Reconstruction of Historical Alloys for Pipe Organs Brings True Baroque Music Back to Life

B. Baretzky, M. Friesel, and B. Straumal

Abstract

The pipe organ is the king of musical instruments. No other instrument can compare with the pipe organ in power, timbre, dynamic range, tonal complexity, and sheer majesty of sound. The art of organ building reached its peak in the Baroque Age (~1600–1750); with the industrial revolution in the 19th century, organ building shifted from a traditional artisans' work to factory production, changing the aesthetic concept and design of the organ so that the profound knowledge of the organ masters passed down over generations was lost.

This knowledge is being recreated via close collaborations between research scientists, musicians, and organ builders throughout Europe. Dozens of metallic samples taken from 17th- to 19th-century organ pipes have been investigated to determine their composition, microstructure, properties, and manufacturing processes using sophisticated methods of materials science. Based upon these data, technologies for casting, forming, hammering, rolling, filing, and annealing selected lead-tin pipe alloys and brass components for reed pipes have been reinvented and customized to reproduce those from characteristic time periods and specific European regions. The new materials recreated in this way are currently being processed and used by organ builders for the restoration of period organs and the manufacture of new organs with true Baroque sound.

Introduction

The first organ-like instrument was built around 246 B.C. by a Greek craftsman in Alexandria named Ktesibios. The oldest still-playable organ in the world, built in about 1435, is in Sion, Switzerland. In the 17th and 18th centuries, the art of organ building reached its peak. During the Baroque Age (~1600–1750), the concept of organ building was governed by the idea of replicating the orchestral sound. For the Protestant church, the organ was a central component of the church service. As a result, the rich and strongly Protestant regions of northern Germany and the Netherlands became primary centers for organ building during the Baroque era.

The industrial revolution, the influence of romantic and modern music styles, and an increasingly avid audience radically changed the aesthetic concept, design, and methods of organ building in the 19th and 20th centuries. Organs were now constructed in large factories by many workers and machines, in contrast to the previous small workshops with only a few artisans and an organ master. More expressive ranks and a crescendo pedal, along with modern technical innovations (e.g., electrification of the mechanical parts), new materials, and the demand for colossal orchestral organs, drastically changed the organ sound. As a result, the profound knowledge of Baroque organ building, which had been passed down and improved over generations, was lost.[1–3]

Recapturing a Lost Art

The second half of the 20th century saw a revival of interest in Baroque music, and the realization that a historically accurate sound could only be achieved by using adequately restored Baroque period instruments or new ones built using traditional techniques. Therefore, interest has grown in recapturing the lost art of organ building in order to restore and build new organs with the appropriate sound qualities.

During the last 10 years, the Göteborg Organ Art Center (GOArt), in close collaboration with researchers at Chalmers University of Technology, both in Göteborg (Gothenburg), Sweden, has developed new techniques for manufacturing organs with Baroque sound based on scientific research.[4,5] As a result, they have succeeded in both accurately restoring historical Baroque instruments and producing new organs with true Baroque sound, within the framework of the Swedish- and European-funded North German Organ Project.

The first of such organs—inspired by the Arp Schnitger organs built in the Lübeck Cathedral (1699, destroyed 1942) in Lübeck and the St. Jakobi Church (1693) in Hamburg, both cities in northern Germany—was constructed in the research workshop of GOArt and installed recently in the Örgryte Nya Kyrka in Gothenburg (Figure 1). Other new organs with true Baroque sound have been recently inaugurated in the Noorderkerk, a church in Rijssen, the Netherlands (built by the workshop of Henk van Eeken, who participated in the North German Organ Project), and at the Korean National University of Arts in Seoul. A copy of the largest and best-preserved late Baroque organ in northern Europe, built by Adam Gottlob Casparini in 1776 for the Church of the Holy Spirit in Vilnius, Lithuania, and suitable for the music of J.S. Bach, is currently under construction at the University of Rochester's Eastman School of Music and will be inaugurated in Christ Church, Rochester, in 2008.

The demand for such Baroque-era instruments—restored originals or new reproductions—is continuously growing. In the framework of a European project called TRUESOUND, four research institutes and five organ builders worked together on the reconstruction of historical copper alloys—namely, brass—which differ in composition, microstructure, mechanical properties, and workability from currently commercial available ones. As a result of this project, organ builders received newly fabricated organ parts made from

Figure 1. New Baroque-style organ constructed using Baroque technology and installed in 1999 in the Örgryte Nya Kyrka in Gothenburg, Sweden.

these alloys, tested them, and installed the parts in Baroque church organs, including the 1718 organ in the Magnuskerk in Anloo, the Netherlands (Figure 2); the 1701 instrument in the Evangelic Lutheran Church in Ugale, Latvia; and the newly built *Vox Humana* stop for the famous Casparini organ (1776) in Vilnius.

The Baroque Pipe Organ: Construction and Operation

The pipe organ is a musical instrument in which the sound is produced by forcing air, or "wind," at a constant pressure through numerous pipes. The organist chooses the sounding pipes by pulling the register knobs and pressing keys either manually or using a pedal keyboard. While all organs have flue pipes (Figure 3), more sophisticated organs also contain reed pipes (Figure 4).

Flue pipe construction is reminiscent of a recorder: the flue pipes are usually open at the top and tapered at the bottom, with a "mouth" running across the flattened section above the tapered part. Inside the pipe is a "languid," or tongue (a fixed horizontal plate), with a "flue" (a narrow slit) between it and the lower "lip" of the mouth. The wind, supplied by large bellows, enters the pipe at the tapered foot and causes the pipe to vibrate. When the wind is admitted to the flue pipe by the actuation of the appropriate stop and key, it flows upward and forms a sheet-like jet as it emerges from the flue slit. The jet flows across the mouth and strikes the upper lip, where it interacts with the upper lip and the languid, thus inducing the column of air in the body of the pipe to vibrate and to maintain the steady oscillation that generates the pipe's "speech."

Reed pipes, which imitate the trumpets and trombones of an orchestra, add beautiful warmth or a blazing fanfare to the tonal composition of the organ. The sound production in reed pipes is similar to that in reed instruments. When wind enters the bottom of the reed pipe, a small metal tongue vibrates against the shallot, producing sound, which is amplified and modified by the resonator (Figure 4a). The sound of the reed pipes crucially depends on the tongue curvature adjusted by the organ builder during voicing. The pitch of the reed pipe is adjusted by moving the position of a tuning wire up or down. This holds the tongue against the shallot, and thus lengthens or shortens the part of the tongue allowed to vibrate. Several parameters determine the organ's characteristic sound and timbre: the shape of the resonator, the metal used for the tongue, the wind pressure, and the pipe dimensions. Without reed pipes, much of the great organ music cannot be performed successfully.

Materials Scientists and Organ Builders: A Research Collaboration

Since the appropriate materials for adequate reconstruction and restoration of

Figure 2. Period Baroque organ (1719) in the Magnuskerk in Anloo, the Netherlands, restored in 1999 using Baroque technology.

Baroque-era organs are either not commercially available or their composition, microstructure, mechanical properties, and workability are not known, several research projects were undertaken to investigate and reconstruct the original techniques for producing and processing alloys for organ pipes and brass for reed pipe tongues. A main goal was to improve both the sound quality and the brass workability, which is especially important for reed tongues. The TRUESOUND project, funded by the European Union, enabled direct cooperation between materials scientists and organ builders. As a result, the organ builders received new copper alloys, tested them, and used these new materials to both restore old organs and build new ones with historical sound. This article contains a brief description of the results of these investigations.

Alloys for Flue Pipes and Reed Pipe Resonators

Studies of historical organ pipes showed that lead-tin pipes were often sand-cast.[5] Unfortunately, detailed descriptions of the sand-casting methods of 17th-century organ builders no longer exist.

Within the framework of the North German Organ Project, the casting process for organ pipe material was reinvented.[1,2,4–6] Tin and lead are melted in a pot. At a certain temperature, depending on the melting temperature of the alloy and the size of the pipe to be cast, the molten metal is poured into a casting box. The worker then quickly moves the casting box at a constant speed lengthwise down the sand bench, leaving a thin metal sheet behind. Due to the casting technique with a moving casting box, the cast sheet thins out continuously in the direction of movement toward the end. The metal solidifies immediately on the thick sand bed, which is a high-heat capacity mixture of sand and fluid (e.g., olive oil). The metal sheet cools down rapidly to the temperature of the sand bed and then cools down further very slowly. The pipe material produced in such a way possesses enhanced materials properties in terms of hardness, stability, workability, and sound quality, compared with commercially available pipe sheets. Historical organ pipes are also often thinner at the top, which gives them better stability and simultaneously better sound resonance. The proportion of impurities or trace elements in the metal, the casting temperature, and the type and temperature of the sand–fluid mixture used further influence the metal properties and consequently the sound quality.[1,2,6]

Alloys for Tongues and Shallots

Reed pipes (Figure 4) are constructed in a different manner than flue pipes. Their central part consists of a tongue and a brass shallot. The resonator is normally made of a lead-tin alloy, as in flue pipes. The tongue vibration crucially determines the reed pipe sound. The vibration behavior depends on the elastic properties of the brass sheet and therefore mainly on the brass composition, microstructure, and processing. The organ builder first receives the brass after casting, mechanical treatment (hammering and/or rolling), and annealing. Then the builder cuts and thins the sheet into tongues with the appropriate size and thickness and finally files and slightly bends the brass tongue to induce the appropriate curvature for creating the best sound. The workability of the material is a very important issue during the voicing of the pipe and is determined by the desired response of the brass to specific treatments made by the organ builder that simplify the work and improve the quality.

In order to meet the organ builders' requirements, the scientific partners investigated the material composition and the sequence of the heat treatments and mechanical forming processes. The workability and acoustic properties of historical and reconstructed alloys were evaluated by the organ builders.

Composition

The composition of period tongues and shallots was nondestructively measured on about 30 samples borrowed from organs produced between 1624 and 1880 in various European countries (Belgium, France, Germany, the Netherlands, Italy, Latvia, Lithuania, Sweden, and the United Kingdom). The need to conserve the period instruments posed severe limitations on the sample size and surface treatment of the metals available for testing. For all samples, the concentrations of the main components (Cu, Zn, Pb) were measured nondestructively by means of neutron diffraction (ND) and x-ray diffraction (XRD), using the tongues and shallots as received. Since such analyses included the contaminated surface layer, the results were controlled by applying electron probe microanalysis (EPMA) to tiny 1–2 mm^2

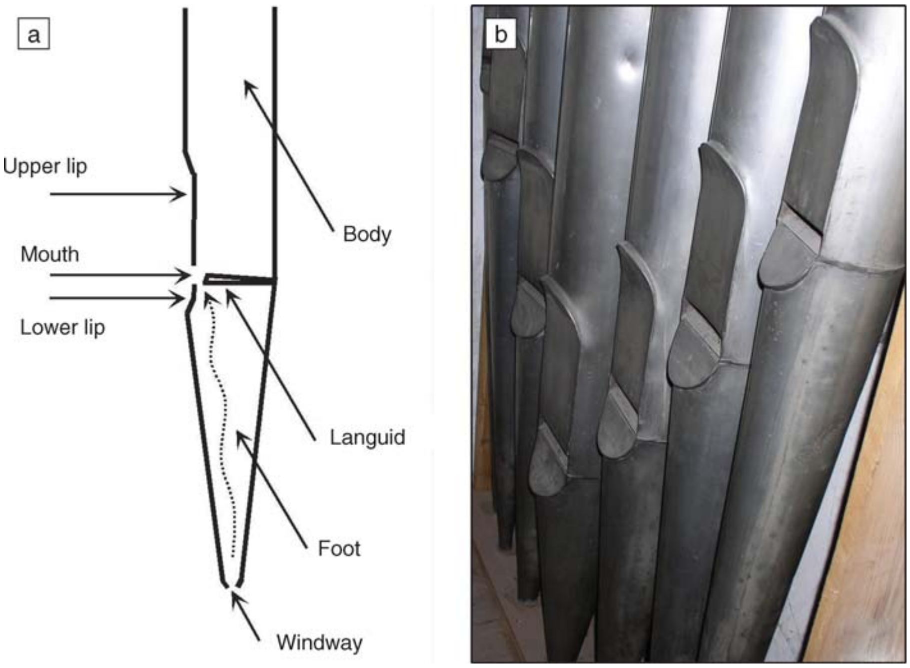

Figure 3. (a) Schematic illustration of a Baroque organ flue pipe. Dotted line shows airflow path. (b) Period flue pipes from the Casparini organ (1776) in the Church of the Holy Spirit in Vilnius, Lithuania.

surface-cleaned triangular samples, cut off from only a few tongues at the edge of the non-vibrating parts (close to the block, behind the tuning wire). Secondary-ion mass spectroscopy (SIMS) was used to identify trace elements in the samples not detectable by ND, XRD, and EPMA, and inductively coupled plasma optical emission spectroscopy was used for chemical analysis. This integral method allowed us to additionally verify the data obtained by local SIMS and EPMA analysis on the concentration of lead, which is distributed non-uniformly in the brass. In order to observe the microstructure of the brass material, light and scanning electron microscopies were performed on some short tongues, which were carefully polished on a small area of the non-vibrating part. Only a few damaged samples (such as those from the organ in the Evangelic Lutheran Church in Ugale, Latvia) could be used and cut into small parts of 3-mm diameter to study by means of transmission electron microscopy.

The main components of tongues and shallots are copper, zinc, and lead. Zinc is soluble in copper, whereas lead is insoluble. The total concentration of other elements—for example, iron, manganese, nickel, and tin—was surprisingly low: <1 wt% for samples from the 17th century and <0.3–0.5 wt% for samples from the 19th century. Since the impurity concentrations are below their solubility limit in Cu, the impurities are all expected to be in solid solution. Therefore, they influence the brass properties in a similar way as Zn and were not considered for the development and manufacturing of new alloys.

In all samples, the Zn concentration was surprisingly constant over time (Figure 5a).[7] Between 1624 and 1790, it was ~26 wt%. A higher zinc concentration of ~32.5 wt% additionally appears around 1750. These two concentrations coexisted for 40 years. From the end of the 18th century up to the present day, the Zn concentration has remained at the higher level of 32.5 wt%. According to the Cu–Zn phase diagram, all historical tongues and shallots were made of α-brass, which contains only one copper-rich phase, namely, the fcc α solid solution of Zn in Cu (Figure 6). Since the Zn concentration does not exceed the solubility limit in Cu, the next phase in the Cu–Zn phase diagram—the

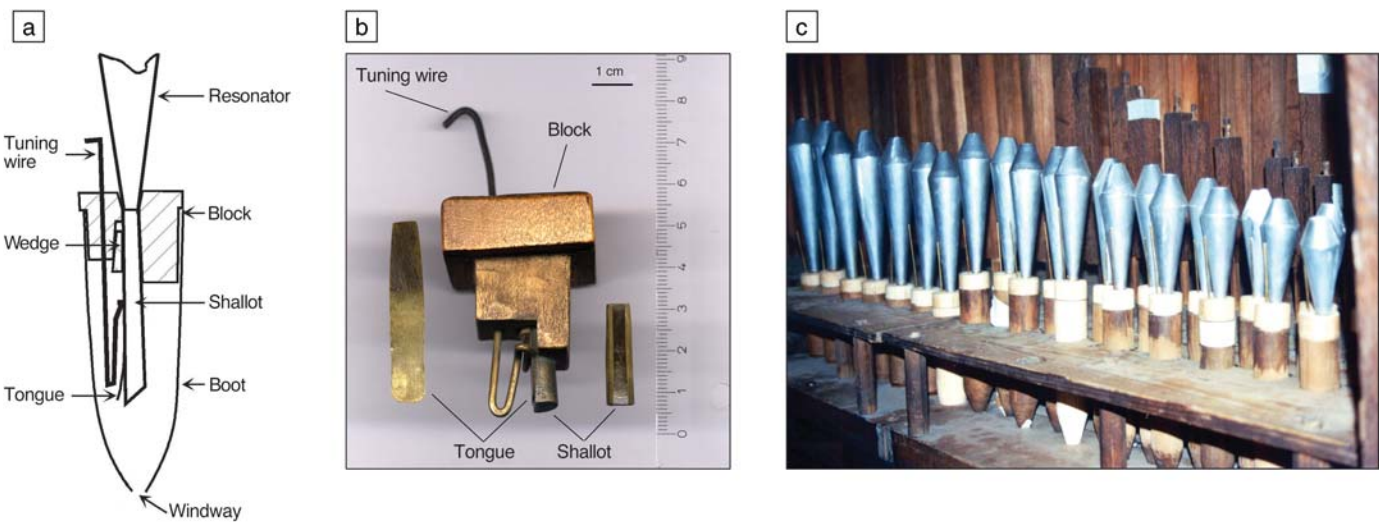

Figure 4. (a) Schematic illustration of a reed pipe. (b) Components of a reed pipe (without resonator and boot), including the tongue and shallot, from the Arp Schnitger organ (1680) from the former St. Johannis monastery church in Hamburg, Germany. This organ was moved in 1816 to St. Peter and Paul Church in Cappeln, Germany. (c) Reconstructed *Vox Humana* reed pipe stop from the Casparini organ (1776) in the Church of the Holy Spirit in Vilnius, Lithuania.

β-phase—does not appear in historical tongues and shallots. The tongues and shallots always contained lead before 1750. The concentration of lead slowly decreased from 7–8 wt% in 1624 to 2 wt% by the middle of the 18th century. The first lead-free tongues appeared around 1750. After 1820, lead completely disappeared from the studied brass.

Why is the zinc concentration at a lower constant level before 1790? Why does it increase later and remain at the level of 32.5 wt%? Before 1738, Zn was only available as zinc oxide or zinc carbonate ("calamine"), and not as pure metal.[8,9] Therefore, brass could not be produced by melting together the pure metal components, as could be done for alloying copper and tin into bronze. If one tries to reduce zinc ore by charcoal in an open furnace, the zinc immediately evaporates and oxidizes.

Brass was produced by a process called cementation: pieces of copper, coal, and calamine were put together into a pot, heated to a certain temperature above the boiling point of zinc (907°C) but below the melting point of Cu (1083°C), and annealed for several hours. The calamine was thus reduced, and the evaporated Zn immediately diffused from the gas phase into the hot but solid copper. Below 907°C, the process is not possible; on the other hand, heating much above 907°C was not economical, since it required too much coal. Therefore, the cementation was performed within a rather narrow temperature range. The experienced human eye can estimate temperature from the color of a furnace to within 20–30°C. The Zn concentration in brass is determined by solidus concentration (maximum solubility of Zn in solid Cu), which is exactly 26 wt% Zn at approximately 920°C (Figure 6).[10] Thus, the cementation processing temperature for period brass was probably around 920°C. This method of making brass was carried out with slight variations throughout the 19th century, and as late as 1858, calamine furnaces were still working (for example, in South Wales).[11]

William Champion took out a British patent in 1738 for distilling metallic zinc from calamine by reduction with charcoal or coal.[9] In 1781, the first patent for alloying brass with metallic Zn appeared in England. After Zn became available as a pure metal, the maximum concentration of Zn in Cu was no longer limited by the solubility at 920°C (i.e., above the boiling temperature of Zn), but by the maximum solubility after crystallization of the Cu–Zn melt, which is 32.5 wt% Zn.[10] It is astonishing how rapidly Zn concentration in brass changed from 26 wt% to 32.5 wt% throughout Europe.

Let us compare the composition of organ brass with concentrations of tin and lead in bronze cannons (Figure 5b, measured by H. Forshell[8]). Bronze cannons were manufactured during the same time period and in the same European areas as organ brass. However, bronze was always produced by the direct smelting together of copper and tin and not by cementation. Therefore, the tin content in bronze varied in a broad way, as depicted in Figure 5b. The points for tin content are scattered and do not group along a horizontal line like those for Zn in brass (Figure 5a).

Additionally, Figure 5 allows us to answer a second important question: was lead intentionally added to brass for tongues, or was it just an impurity? Lead is not soluble in copper, and it embrittles the brass. After only small deformations, the lead-containing brass must be annealed to relax the internal stresses, otherwise this can cause cracking and material failure. Comparing Figures 5a and 5b reveals that the lead concentration in brass and bronze behaves similarly over time. Between 1600 and 1750, the mean Pb concentration in historical brass and bronze slowly decreases from 7 wt% to 2 wt%, and then, around 1750, it plummets to almost zero. According to historical sources, the purification of copper in the 17th century through to the beginning of the 18th century was a rather simple and limited process. Copper refining factories were placed in the neighborhood of the copper mines, such as Swansea in Britain, Falun in Sweden, and Goslar in Germany. Various impurities remaining in commercially available copper can be seen as "fingerprints" indicating the origin of the

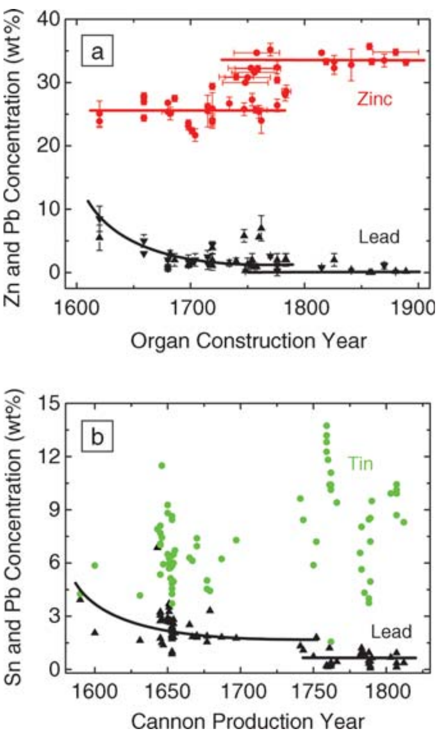

Figure 5. (a) Zn and Pb concentration in period tongue and shallot brass from historical organ reed pipes, compared with (b) Sn and Pb concentration in period cannon bronze.[8]

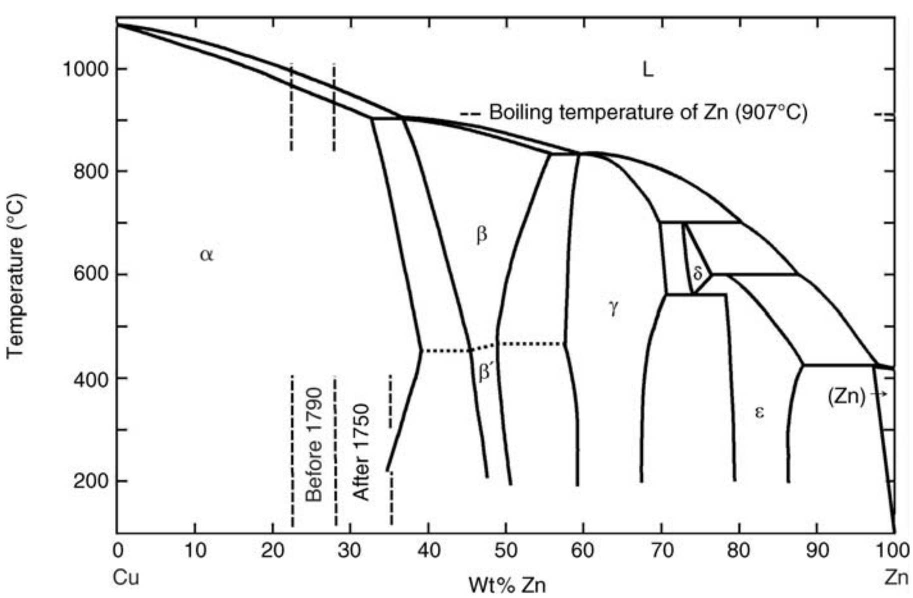

Figure 6. Cu–Zn phase diagram showing the concentration range for brass produced before 1790 and after 1750. Between 1750 and 1790, the two concentration ranges coexisted.

copper ores. Indeed, chemical analysis shows that impurities in copper obtained from different mines vary widely.[8,12] Of course, the exact composition was unknown to the organ builders buying copper on the marketplace or from a coppersmith in the Baroque era. However, they knew the differences in properties among copper products from different mines, and which copper was more suitable for which application.

At the end of the 18th century, copper production exploded and copper refining factories became very large. They even moved from the neighboring copper mines to harbors. Copper ores were delivered from different mines and even imported from overseas.[9] This mixing of ores resulted in the production of copper with similar properties irrespective of the mine from which the raw material came. A rather complex multistage refining process was invented, resulting in the elimination of most of the impurities such as tin, iron, and lead.[12]

The earlier, one-stage refining process was simply not able to remove all the lead from the copper, although the refining of copper from lead and silver was a goal of craftsmen even in the 16th century, as evidenced by Georgius Agricola's (1494–1555) description of contemporary metallurgical technologies in his encyclopedic *De re metallica libri XII*.[13] Organ brass and cannon bronze are completely different products. However, lead concentration levels display a similar pattern both in organ brass and cannon bronze, as shown in Figure 5. Therefore, it is rather improbable that lead was added intentionally to the organ brass by craftsmen or organ builders. An additional source of lead can also have been the Zn ore, which always contains some lead.[14]

Mechanical and Heat Treatment of Brass

According to Dom Bedos, writing in 1766, organ builders did not produce the brass material themselves (in contrast to the lead-tin alloys for pipes),[15] since it was too complicated and required special high-temperature equipment. Organ builders probably purchased their brass directly from coppersmiths in sheets or bands. Historical sources tell us that melted brass was cast into molds or "poured between two stones of a ton weight or more, each of which was elevated at one end. The molds were placed in an upright position, and the metal was allowed to cool, producing a plate of about 70 lb. weight."[9] Experiments showed that the minimum sheet thickness that could be obtained by this method is ~3–4 mm. Dom Bedos does not tell us about the thickness of the brass strips purchased by the organ builders. However, the final thickness needed for the brass tongues is ~0.2–0.5 mm, depending on the pitch. The thickness of the shallot walls is ~1–2 mm. In order to get the appropriate thickness for the tongues and shallots, respectively, the brass sheets had to be thinned further.

According to historical sources, the cast brass blocks were hammered either by coppersmiths in battery mills or manually by the organ builders.[8,9,11,13,14] Toward the end of the 17th century, rolling in addition to hammering came to be used (at least in Britain) for flattening brass and copper ingots.[9] These were huge rolling mills, powered first by water and later by steam, but they were not economical for small organ manufacturers. Therefore, the organ builders probably obtained brass sheets 2–4 mm thick and thinned them further by hammering.[15]

However, if one tries to hammer brass containing 1–2 wt% Pb from 2 mm down to 0.5 mm, the brass easily breaks. In order to prevent failure, several intermediate anneals had to be performed. Microstructural investigations revealed that historical tongues contain well-annealed and recrystallized grains with numerous twins, typical of all copper alloys (Figure 7).[17,18] The mean grain size is rather constant in samples from the same organ, but varies enormously, from 10 μm to 200 μm, in samples from different organs (Figures 7a and 7b). X-ray diffraction measurements did not reveal a rolling texture. These results almost exclude rolling as a technology for mechanically treating organ tongues; they were most likely cast and hammered (with intermediate anneals). Numerous twin boundaries, always present in Cu-based solid solutions, allowed us to estimate roughly the temperature of the intermediate anneals of historical brass. The twin boundaries in copper and copper-based alloys may contain crystallographically different facets.[16–18] At high temperatures close to the melting point, only two facets are present in twin boundaries, namely, the symmetric twin boundary and the so-called 9R facet.[16–18] If the annealing temperature decreases, new crystallographically different facets gradually appear.

The temperatures for the appearance of different facets were measured experimentally. The spectrum of facets observed in historical brass tongues was compared with the spectrum of facets observed in the model alloys.[17,18] The estimated temperature of intermediate anneals is ~600°C.

At the last stage, tongues were carefully filed from both sides and slightly rolled from one (upper) side in order to get a small curvature. This is needed to let the air inside the reed pipe through the gap between tongue and shallot. The tongue starts to vibrate under the action of the wind. However, the vibration should not be too strong, which would cause the tongue to hit the shallot.

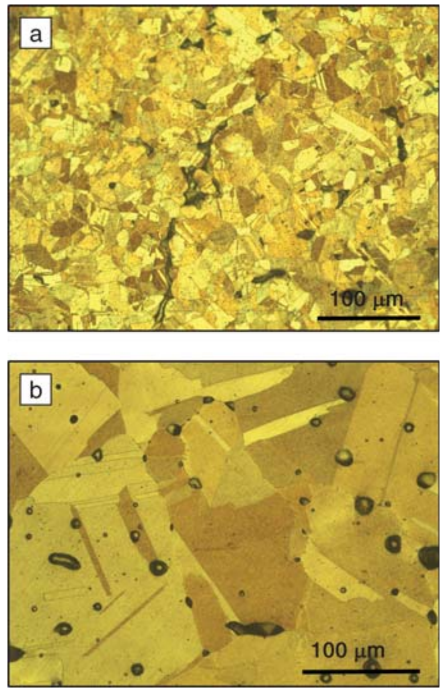

Figure 7. Light microscopy images of brass tongues from (a) the Antonius Wilde organ (1598–1599), restored by Arp Schnitger (1682) in the St. Jakobi Church, Lüdingworth, Germany; and (b) the Radeker & Garrels organ (1719) in Magnuskerk, Anloo, the Netherlands.

Manufacturing New Brass Materials for Historical Reed Pipes

Taking into account our investigations described here, two new alloys were prepared in order to reproduce brass from the 17th and 18th centuries (25 wt% Zn and 2 wt% Pb) and from the 19th century (30 wt% Zn, Pb-free). The 10-mm-thick cast ingots of Pb-free alloy were hammered with 2–4 intermediate anneals at 600°C. The alloy containing lead was hammered or carefully rolled from the 3-mm cast sheet with 6–8 intermediate anneals at 600°C. Five organ builders performed the final treatment and voicing of historical reed pipes with original and reconstructed tongues. They judged the workability of new alloys as being very close to that of historical tongues.

Good workability is essential for the final treatment and voicing process of the brass tongue. The final process is extremely delicate: the organ builder must ensure that the tongue has the right thickness, form, and curvature, which must remain stable and durable. These parameters crucially influence the tongue's vibration and, with that, the reed pipe sound. In the last mechanical treatment, before making the curvature in the tongue, the organ builder files down the tongue to its final thickness using a special file. The file must glide over the metal and not stick, in order to prevent warping during this treatment. Warping is a serious problem because a warped tongue does not vibrate properly. The target of the last step is to create a permanent curvature in the tongue. According to the organ builders' observations, modern brass materials do not fulfill all of these qualities.

After proper treatment and voicing of the new tongues in the historical reed pipes, the sound created by the new tongues could not be distinguished from that produced by historical ones. The new alloys enabled many irreparably damaged tongues in the Lutheran church organ in Ugale, Latvia, to be completely reconstructed, and the missing *Vox Humana* stop in the Casparini organ in the Church of the Holy Spirit in Vilnius to be built.

Conclusions

As a result of our investigations,[1,2,4–7,17,18] the period sound of Baroque pipe organs has been brought back to life. Newly developed alloys were applied for the restoration of historical organs and for building new organs with Baroque sound. Careful investigations of historical organ alloys from nine European countries were performed. Composition, structure, properties, and processing parameters for historical brass were determined by using sophisticated methods of materials science. The breakthrough was achieved by sandcasting the appropriate pipe alloy and by fabricating reproduction brass tongues for reed pipes.

Acknowledgments

Authors would like to thank the organ builders Henk van Eeken (Holland), Patric Collon (Belgium), Marco Fratti (Italy), Mats Arvidsson (Sweden), Rimantas Gucas (Lithuania), Jānis Kalninš (Latvia), and Alexander Schuke (Germany) for providing historical tongues for our investigations and for fruitful discussions. The inspiration of artistic organ playing and discussions with Profs. Harald Vogel and Hans Davidsson are heartily acknowledged. The investigations were supported by the European Commission under CRAFT project TRUESOUND (contract COOP-CT-2004-005876) and INTAS (contract 05-10000008-8120).

References

1. T. Clarke, *Nature* **427** (2004) p. 8.
2. M. Yokota, *The Overtornea Project*, edited by L.W. Ericsson (Musikhogskolan i Pitea, Pitea, Sweden, 1997).
3. G.A. Audsley, *The Art of Organ Building* (Dover, Mineola, NY, 1965).
4. J. Speerstra, ed., *The North German Organ Research Project at Göteborg University* (GOArt, Gothenburg, Sweden, 2002).
5. A. Carlsson, H. Davidsson, P. Ruiter-Feenstra, S. Dunthorne, and J. Speerstra, *Tracing the Organ Masters' Secrets: The Vision, The Process, The Goal, The Reconstruction of the North German Baroque Organ for Örgryte Nya Kyrka* (GOArt, Gothenburg, Sweden, 2000).
6. P. Svensson and M. Friesel, *Influence of alloy composition, mechanical treatment and casting technique on loss factor and Young's modulus of lead-tin alloys* (Chalmers University of Technology, Gothenburg, Sweden, 1999).
7. B. Straumal, A. Mazilkin, A. Manescu, F. Rustichelli, M. Friesel, and B. Baretzky, *Wiederaufbau der Casparini Orgel in Vilnius*, edited by R. Gucas (University of Vilnius, Vilnius, Lithuania, 2007).
8. H. Forshell, *The inception of copper mining in Falun* (Akademitryck AB, Edsbruk, Sweden, 1992).
9. W.O. Alexander, *Murex Rev.* **1** (1955) p. 1.
10. T.B. Massalski, ed. *Binary alloy phase diagrams* (ASM International, Materials Park, OH, 1993).
11. J. Percy, *Metallurgy: The art of extracting metals from their ores, and adapting them to various purposes of manufacture* (John Murray, London, 1864).
12. Rh. Jenkins, *Trans. Bristol Gloucestershire Arch. Soc.* **63** (1946) p. 1.
13. G. Agricola, *De re metallica libri XII* (Froben, Basel, 1556).
14. J.-G. Gallon and H.L. Duhamel du Monceau, *Die Kunst Messing zu machen, es in Tafeln zu gießen, auszuschmieden, und zu Drathe zu ziehen* (Akademie der Wissenschaften zu Paris, Leipzig, 1766).
15. Dom François Bedos de Celles, *L'art du facteur d'orgues* (Académie Royale des Sciences, Bordeaux, 1766).
16. B.B. Straumal, S.A. Polyakov, and E.J. Mittemeijer, *Acta Mater.* **54** (2006) p. 167.
17. B. Baretzky, M. Friesel, A. Petelin, A. Mazilkin, and B. Straumal, *Def. Diff. Forum* **249** (2006) p. 275.
18. B. Baretzky, M. Friesel, A. Petelin, A. Shotanov, and B. Straumal, *Def. Diff. Forum* **258–260** (2006) p. 397. □

***Brigitte Baretzky** is deputy head of the Department for Advanced Magnetic Materials at the Max Planck Institute for Metals Research (MPI-MR) in Stuttgart.*

She obtained her PhD degree in surface science and plasma physics from Ludwig Maximilian University and the Max Planck Institute for Plasma Physics in Munich in 1990. From 1990 to 1994, she was a co-owner of an advisory company for scientific research centers and industry. In 1994, she started her scientific career at the MPI-MR. From 1995 to 2003, Baretzky headed the Central Scientific Facility for Surface Analysis at MPI-MR. She became the deputy head of her current department in 2003.

Baretzky's research interests are surface science, interfaces in condensed matter, phase transformations, oxidation, coatings, multilayers, nanomaterials, and magnetic materials.

Baretzky can be reached at Max-Planck-Institut für Metallforschung, Heisenbergstrasse 3, D-70569 Stuttgart, Germany; tel. 49-711-689-1890, fax 49-711-689-1892, and e-mail baretzky@mf.mpg.de.

***Milan Friesel** is an associate professor at the SIMS Laboratory at Chalmers University of Technology in Göteborg, Sweden.*

He obtained his PhD degree in experimental high-pressure physics from Chalmers in 1987. From 1988 to 1991, he was a guest researcher at the Max Planck Institute for Metals Research in Stuttgart. Friesel joined the SIMS Laboratory at Chalmers in 1994. His research interests are superionic conductors, metals and alloys, semiconductors, and characterization by the SIMS technique.

Friesel can be reached at Fysik och Teknisk Fysik, Fysikalisk Elektronik och Fotonik, 41296 Göteborg, Sweden; tel. 46-31-7723434, fax 46-31-7722092, and e-mail friesel@fy.chalmers.se.

***Boris Straumal** is head of the Laboratory for Interfaces in Metals at the Institute for Solid-State Physics of the Russian Academy of Sciences in Chernogolovka and a full professor at the Moscow State Institute of Steel and Alloys, University of Technology (MSISA).*

He obtained his PhD degree in materials science from MSISA in 1983. For many years, he was a guest researcher at the Max Planck Institute for Metals Research in Stuttgart. Straumal has been with the Russian Academy of Sciences and MSISA since 2003. His research interests include grain boundaries, phase transformations, diffusion, thermodynamics, coating technologies, crystal growth, and nanomaterials. He has authored or co-edited six monographs and textbooks, translated seven scientific books into Russian, and written approximately 180 papers.

Straumal can be reached at Max-Planck-Institut für Metallforschung, Heisenbergstrasse 3, D-70569 Stuttgart, Germany; tel. 49-711-689-3478, fax 49-711-689-1892, and e-mail straumal@mf.mpg.de.