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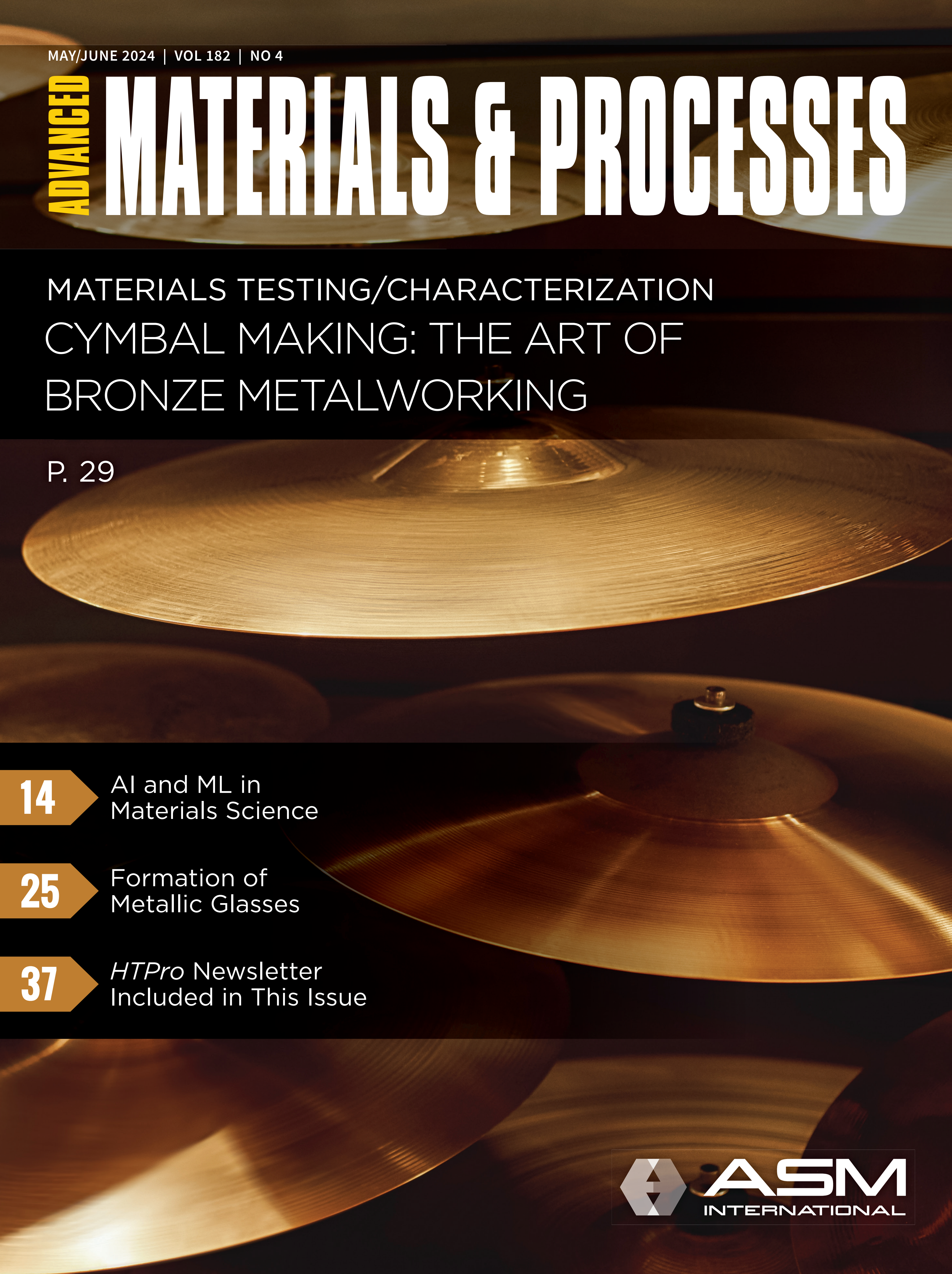
ADVANCED MATERIALS & PROCESSES



MATERIALS TESTING/CHARACTERIZATION

CYMBAL MAKING: THE ART OF BRONZE METALWORKING

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ASM INTERNATIONAL

CYMBAL MAKING: THE ART OF BRONZE METALWORKING, PART I

The initial steps in the art of manufacturing cymbals are discussed from ancient times through the modern era, including alloying copper and tin, pouring the molten metal into buns, and processing the ingots.

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The Chalcolithic Age (5000-3000 BCE)[1] is of great interest when studying archaeometallurgy. Stone workers, who for millions of years provided tools for survival and weapons of war, beautiful decoration in the form of jewelry, and mysterious figurines for the elite of society or religious rites and burial ceremonies, now worked side-by-side with small, but growing guilds of metalsmiths. These metalsmiths were slowly learning a developing technology: copper smithing. The Bronze Age (3000-1500 BCE)[1] followed and humankind slowly unlocked the secrets of locating mines, smelting copper ores, and alloying copper. Again, new and innovative technologies emerged. Throughout this journey into metalworking, humans around the globe made beautiful objects, one of which was the bronze cymbal. A percussion instrument of lustrous beauty, the cymbal possessed a magical sound, which evolved in the distant past, yet remains vibrant in today's world of music. Humankind's existence is interwoven with musical expressions (song, dance, and instruments), which date back to time immemorial. In all parts of the ancient world, the metalsmiths who produced cymbals gave the means for expressing joy in worship or celebration, startling and alarming one's enemies in battle, and providing brilliance of sound when played in musical ensemble.

The cymbal is an example of the value ancient society placed on metal objects that had no function as tools for construction of homes, farming the land, or utensils for preparing food. Yet, despite the need for tin and copper for pragmatic use, metalworkers of civilizations past searched out or traded for the elements needed, exerted tremendous labor hours, and learned specialized processes to produce these objects. Among them was the bronze cymbal, which served an arguably higher purpose helping humans of all epochs commemorate life's mirthful occasions and which today is used in almost all musical genres: accompanying religious ceremonies, bringing forth brilliant, shimmering sound in monasteries, temples, symphony orchestras, jazz ensembles, and music venues throughout the world.

Cymbal players depicted on an Italian relief panel from the 15th century.

This article, Part I of II, examines the first steps in the art of cymbal making, which involve alloying copper and tin, pouring the molten metal into high-tin bronze ingots (buns), and processing the ingots by hand-hammering or rolling a finished blank.

COPPER SMELTING

In the ancient past, metalworkers refined their skills and knowledge of smelting copper. For example, as described by Professor K.T.M. Hegde, Indian metalworkers designed small copper smelting furnaces, approximately 35 cm in height with 5390 cc capacity[2]. The furnaces consisted of clay-walled crucible shaped structures with slag-tapping and bellows[3]. The

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furnaces produced 98% pure copper and remained in use for at least 1000 years[4]. The Chalcolithic Age progressed slowly. The Bronze Age gradually arrived and the secrets of alloying copper with tin passed orally from families or guilds of skilled craftsmen. The cymbal's exact place of birth is unknown, but China, East Asia, India, or Anatolia are cited as places of origin in books concerned with the subject[5]. Many of the earliest cymbals of antiquity exhibited in museums are small (Figs. 1-3). These finger cymbals or clappers, which were connected by straps or handheld, underwent minimal change of form for hundreds of years.

Fig. 1 — Bronze cymbal, Central Anatolia, Hattian, 2300-2000 BCE (height 6.4 cm). Public Domain https://www.metmuseum.org/art/collection/search/324442.

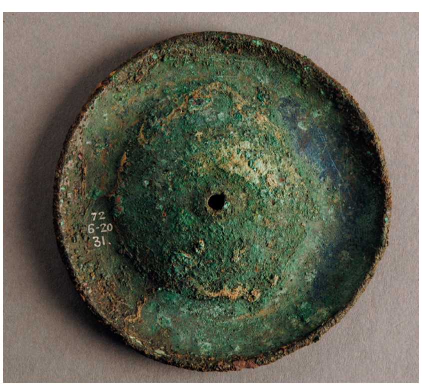

Fig. 2 — Bronze cymbal, Greece Late Helladic III, 1400–1060 BCE (8.0 cm diameter). Creative Commons: https://www.britishmuseum.org/collection/object/G_1872-0620-31.

Fig. 3 — Copper alloy cymbal, excavated from Nimrud, Middle East, Iraq, North, 900-700 BCE. (height 3.5 cm, width 6.3 cm). Creative Commons: https://www.britishmuseum.org/collection/object/W_N-116.

In the 21st century, foundries and artisans throughout Turkey, China, Japan, India, Thailand, and other East Asian and Southeast Asian countries continue the traditional practice of manufacturing cymbals. Similarly, throughout the world independent cymbalsmiths handcraft bronze cymbals for artists and other instrument markets. As in the ancient past, the metal used for achieving the most sonorous voice is high-tin bronze (known as bell metal) with tin content in the range of ~20%.

ALLOYING Cu AND Sn

Foundry workers melt copper and tin (Fig. 4), sometimes intentionally or unintentionally, alloyed with small quantities of other elements (Ag, Pb, and Fe), in a ceramic crucible. Traditionally, the heat source is a wood log and charcoal fire heating a stone oven, but foundries may use a crucible pit furnace. Modern foundries may use a high-frequency induction melt furnace and clay graphite crucibles. In ancient times, just as in modern foundries, a blanket of charcoal sprinkled over the molten metal provides protection against O_2. The high-tin bronze and often "secret" mixture of copper and tin is the formula for creating bell metal used in cymbal casting. High-tin bronze is an alloy notoriously difficult to forge, but once cast and worked into a cymbal, resonates with clarity and innumerable nuances of percussive sound. The fact that some cymbal manufacturers to this day keep the activities performed within the foundry off-limits to visitors and the public at large is testament to the continued tradition of mystery surrounding metal mixing, temperature parameters, and other traditional practices applied for making a given casting and continuing a family legacy.

Fig. 4 — Copper scrap (left and right) and tin ingot (top) for producing a high-tin bronze bun (bottom).

POURING MOLTEN METAL

In antiquity, foundry workers poured molten metal into open clay or stone bowls (molds). This step of cymbal manufacturing remains unchanged, only the bowls are now clay graphite or other specialized cast iron (e.g., Meehanite)[6]. This step is deceptive in its simplicity; the goal is an ingot (bun) exhibiting a smooth, void-free surface without defects (Figs. 5-6). The size of the bun depends on the final cymbal size desired and may range from 2 to 20 lb. The challenges ancient metalworkers encountered (as do metalworkers today) during the pouring and solidification processes include pour temperature, pour rate, slag/dross removal, bowl temperature, reaction of metal at contact with bowl, type and application of bowl dressing, size of final casting, volume change from liquid to solid, temperature range of metal freezing, and dwell time in mold[7]. When using hand ladles, foundry workers must work in unison and develop a rhythm for transferring crucible and pouring molten metal. If using an auto-pour system (e.g., tilt-furnace) for pouring molten metal, the timing and weights are meticulously controlled; consistency and efficiencies are improved[8]. Tin bronze is a castable alloy which has a wide solidification temperature range (150° – 300°F)[9]. This wide freezing range is a challenge for metalworkers because segregation of the tin from copper may occur at grain boundaries, creating brittle areas which crack when hot worked (Fig. 7)[10]. Control of

Fig. 5 — As-cast bun, top surface.

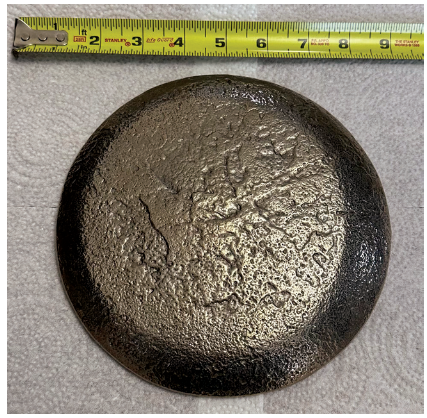

Fig. 6 — As-cast bun, bottom surface.

Fig. 7 — Hot-worked blank exhibiting edge cracks; as-rolled, first pass.

Fig. 8 — Casting defects observed on buns.

Fig. 9 — Bronze buns exhibiting surface conditions relating to pour temperature and cooling rate. Top row from left: Bun 1 temperature too low at pour; bun 2 and bun 4 exhibit tin-rich phase at surface (inverse segregation); bun 3 color suggests low Sn content. Bottom row: Various smaller cast buns for finger cymbals or medallions.

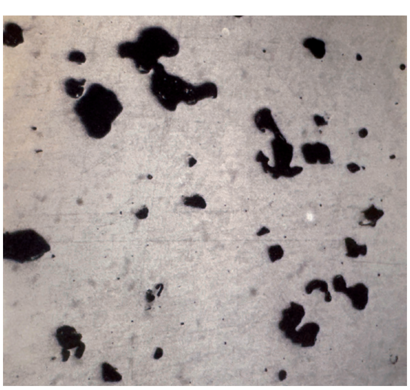

Fig. 10 — As-cast, bun cross-section, unetched, 50×. Heavy porosity is evident. Courtesy of Fredrick A. Skinner, metallurgical consultant.

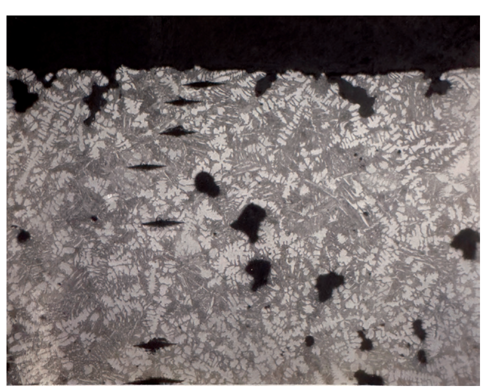

Fig. 11 — As-cast, etched, 50×. Dendritic microstructure, porosity at surface and subsurface. Microhardness, ~ 95-98 HRB. Courtesy of Fredrick A. Skinner, metallurgical consultant.

porosity (gas or shrinkage)[11] is also a challenge when casting high-tin bronze for cymbal production, both at the surface and throughout the internal dendritic microstructure. Figures 8 and 9 show typical surface defects (i.e., slag impurities, uneven cooling, underweight pours, and unbalanced bowls) and varying surface colors relating to variations in temperature and pouring conditions. Figures 10 and 11 show porosity in an as-cast (8.0 lb) bun, cross-sectioned approximately 13.0 mm from center of bun. Excessive porosity trapped within the cast bun, or located at surface (surface voids), may manifest during downstream processing and cause surface defects (i.e., pits), which hammering or lathing cannot remove.

HAND HAMMERING AND ROLLING INGOT INTO A BLANK

Starting with a cast bun of proper weight and surface condition, the arduous task of working the thick metal bun into a thinner shape, and eventual flat blank, begins. In ancient times, a group of metalworkers armed with hammers hot forged the castings into the shape of a blank, at which point the metal met cymbal criteria (thickness, diameter, and weight). Ancient metalworkers learned high-tin bronze must be in a red-hot state (~800°C) when forging. The practice involved heating the bun, hot working (hammering) within a narrow temperature range, reheating, and repeating. If heated properly, the thick shape of the cast buns (a result of the bowl molds) helps retain heat during hot working. This understanding of shape as related to heat retention is noted in the hot working of other high-tin bronze objects from antiquity[12].

During thermal treatment and forging, and most importantly, following the last thermal treatment, ancient workers performed a water quench, thus transforming the brittle bell metal into a ductile condition (β phase) necessary for cold-working techniques. The temperature of bronze metal entering the quench should be as close as possible to annealing temperature. The importance of proper annealing between hot working cannot be overstated; fluctuation or unstable furnace temperatures affect workability of bronze metal during downstream forming processes and often result in rework (e.g., reannealing, repressing, cracking, or modification in equipment setups which compensate for loss of ductility). Beginning in the 14th century, goldsmiths used hand driven rolls, forming thin sheets of gold and silver[13]. This technology evolved and the semi-industrial practice of using a two-high rolling mill became common practice when hot working bronze castings into cymbal blanks. Figure 12 shows a rolled finished blank (~ 46.0 cm diameter). The original casting (bun) may be processed through the two-high mill up to 8 times, rotated 90° at intervals for the purpose of maintaining a round shape. Hardness of grains and matrix increase after each rolling pass. If air cooled, the blanks are brittle; matrix hardness range is 45-47 HRC. Figure 13 shows blank microstructure post-quench; twinning grains are evident in the microstructure, a common condition of most copper alloys when annealed. Post-quench, ductility is increased, hardness is decreased; the dendritic microstructure is completely dissolved.

Fig. 12 — Cymbal blank, finished size, as-rolled. (15-in. diameter, 0.050 – 0.053-in. thickness)

Fig. 13 — Cymbal blank microstructure; finished blank, as-rolled and quenched, 75×. Twinning, 77 HRB, matrix, 39 HRC (converted: HK 25-gram load). Courtesy of Fredrick A. Skinner, metallurgical consultant.

The subsequent cold-working techniques include forming the raised bell (boss) and flattening the outer edges by hand hammering (Fig. 14), or use of industrial machines (forming press and automated hammers), and lathing for weight removal and surface profile. Part II of this series, to be published in a future issue of *AM&P,* will discuss the remaining processes in the manufacturing of finished bronze cymbals. **~AM&P**

Fig. 14 — Hand-hammered cymbal. Courtesy of Manabu Yamamoto, Art Cymbal.

GET ENGAGED, GET INVOLVED, GET CONNECTED

The ASM Archaeometallurgy Committee welcomes new members with interest and experience in the study and characterization of historic metals and artifacts. For more information, contact staff liaison Scott Henry, **scott.henry@asminternational.org.**

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