pure metal, as well as the proper composition of it."[50]

From Markneukirchen in Saxony at the end of the 18th century we have a detailed account of brass-instrument makers. The craftsmen were charged with producing their instruments with brass from Niederauerbach, near Rodewisch in Saxony. There were high duties on brass imports from nearby Graslitz in Bohemia. In 1788 the craftsmen complained about the poor quality of brass from Rodewisch. They said it was coppery, like lead, too thick, it would crack when heated, and would split during the hammering process. The foreign Graslitz brass, however, had a better color, did not crack and was

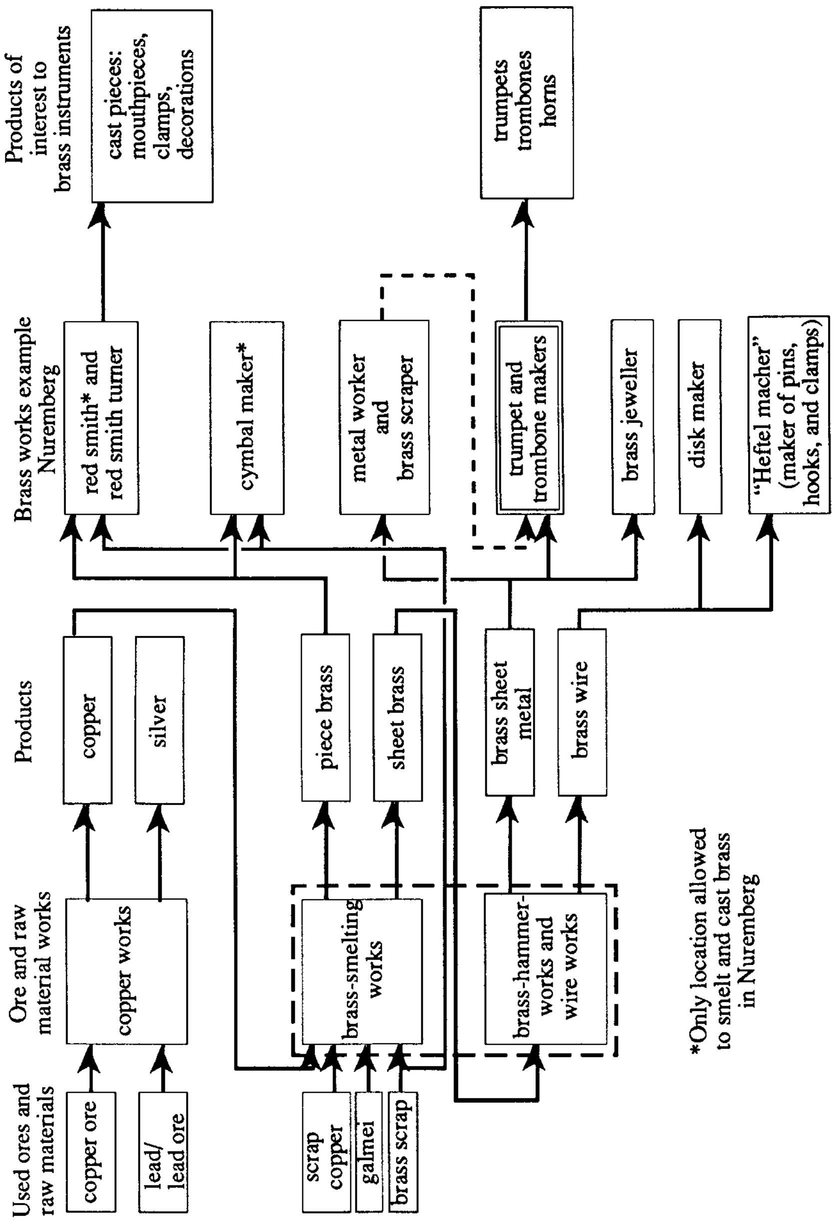


Figure 5
Flow chart from ore to production-ready brass

more durable when hammered. They said it was lighter (i.e., thinner), so that four additional pairs of horns per hundredweight could be produced. Also, while a hundredweight of Graslitz brass only cost fifty-six Thaler, Rodewisch brass cost fifty-eight Thaler per hundredweight. In 1792 the Markneukirchen craftsmen renewed their complaint and submitted samples of the Graslitz and Rodewisch brasses for examination. The "chemical and mechanical" examination was done in Freiberg, Saxony and confirmed their complaint. As a result the instrument makers were allowed to import their yearly requirements from Graslitz for six years—approximately 20 cwt., free from import duties.[51]

The reports of the Markneukirchen craftsmen are interesting in many respects. In the first place they confirm the negative effects of impurities in the making of brass instruments. In the case of the Rodewisch brass this implies a relatively high lead content and a low content of zinc. Secondly, their concerns about quality related only to its effects on the manufacture and the eventual number of instruments produced. The possible effect on the sound of the instruments is not mentioned. Clearly, in the selection of the material only technical and economical reasons were important. Thirdly, clear quality differences between the products of different brass works are mentioned. These differences can be connected with either the quality or type of the raw materials used, and/or the production process used. For this reason it is quite possible that the Graslitz process of copper production—precipitating copper out of a watery solution— was an important factor.[52] This so called *cement-copper* was distinguished by a relatively high degree of purity. In addition, the Graslitz brass was melted twice, thereby producing an especially pure alloy.[53] It must be noted that copper and brass production in Graslitz were exceptional and did not correspond to common practice.

8."Historical" brass quality from today's standpoint

For a better understanding of the following section regarding the quality of historical brass, a few remarks on the structure of metals and alloys are in order. Pure metals consist of a single type of atom, which solidifies out of a liquid state into a crystal structure specific to that particular metal. Copper exhibits a cubic face-centered lattice structure (Figure 6) which means that there is one copper atom on every corner and in the center of the cube face. This crystal structure is characteristic for the malleable metals such as copper, aluminum, lead, gold, nickel, platinum and silver. In addition there are other crystal structures such as the body-centered lattice of iron, chromium, molybdenum, vanadium and tungsten (Figure 7). Zinc has a hexagonal crystal structure as do beryllium, cobalt, magnesium and titanium (Figure 8).[54]

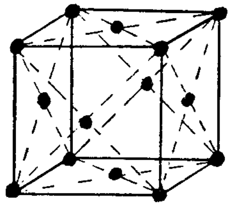


Figure 6
Cubic face-centered lattice structure of copper crystals

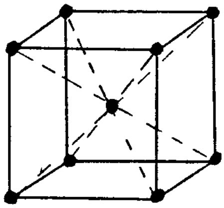


Figure 7
Body-centered lattice structure typical of iron, chromium, moybdenum, vanadium and tungsten

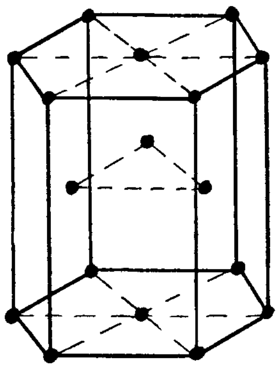


Figure 8
Hexagonal crystal structure of zinc

Very often alloys exhibit the same lattice structure as one of the elements of the alloy. This, for example, is true for brasses with zinc content of up to 37%. These brasses, like copper, have a face-centered crystal structure. The zinc atoms replace individual copper atoms in the crystal in a completely random manner (Figure 9).[55] Due to different properties of metal atoms, this substitutability of one atom for another is limited. For example, in copper elementary cells only 37% of copper atoms can be replaced by zinc atoms. Other metal atoms, with more significant properties than copper atoms, can be accepted into the crystal only within limits or not at all.[56] One of these is lead, which is soluble in copper and brass only in amounts of less than 0.1%.[57]

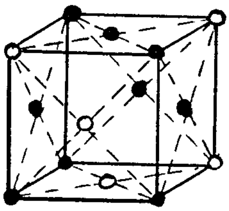


Figure 9
Cubic face-centered lattic structure of brass showing substitution of copper atoms (●) by atoms of zinc (o).

As already explained in the previous chapters, historical brass was not a pure copper and zinc alloy; rather it showed significant amounts of metallic and non-metallic impurities. It was therefore a multi-element alloy with a very complex heterogeneous crystal formation. It is difficult to say to what extent the impurities influenced each other and consequently influenced the quality of the brass. In principle it can be assumed that with high quantities of foreign elements the following factors would come into play:

— The ability of copper to accept zinc would be reduced.[58]

— The crystal structure of the brass would be distorted[59] and therefore the malleability of the material would also be limited.

The first factor has a negative effect on the anticipated increase of weight during brass production. Thus, during cementation, copper with high amounts of impurities would have a lower increase of weight and the final amount produced would also be less. The second factor especially influenced the production of thin sheets and their processing. The number of intermediate heatings had to be increased, which meant higher costs and often also lower quality. Lead is a special case in this context because it was often present in old brasses in quite high amounts. As brass can absorb less than 0.1% dissolved lead, there must be inclusions of undissolved lead in the structure. Figures 10 and 11 show lead inclusions in samples of historical brass with different lead contents. The inclusions have the disadvantage that they lower the ability to work the material cold, and when heated can cause damage to the material (Figure 12). The danger of ruining the material increases with an increasing lead content. The complaints of the Markneukirchen instrument makers concerning the working and heating quality of the Rodewisch brass can be accounted for by its relatively high lead content.

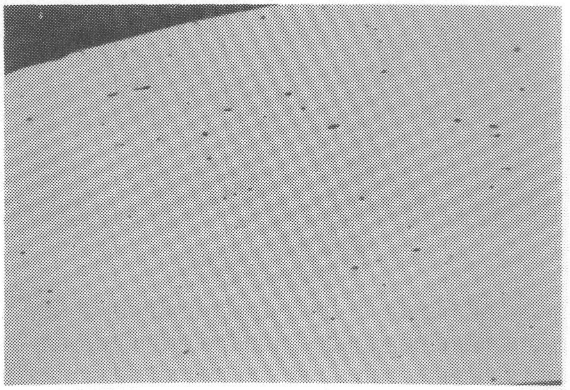


Figure 10
Small, partly stretched lead inclusions in a piano wire from an instrument by Kanemeyer, Mannheim, 1794
(lead content, 0.2%)

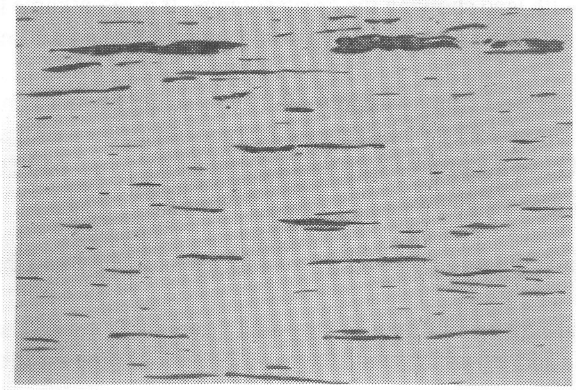


Figure 11
Distinct, stretched lead inclusions in a grand piano wire by Knaur, Naumberg, c. 1850 (lead content 2.9%)

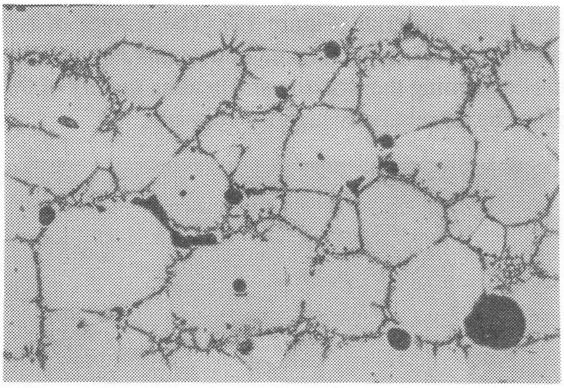


Figure 12
The same sample as Figure 11 after heat treatment at 900°C for one hour. The lead inclusions have coagulated and the grain-borders have melted. The material is heavily damaged and cannot be worked further.

In summary it can be said that high amounts of impurities were not a sign of good quality, but rather of lower quality, a fact appreciated neither by quality-conscious brass producers nor by brass workers. Figure 13 illustrates the variety in composition of historical brass sheet, wire and castings over a period of approximately 1,800 years. Apart from the main elements copper and zinc, all samples indicate high amounts of other elements, with lead showing the greatest range. It is remarkable that the analyses show no significant differences between a Roman wire cable and a trombone of the 19th century!

These analyses are definitely representative of the quality of the brass given to the craftsmen by the brass works. It must also be pointed out that in some cases even greater deviations could have occurred. From the material technicians' point of view, one can draw the following conclusions:

- There is no significant difference between brass used for sheet and that used for wire.

- In both sample groups we find high-quality brass (samples 3, 8 and 9) and lower-quality brass (samples 5a and 10) which could have caused serious problems for the craftsmen.

- There is no significant difference between Nuremberg brass and brass from other regions.

- The impurities are in no relative proportions; their quantities are purely coincidental.

- It is confirmed that the brass-instrument makers used the brass available on the market and that they did not choose special types.

9. Summary and Conclusion

The brass used in the production of instruments from the 16th to 18th centuries exhibited, apart from the main alloy elements copper and zinc, quantities of impurities in different amounts. These resulted from the raw materials that were used in brass production and could have been eliminated or reduced only at a prohibitive cost. The brass producers and the brass processors were aware of the negative effects that the trace elements had on the alloys and the quality of the metals. They therefore desired material as pure as possible, since production of good instruments required pure brass. Trade policies restricted the already limited choice of materials, thus usually making instrument makers dependent on the materials produced in their own region, or the materials offered on the market. The brass used for instrument production was of the "standard" quality during the period under study, and accordingly exhibited a high quantity of trace elements. In addition to instruments made of very pure brass, there were others with high amounts of impurities.

There are no indications that the quality and quantity of the impurities influenced the sound and/or the playability of the brass instruments. In any case, the instrument makers did not take this into consideration. Their foremost interest was the problem-free processing of the material. Good manufacture meant working with pure brass, free of trace elements. Therefore, we can conclude that trumpet and trombone makers, between the 16th and 18th centuries, could have made instruments of better quality if they had been able to use materials of today's high standard.

NOTES

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