Preliminary Investigation of Sri Lankan Copper-alloy Statues

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Abstract

The historical framework for the discussion is the chronology of Sri Lankan culture, which, based on the most recent archaeological evidence and radiocarbon dates, has been defined by three major periods: Early Historic (500 BC-300 AD), Middle Historic (300 AD-1200 AD) and Late Historic (1200 AD-1815 AD). A classification for the evolution of bronze sculpture with reference to the established historical chronology for Sri Lanka has been proposed by Reedy (2007) who sets out the following four major developmental periods of Late Anuradhapura (ca. 432–993 AD), Polonnaruva (late 10th to early 13th century), Divided Kingdoms (13th to late 16th century), and Kandyan (17th to 19th century). This technical study investigated thirty sculptures including 25 tin bronzes in The Metropolitan Museum of Art and five from the Archaeological Department of Sri Lanka, representing all four major historic periods. The methods used to analyse the manufacture, composition, and condition of the statues were examination under magnification and Ultraviolet light, X-ray radiography, elemental analysis using X-ray fluorescence spectroscopy, and metallography.

The results of the study included the finding that all the statues in the sample were cast using the lost-wax technique. Size does not seem to have had a bearing on whether statues were cast solid or hollow. Many of the small seated figures in the sample were solid cast, while a few were hollow cast. In addition the radiographs indicate that a variety of armatures of different thickness, size, and shape were present inside the hollow figures, irrespective of the size of the statues. Generally, metal of low porosity and few casting defects are observed in most of the radiographs, indicating that the castings are generally of good quality. Traces of five gates (or vents) observed on the backs of a group of five Lokapala figures examined, indicated that they were cast face-down in a horizontal position. Ten figures, particularly those from the later periods, show traces of gilding or intact gold layers. In all but one case, gold was found in association with mercury, confirming that they were amalgam gilded.

Metallurgical studies were carried out on four figures in the sample: a Buddha, a Bodhisattva and two Hindu deities. A sample from a tang that was cast onto the goddess figure in antiquity proved to be quenched high-tin bronze, as evident from its microstructure; a tin content of 24.8 w/o was confirmed using X-ray energy dispersive spectroscopy in a scanning electron microscope. The four statues were from different historical periods and showed different microstructures, reflecting dissimilarities in composition, thermal history, and state of preservation.

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Introduction

The origin and development of copper and bronze technology in Sri Lanka has been the subject of considerable research, yet many questions remain unanswered. Much has been written on the historical, stylistic and iconographic aspects of Sri Lankan bronzes, but only rarely have questions of manufacture or technology been addressed. In the absence of analysis, production technology has often been deduced from features observed in extant bronzes which correspond with those found in dated Indian examples. This preliminarily technical study was undertaken to understand as far as possible, given the size and variety of the sample, some differences in bronze technology used in different historical periods in Sri Lanka.

The historical framework for the discussion is the chronology of Sri Lankan culture, which, based on the most recent archaeological evidence and radiocarbon dates, has been defined by three major periods: Early Historic (500 BC-300 AD), Middle Historic (300 AD-1200 AD) and Late Historic (1200 AD-1815 AD) (Deraniyagala,1992). Within this framework, the Anuradhapura Kingdom was the first established kingdom of ancient Sri Lanka. The extant evidence for the material culture of the beginning of this period shows the use of iron tools, irrigated rice cultivation, the manufacture of high grade pottery and the use
of the horses and cattle. The recovery of copper slag and terracotta crucibles with traces of copper from excavations at the site of the ancient citadel of Anuradhapura establish the smelting of copper at this site as early as the 6th–5th century BC (Deraniyagala 1972). The discovery at the same site of what appear to be a furnace and coin molds from levels dated between 200 BC and 200 AD also indicate that copper and/or bronze casting was practiced (Deraniyagala 1986).

Inscriptions and literary sources clearly show that metal use and metal-based crafts were widespread and well organized in the island during pre-Christian centuries (Karunatilake 1992, 107). 3rd century BC, Early Brahmi inscriptions from different parts of the country, refer to metal workers who lived in those times. For example, two Early Brahmi inscriptions from Periyapuliyankulam in the Vavuniya district, describe two persons as “tabakara”, which Paranavitana interprets as ‘copper smith’ (Paranavitana 1970, 28). Another inscription from Periyapuliyankulam describes a person called Sumana as ‘topasa’, which has been interpreted as ‘tin smith’ (Paranavitana 1970, 28).

A large body of information on art traditions including, sculpture, architecture, painting, and other minor arts and crafts are mostly found in ola (palm leaf) manuscripts in Sri Lanka. The texts Sariputra, Rupavali and Manjushri-citrakarmasstra provide in depth details of methods, techniques, and materials used in the production of traditional art and craft in Sri Lanka. The Sariputra is a well-known work on image making in Sri Lanka. Ananda Coomaraswamy published in a summarized form an English translation of the Sariputra in his monumental work on Medieval Sinhalese Art. As Part 1 published by him, deals with the measurements of images of gods and men and Part II deals with the images of the Buddha (Coomaraswamy, 1956, 150–63). The date of Sariputra text however is disputed, with Coomaraswamy (1956, 163) claiming it is from 5th century, Listopad (2003, 43) as twelfth century, Schroeder (1992, 30) as ninth century, and Prematilleke (1995, 160) as fifteenth century. Ananda Coomaraswamy (1956, 111–112) claimed that the Rupavali, the art canon of the Sinhalese painter consisting of the iconographic characteristics of several Hindu deities is a work of Hindu origin datable to about the 11th century. The Manjushri-citrakarmasstra is a palm-leaf manuscript of a Mahayanist silpasatra text, dealing with architecture as well as sculpture and is written in Sanskrit. Briefly its contents areas are, measurements (of buildings), rites associated with stupas, bodily marks of the Buddha, bodily marks of Bodhisattvas, of Indra and others, colours, measurements, eye making, ten kinds of stupas, making of image houses, analysis of an image into its component parts and making of makara-toranas and thrones etc. Guidelines in Sinhalese on the art of making images of the Buddha are given in the ola manuscript Sugat pamana (Mudiyanse 1978, 70–71).

Metal statues in Sri Lanka

According to the historical chronicles, Buddhism was brought to Sri Lanka from India in c. 250 BC by the monk Mahinda - son of the Mauryan Emperor Ashoka - who founded the Mahavihara monastery of the Theravadins in Anuradhapura (Mahavamsa XIII: 8–21). The Abhayagiriya Monastery of the Mahayanist, considered to be one of the largest Buddhist monastic complexes of ancient times was founded by King Vattagamini or Walagamba in 89–77 BC.

Despite mention in the historical texts of religious metal sculptures with the enshrining in the 2nd century BC by king Duttagamini of a golden image of the Buddha along with figures of the Dikpala divinities in the relic chamber of the Mahathupa (now Ruwanwelisaya) (Prematilleke 1995) there is little or no metal sculpture found between the 5th century BC and the 3rd century AD. A solid-cast yaksha/guardian figure found in the Ampara district and dated to around the 4th century AD was until recently considered to be the oldest extant copper alloy statue made in Sri Lanka (Schroeder 1992, 296). However, some scholars believe that a group of eight copper alloy deities including a tin-bronze (Figure 1) and one animal figure, discovered in 2011 at the Deegavapi stupa in the same district, may be of an even earlier date. According to the Mahavamsa, the Greater Chronicle of Sri Lanka, this stupa was built during the reign of King Sadda Tissa (137–119 BC).

Although, the earliest direct evidence for the production of copper alloy sculpture is uncertain, according to Wikramagamage, all existing Buddhist sculptures in Sri Lanka belong to two distinctive schools on the basis of iconography. Of these, the older is the Theravada Mahavihara School which seems to be an indigenous school with a history going back to the second century BC. The other school the Anda-Anuradhapura School goes back to
the second century A.C. (Wikramagamage 1990, 161). Wikramagamage gives several examples of sculptures from the two schools and attributes the famous Samadhi Buddha and a colossal standing Buddha in Raswehera in Anuradhapura district and three bronze Buddha statues from the Abhayagiriya monastery to the Mahavihara School. The colossal Aukana Buddha and a bronze Buddha statue from Badulla in the Colombo National Museum are considered as examples of the Andra-Anuradhapura school (Wikramagamage 1990, 153–166).

A high quality 100 cm gilded standing Buddha figure (Figure 2) in the Department of Archaeology found in 2011 in Galgamuwa in the Kurunegala district (Arch ML 151) was identified as belonging to the Theravada Mahavihara tradition by Wikramagamage. In order to establish a date for the Theravada Mahavihara Tradition a sample of core material was removed by me from this statue and sent for analysis by the Department of Archaeology to Beta Analytic Inc., Florida, US. The sample was very recently dated to Cal AD 385–538 (Cal BP 1565–1415). To my knowledge this is the only scientifically dated Sri Lankan Bronze. It helps to indicate an earlier date than accepted thus far by many scholars for Bronze Buddha Statues in Sri Lanka. However, according to Brown (2012, 18), the earliest Sri Lankan metal images date to the sixth-seventh centuries at the earliest. Till the dating of the Galgamuwa statue, many scholars believed that the hollow cast seated Buddha from Badulla now in the Colombo National Museum was the oldest known Buddha image. This statue has been dated on the basis of iconography from the 5th century AC (Paranavitana 1971), to 5th – 6th centuries AC (Premathilake 1995, 15), 6th century AC (Schroeder 1992, 188) or even later (Wararatana 1985), and to the period between the 7th - 8th centuries AC (Wikramagamage 1990).

A classification for the evolution of bronze sculpture with reference to the established historical chronology for Sri Lanka has been proposed by Reedy who sets out the following four major developmental periods of Late Anuradhapura (ca.432–993 AD), Polonnaruwa (late 10th to early 13th century), Divided Kingdoms (13th to late 16th century), and Kandy (17th to 19th century) (Reedy 2007). The widespread production of copper-alloy Buddha and Bodhisattva images in Sri Lanka was first seen in the beginning of the late Anuradhapura period (Listopad 2003).

A wide range of bronze objects and images have been found from the sites of both the Mahavihara and Abhayagiriya monastic complexes (Personal knowledge). Archaeological evidence from the citadel of Anuradhapura and Abhayagiriya indicate that bronze-casting was carried out at foundries located at these sites.

Developments in the Polonnaruva Period reflect South Indian traditions and artistic styles as a result of the Chola occupation from 993 to 1070 and the corresponding influence of Hinduism during this period (Bell 1908; Premathilake 1995). A significant group of copper alloy figures discovered in 1907 in Polonnaruwa the capital during the Chola occupation reflects the influence of Hinduism during the Polonnaruva period according to H. C. P. Bell who also expressed the view that “there is every likelihood that when the Cholas who brought the Sinhala people under subjection, began building shrines to worship their gods and started making images of their deities and saints, they employed Sinhala artisans” (Premathilake 1995). Images in bronze of Siva, Parvati, Ganesa, Kali, Lakshmi etc. have been found at Polonnaruwa and other historic sites in Ceylon assignable to this period (Coomaraswamy, A.K. 1914, 13). However, Buddhist sculptures also continued to be produced during this period.

The Divided Kingdoms and early Kandyan periods where characterised by political instability and cultural decline. From the fall of the Polonnaruva Kingdom, there was a gradual decadence in sculpture in the Divided Kingdoms. However, Buddhist sculptures continued to be produced in scattered regional workshops under the patronage of local elites and regional rulers. Of Buddha images in stone, there are very few examples that can be dated during this period (Attigalle 1959, 788). The remarkable example of a metal image from this period is a bronze statue, preserved in the Lankatilaka Temple, which is believed to be a representation of king Bhuvanaikabahu IV (Attigalle 1959, 789).

With the reestablishment of a stable Buddhist dynasty in the later Kandyan period, we see the production of large-scale, solid-cast gilded and painted metal images. This study includes three large scale solid cast figures which are described in the section on gilding and inlay. Evidence from archaeological excavations in the Palace Complex and Naga Vimana temple in Kandy indicate that foundries for bronze-casting had been located at these sites.

Figure 2 Amalgam gilded Theravada Mahavihara tradition’s Buddha figure dated to Cal AD 385–538, currently in the Conservation Laboratory Colombo (unpublished) © Department of Archaeology.
Technical study

The present study concerns twenty-five tin bronze statues in the collection of the Metropolitan Museum of Art and five from the Archaeological Department of Sri Lanka. Stylistically, this group represents the above mentioned four evolutionary periods of bronze production defined by Reedy (2007). The materials and technology of these figures were investigated using optical microscopy, X-ray radiography using the Kodak HPX-1 Computer radiography system, a Bruker Artax X-ray fluorescence spectrometer and metallography (Table 1). X-ray energy-dispersive spectroscopy in the scanning electron microscope (SEM-EDS) was used for only two samples in the Durga figure.

Examination and analysis

Twenty-two objects in the study date to the Anuradhapura period. Eleven statues are of the Buddha and include six solid cast and five hollow cast statues. The study sample also includes seven solid cast statues of deities. Of the four Bodhisattva figures in the sample, one was cast solid while three are hollow. Three objects in the sample were known to belong to the Polonnaruva period. One of these objects is a solid cast seated Buddha while the other is a hollow cast stupa. The only Hindu sculpture in the study is a solid cast image of the goddess Durga which was established through this study as belonging to the Polonnaruva period. Three objects date to the divided Kingdoms period. Two of these sculptures are solid cast Buddha statues, while the third is a solid cast attendant figure. The other objects included in the study are two solid cast standing Buddha figures from the Kandyen period (Table 2).

Casting technology

Close investigation of the sculptures established the use of the direct lost-wax techniques in the casting of nine hollow and twenty-one solid images. Of the twenty-two objects from the Anuradhapura period, fourteen are solid cast while eight are hollow cast figures. The larger statues (three), which mostly date to the later periods, are for the most part solid cast. However, the one exception to this trend in the study sample was a large hollow cast standing Buddha (MMA 1993.387.8) dated to the tenth century in the Anuradhapura period. The restriction to solid figures was codified in the Sariputra, a Sinhalese text describing canons of proportions and other

Table 1 Investigation methods.

| Object                   | ID          | Cultural Period | Date(CE) | Radiography | XRF | EDX | Metallography |
|--------------------------|-------------|-----------------|----------|-------------|-----|-----|---------------|
| Standing head and body of Buddha | Archa. ML.151 | Anuradhapura | 4th - 6th c | √           |     |     |               |
| Head of Buddha           | MMA:1986.501.9 | Anuradhapura | 5th c    | √           | √   |     |               |
| Seated Buddha            | MMA:1982.21  | Anuradhapura | 6th c    | √           | √   |     |               |
| Guardian/Yaksha          | Deegavapi (2011) | Anuradhapura |          | ?           | √   | √   | √             |
| Standing Buddha          | MMA:1987.142.63 | Anuradhapura | late 7th c | √           |     |     |               |
| Standing Buddha          | MMA:1987.142.64 | Anuradhapura | late 7th c | √           |     |     |               |
| Standing Buddha          | MMA:2009.60 | Anuradhapura | 8th c    | √           |     |     |               |
| Standing Avalokiteshvara | MMA:1987.142.65 | Anuradhapura | 7-8th c | √           |     |     |               |
| Standing Avalokiteshvara | MMA:1994.509 | Anuradhapura | 8th c    | √           |     |     |               |
| Standing Maitre Bodhisattva | MMA:TR.340.1.2012 | Anuradhapura | 8th c? | √           |     |     | √             |
| Standing Avalokiteshvara | MMA:1991.458.3 | Anuradhapura | 9th c    | √           |     |     |               |
| Standing Buddha          | MMA:1986.149 | Anuradhapura | 9th c    | √           |     |     |               |
| Standing Buddha          | MMA:1991.458.1 | Anuradhapura | 9th c    | √           |     |     |               |
| Lokapala Yama            | MMA:2005.468.1 | Anuradhapura | 9th c    | √           |     |     |               |
| Lokapala Indra           | MMA:2005.468.2 | Anuradhapura | 9th c    | √           |     |     |               |
| Lokapala Kubera          | MMA:2003.548.1 | Anuradhapura | 9th c    | √           |     |     |               |
| Lokapala Brahma          | MMA:2003.548.2 | Anuradhapura | 9th c    | √           |     |     |               |
| Lokapala Varuna          | MMA:2004.465 | Anuradhapura | 9th c    | √           |     |     |               |
| Jambhala figure          | MMA:2010.475.4 | Anuradhapura | 9-10th c | √           |     |     |               |
| Standing Buddha          | MMA:1993.387.8 | Anuradhapura | 10th c   | √           |     |     |               |
| Standing Buddha          | MMA:1979.510.1 | Anuradhapura | 10th c   | √           |     |     |               |
| Standing Buddha          | MMA:1987.422.1 | Anuradhapura | 10th c   | √           |     |     |               |
| Durga?                   | MMA:TR.340.3.2012 | Polonnaruva | 10th c | √           |     |     | √             |
| Standing Buddha          | MMA:1991.458.4 | Polonnaruva | 12th c   | √           |     |     |               |
| Stupa                    | MMA:1987.422.2a,b | Polonnaruva | 12th c   | √           |     |     |               |
| Standing Attendant       | MMA:1991.458.2 | Divided Kingdoms | 14th c  | √           |     |     |               |
| Standing Buddha          | MMA:2010.66a,b | Divided Kingdoms | 15-16th c | √           |     |     |               |
| Standing Buddha          | MMA:2010.67 | Divided Kingdoms | 16th c  | √           |     |     |               |
| Standing Buddha          | MMA:TR340.2.2012 | Divided Kingdoms | 12-18th c? | √           |     |     | √             |
| Standing Buddha          | MMA:2010.68a,b | Kandyen | 18th c | √           |     |     |               |

Note: The three objects with MMA temporary receipt (TR) numbers from the Department of Archaeology and the yaksha [Deegavapi (2011) 114] and (Archa. ML) belong to the Archaeological Department of Sri Lanka. All other objects listed belong to the Metropolitan Museum of Art, New York.
| Object Description                  | ID      | Cultural Period | Ht (cm) | Cast | Armature | Alloy type | Gilding | Notes                                      |
|-----------------------------------|---------|-----------------|---------|------|----------|------------|---------|--------------------------------------------|
| Head and body of Buddha           | Archa. ML.151 | An              | 100     | hollow | Two iron armatures | Tin bronze | Hg gilded (intact layer) | Black core appeared |
| Head of Buddha                    | MMA: 1986.501.9 | An              | 6.3     | hollow | Straight armature  | Tin bronze  |                     |                             |
| Buddha                            | MMA: 1982.21  | An              | 13.6    | solid  |          | Tin bronze  |                     |                             |
| Guardian/Yaksha                   | Deegavapi (2011) 114 | An             | 9       | solid  |          | High-tin bronze | Hg gilded (traces) | Cast horizontal |
| Buddha                            | MMA: 1987.142.63 | An             | 5.6     | solid  |          | Tin bronze  |                     |                             |
| Buddha                            | MMA: 1987.142.64 | An             | 6.2     | solid  |          | Tin bronze  |                     |                             |
| Buddha                            | MMA: 2009.60  | An              | 26.7    | complex | Complex armature   | Tin bronze  |                     |                             |
| Avalokiteshvara                   | MMA: 1987.142.65 | An             | 8.4     | solid  |          | Tin bronze  |                     |                             |
| Avalokiteshvara                   | MMA: 1994.509 | An              | 29.2    | hollow | Twisted wire armature | Tin bronze  |                     |                             |
| Bodhisattva                       | MMA: TR 340.1.2012 | An        | 34      | hollow | Straight armature | Tin bronze  |                     |                             |
| Avalokiteshvara                   | MMA: 1991.458.3 | An             | 13.7    | hollow | No armature | Tin bronze  |                     |                             |
| Buddha                            | MMA: 1986.149 | An              | 10.8    | hollow | Straight armature  | Tin bronze  |                     |                             |
| Buddha                            | MMA: 1991.458.1 | An             | 12.7    | solid  |          | Tin bronze  | Hg gilded (intact layer) |                             |
| Lokapala Yama                     | MMA: 2005.468.1 | An             | 24.1    | solid  |          | Tin bronze  | Cast horizontal |                             |
| Lokapala Indra                    | MMA: 2005.468.2 | An             | 24.1    | solid  |          | Tin bronze  | Cast horizontal |                             |
| Lokapala Kubera                   | MMA: 2003.548.1 | An             | 23.5    | solid  |          | Tin bronze  | Cast horizontal |                             |
| Lokapala Brahma                   | MMA: 2003.548.2 | An             | 33      | solid  |          | Tin bronze  | Cast horizontal |                             |
| Lokapala Varuna                   | MMA: 2004.465 | An              | 23.5    | solid  |          | Tin bronze  | Cast horizontal |                             |
| Jambhala                          | MMA: 2010.475.4 | An             | 9.3     | solid  |          | Tin bronze  |                     |                             |
| Buddha                            | MMA: 1993.367.8 | An             | 59.7    | hollow | No iron armature and unknown bent rod in body | Tin bronze  | Hg gilded (intact later) |                             |
| Buddha                            | MMA: 1979.510.1 | An             | 10.5    | solid  |          | Tin bronze  | Hg gilded (traces) |                             |
| Buddha                            | MMA: 1987.422.1 | An             | 10.5    | solid  |          | Tin bronze  | Hg gilded (intact layer) |                             |
| Durga                             | MMA: TR 340.3.2012 | Po            | 22.7    | solid  |          | Low- tin body and High-tin tangs |                     |                             |
| Buddha                            | MMA: 1991.458.4 | Po             | 6.8     | solid  |          | Tin bronze  | Red colour pigment |                             |
| Stupa                             | MMA: 1987.423.2 a, b | Po       | 15.3    | hollow | No armature | Tin bronze  |                     |                             |
| Attendant                         | MMA: 1991.458.2 | DK             | 11      | solid  |          | Tin bronze  |                     |                             |
| Buddha                            | MMA: 2010.66a,b | DK             | 53      | solid  |          | Tin bronze  | Hg gilded (intact layer) | black pigment |
| Buddha                            | MMA: 2010.67  | DK              | 48      | solid  |          | Tin bronze  | Hg gilded (intact layer) | black pigment and silver inlay |
| Buddha                            | MMA: TR 340.2.2012 | K            | 19.2    | solid  |          | Tin bronze  | Hg gilded (intact layer) | black pigment and silver inlay |
| Buddha                            | MMA: 2010.68a,b | K              | 65      | solid  |          | Tin bronze  |                     |                             |

Note: The three objects with MMA temporary receipt (TR) numbers from the Department of Archaeology and the yaksha [Deegavapi (2011) 114] and (Archa. ML) belong to the Archaeological Department of Sri Lanka. All other objects listed belong to the Metropolitan Museum of Art. XRF analyses show all objects to be Cu-Sn alloys. Abbreviations: An = Anuradhapura; Po = Polonnaruwa; DK = Divided Kingdoms; K = Kandyan.
guidelines for sacred figures, in which the casting of hollow statues to be used for worship was explicitly forbidden (Schroeder 1992, 30).

From the study sample we do not see any consistency in the use of casting methods even within the same period. The size of the statues does not seem to have had much bearing either, on the techniques used as both small and large statues were made using both solid and hollow casting techniques. For example, a 9th century 10.8 cm high seated Buddha (MMA: 1986.149) is hollow cast while a 9th century 12.7 cm high seated Buddha (MMA: 1991.458.1) is solid cast.

Radiographic studies of the sample have provided important information on the techniques used to create stylistic details in the sculptures. Radiographs illustrate how the wax models were sculpted, punched, or scored to produce different hairstyles (Figure 3). For example, in some sculptures, curls of hair were modelled onto the wax layer cladding the core. In other sculptures, the hair was delineated in the wax by a punch tool. In some others, wax was scored in a solid wax model with a pointed tool. In the lion figure which accompanies a Lokapala image (MMA: 2003.548.1), the fur was articulated on the solid wax model with wax coils. In some statues we can see how the wax was sculptured to form every minute detail including hair, facial features, jewellery, clothing, decorative pattern etc. There is also evidence of pre-formed wax as separate pieces which were later adhered to the sculpture. In addition, radiographs of a Maitre Bodhisattva (MMA: TR 340.1.2012) which shows thin and even wall thickness enables us to understand the thickness of the wax applied which was replaced by metal during casting.

Armatures

In the hollow cast statues, armatures varying in thickness, size and shape were used. This study revealed that armatures range from solid metal rods and dowels to hollow metal tubes and twisted wire. For example a 10.8 cm high, 9th century hollow cast seated Buddha (MMA 1986.149), has a simple armature (Figure 4) relatively well preserved in the centre of the figure, as well as three core supports (iron chaplets) located in the front of the belly, back of the lower body and back of the chest, with a triangular patch (maybe a closed sprue) in the right armpit. However, two of four Bodhisattva sculptures probably of the same period have several different types of armatures some of which are quite complex. The first of these which probably belongs to the 8th century was
identified as a Theravada Mahavihara tradition (Wikramagamage personal communication) Maitre Bodhisattva (MMA: TR 340.1.2012). The simple straight armature of the statue, still in place, starts in the head and extends down to the bottom of the robe ensuring the integrity of the core and the wax around it. A similar hollow cast Sri Lankan standing Bodhisattva with a simple centre armature is referred to by Chandra Reedy in her study of the Guardian of the Flame collection in Phoenix.

In the second statue in this sample, an 8th century standing Bodhisattva (MMA: 1994.509), radiographs show a complex armature in the torso which has a smooth piece of metal rod that extends from the neck to the middle of the thigh. This rod is reinforced by two more pieces of approximately the same diameter flanking it, which begin at the centre of the chest and extend into the feet. An interesting feature of this complex armature is a continuous piece of twisted wire running horizontally through both arms ending at each elbow (Figure 5). The wire was probably twisted to provide more tooth for the core, as the arms would be less likely to slip off a rough surface (Pace, J. and A. Kasthuri 2010).

The third Bodhisattva (1991.458.3) has no visible armature but chaplets holes are visible in the radiographs.

The 5th century head fragment (MMA: 1986.501.9) is from a Buddha figure which was hollow cast with an armature. It was confirmed by the use of a magnet that the armature in this statue was made of iron. As iron in archaeological contexts corrodes quickly, this armature is only faintly visible in the radiograph.

A 26.7 cm high, 8th century seated Buddha has a complex armature, consisting of an upright rod that extends from the head through the torso and possibly continues into the legs, with a second piece running across the chest and into both arms.

The head and body of the gilded standing Buddha image from Galgamuwa (Arch. ML.151) mentioned above, exhibits the typical placement of an armature with the integrity of the core and wax around it. The wall thickness of this statue is about 3 mm. Due to later damage it was possible to see a 7 mm thick and 12 mm wide rectangular cross section of two iron armatures and core material which had a very black, carbon rich appearance (Figure 6). The armature starts in the head and may have continued down into the tangs of the feet. However, the armature which is visible through a damaged tang in one foot appears to be thicker than the armature visible through the neck. It was possible to remove a sample of metal from this image for metallurgical study. Some of the core material was extracted for petrographical analysis.

An interesting finding of the study was the absence of an armature in the 59.7 cm high, 10th century hollow cast standing Buddha (MMA 1993.387.8). In the lower armature.
part of the body of this image, there is an odd bent metal rod that so far defies explanation but may have been used for maintaining the shape of the fold in the robe intact. There are three core cavities in this image and surviving core material is visible in the belly area (Figure 7). When the statue was examined, two square perforations were seen on the reverse of the figure through which most of the refractory core was removed. The perforations had been subsequently patched up. When compared with the elemental composition of the Buddha statue, the patches on the two square perforations when analysed, appear to have more tin, lead and iron. Variations in wall thickness are also clearly visible in the radiograph.

**Casting orientation**

In many ancient and traditional casting industries, it is assumed or known, that figural bronze statuary is cast in a vertical position, usually upside down, but both directions are possible. The hollow cast Maitre Bodhisattva illustrates the practice of casting statuary in a vertical position. A main sprue under the feet with a tang indicates cast-on repairs. The Bodhisattva’s ankles and feet have been repaired in ancient times and we can see where the cast-on metal has run into the core in the robe. Square runners are visible on the back of the garland (Figure 8).

A set of five 9th century Brahmanical directional deities known as Lokapalas from the MMA exhibited a gating system on the back of the statues which provided a rare and ideal illustration of the practice of casting statuary in a horizontal position (Figure 9). Traces of more than five gates (or vents) were observed on the back of each Lokapala examined, distinct from the typical casting system in Sri Lanka (Figure 10). The colossal Aukana Buddha image (conventionally dated to the 5th century but believed by some scholars to belong to c. 7th century AD) is about 12.5 meters in height and was carved into the living rock, while the five protective Lokapalas (currently in the Archaeological Museum, Anuradhapura) were placed inside a semi-circular lotus pedestal under the statue (Figure 11), were also cast in horizontal position. Apart from the Lokapalas eight small yaksha figures from Deegavapi stupa also exhibit a horizontal casting position. The casting of bronzes in this orientation is known from traditional practice in Southern India and has been demonstrated for Buddhist statuary made in Tibet.

**Casting defects and joining**

The majority of the statues in the sample are cast in one piece with the exception of the larger standing Buddha images from the later Divided Kingdoms and Kandyan
periods. The bases of these sculptures were cast separately and were not permanently or mechanically attached by hammering flanges. Some details, such as the siraspatha were cast separately as a solid piece and were inserted with a tang into the top of the head of the standing Buddha statue (MMA 1993.387.8). The 65 cm high, Kandyan style gilded standing Buddha statue (MMA: 2010.68a, b) was cast in three pieces. The hands may have been cast separately after casting the rest of the image or the separately cast hands may have been cast-on to a precast body.

Metal of low porosity and few casting defects are observed in most of the radiographs. However, casting flaws on the front and back and at the bottom of the pedestal were visible in radiographs of the seated Buddha (MMA: 1982.21). The flaws have been repaired with iron fills, which seems unusual. The fills were identified as iron because they are magnetic and associated with an iron corrosion product. The radiograph shows the missing spaces within the statue. Also the radiographs of the solid cast figure (MMA: 2010.68a, b) shows three significant casting defects on the Buddha’s robe. On the figure itself, patches of bright bluish corrosion indicate cast-in repairs using a copper-based alloy (Figure 12).

The only solid cast Bodhisattva (MMA 1987.142.65) in the study also has two cast-in repairs using a copper-based alloy which is different from the statue itself. Qualitative analysis carried out on metal from both the pedestal and the repairs, shows that the bronze used in both was not identical (Figure 13).

Radiographs also indicated that the Avalokitesvara Bodhisattva (MMA: 1994.509) is neither cast onto the base nor joined to it by any mechanical means using metal components. The two parts appear to be joined together possibly during conservation by a non-metallic substance which is completely radio transparent (Pace and Kasthuri 2010). The analysis corroborates the radiographic evidence that the pedestal is not the original one cast with the body. The base may have been attached later and is also likely to have been made for another statue because the

![Figure 9 Major in-gates and side view of Kubera/guardian of North (MMA 2003.548.1) © MMA.](image-url)
protrusion of metal on the underside of the base has no apparent connection to the feet of the Bodhisattva (Figure 14).

In the Department of Archaeology Maître Bodhisattva (MMA: TR 340.1.2012), the ankles and feet have been repaired in ancient times and we can see where the cast-on metal has run into the core in the robe. The casting is generally very high quality in this figure, with less casting defects visible. A cast-in patch in the belly, chest and middle of the body of this Bodhisattva is visible.

The Durga figure (MMA: TR340.3.2012) which belongs to the Department of Archaeology, appeared to be in good condition but radiograph show a high level of porosity in its structure.

The standing solid cast Buddha figure (MMA: TR340.2.2012) has no apparent casting defects but according to Wikramagamage, it is out of proportion from an iconometric point of view (figure 15).

Gilding and inlays

Ten sculptures mostly from the later periods bear traces of gilding or intact gold layers. Evidence for mercury or fire or amalgam gilding was found in the analysis of most statues. In all but one case, gold was found in association with mercury, confirming that they were amalgam gilded. The one exception is a head of a Buddha dating to the fifth century, which is the earliest piece from the MMA collection in this study. Flakes observed during visual examination of this statue were confirmed as gold through x-ray fluorescence. As Donna Strahan, Conservator, Object Conservation Department at the Metropolitan Museum pointed out the flakes are embedded in a wax layer on the surface, and probably adhered to the surface of the bronze when it was restored. This serves as a gentle warning: of the tools available in the laboratory, the educated eye is one of the most valuable. We can therefore say that the oldest statue in this sample with traces of gilding in the small late 7th century seated Buddha (MMA: 1987.142.63) (Figure 16). According to Craddock in his analysis of 8th -10th century Sri Lankan bronzes in the British Museum, five out of ten status he analysed were amalgam gilded. Some amalgam gilded Buddha statues were decorated with patterns of flowers and motifs (Figure 17). The scientifically dated, gilded head and body of the Buddha in the Department of Archaeology (Arch. ML.151), when analysed through XRF at the Atomic Energy Agency in Sri Lanka showed traces of mercury. This shows that the amalgam gilding technique in Sri Lanka could go back to the 4th-6th centuries AD. Traces of gilt observed under magnification on the only solid cast Bodhisattva image (MMA 1987.142.65) in the sample were confirmed as gold in association with mercury through x-ray fluorescence (Figure 18). However, this figure was recorded by Schroeder in his publication as an ungilt seated Bodhisattva on Plate 79 D and E (Schroeder 1992).

Both seated Buddhas (MMA: 2010.67 and MMA: 2010.68a) from the Kandyan period have a silver inlay in the urna in the forehead (Figure 19).
Black colour hair is painted on in the later period Buddha statues (MMA: 2010.67, MMA: 2010.68 a, and MMA: 2010.66 a). The eyebrows and the pupils of the eyes are also painted in these statues. Red coloured pigments can be seen on MMA: 1991.458.4.

**Composition of the metal**

Metallurgical studies were carried out on four figures belonging to the Department of Archaeology: a Buddha, a Bodhisattva and two deities including one excavated from the Deegavapi stupa which is among the oldest images in the study and based on microstructure analysis is an as-cast high tin bronze figure (Figure 20).

According to the microstructure analysis the Buddha statue that was dated to the Kandyan period, is an as-cast low-tin bronze. In this image, a homogeneous bronze phase is present in which all the tin has dissolved with the copper. It does not display coring that corresponds to the ideal model of metallic grains. Unetched structure of what appear to be primary alpha dendrites surrounded by grey coloured intergranular and some transgranular corrosion has taken place in the field. According to the explanation of Tony Frantz, these transgranular and...
intergranular corrosion are thermodynamically controlled phenomena that generally occur on long-term soil burial, where the prevailing weak oxidizing environment allows corrosion to preferentially attack the regions of highest free energy: namely, grain boundaries and interfaces of high-energy crystallographic planes. It could also reflect different cooling and/or post-casting annealing regimes. (Personal communication with Tony Frantz).

The Maître Bodhisattva (MMA: TR 340.1.2012) is an as-cast low tin bronze. The unetched microstructure shows what appears to be a corroded dendritic structure consistent with that of a low-tin bronze in the as-cast condition. Although, there is as-cast low tin structure in this statue, intergranular and transgranular corrosion has not taken place in the field like above structure of Buddha statue. As explained by Tony Frantz this may well be due just to differences in the burial environment or could also reflect different cooling and/or post-casting annealing regimes (personal communication with Tony Frantz).

Metallurgical study was also carried out on the above mentioned deity figure excavated from the Deegavapi stupa. The microstructure shows large, undeformed primary alpha dendrites with what appears to be unresolved alpha-delta eutectoid in the as-cast condition.

Analysis of the microstructure of a sample of the tang of the second deity - the Durga figure from Okewela, Giribawa indicated that it is as-cast high-tin bronze. The microstructure of this sample shows the acicular, or needle-like, beta phase together with a dendritic copper-rich alpha phase. What this indicates is that the alloy was hammered at between 586–798 °C when beta intermetallic compound of equilibrium composition (22.9 wt. % tin) forms, followed by quenching directly after casting, or when subsequently reheated resulting in the retention of the needle like beta phase. SEM analysis confirmed the sample to be 24.8% tin by weight. Close investigation of the figure under a microscope and through x-radiography, unmistakably demonstrated that the tang is an ancient cast on repair. Subsequently, a second sample taken from the arm was found to be quite different in composition from that of the tang, comprising mainly of copper with only a relatively small amount of tin (2.4%). Based on the data reported here, there is no zinc in either the statue or the tang (see Table 3).

According to Reedy’s (2007) study zinc is absent in bronzes from the Anuradhapura, Polonnaruva and Divided Kingdoms periods. Her study further claimed...
Figure 14  The base has no apparent connection to the feet of the Bodhisattva (MMA: 1994.509) © MMA.

Figure 15  The standing solid cast Buddha figure (MMA: TR340.2.2012) has no apparent casting defects © Department of Archaeology.
that high-lead objects tend to be more common in the late Anuradhapura period. The proportion of silver, antimony and iron content in this statue are similar to those in Reedy’s study of Polonnaruva period objects. Therefore, it is clear that this figure fits into the Polonnaruva period more than any other period on the basis of metal composition and style.

In this study, some statues show a silvery surface characteristic of a high rather than low tin content in the alloy. For example the area with less decoration on the Bodhisattva figure (MMA: 1994.509), exhibits a smooth surface with a light grey metallic sheen consistent with those found on some high tin bronzes. In areas where the light grey metallic surface is exposed black dendrites are visible within a light grey matrix (Pace, J. and A. Kasthuri 2010). Also seated Buddha statue (MMA: 2009.60) shows silver surface too.

**Discussion**

Unlike Chinese and North Indian bronzes, Sri Lankan bronze statues have generally been cast in one piece using the lost wax technique like in South Indian...
Bronzes. However, in the larger statues from later periods, the *siraspatha* were inserted into the head and pedestals were temporarily connected to the statue through the tangs. Craddock and Hook have shown that in some South Indian Bronzes which were cast in a one piece mold using the lost wax technique, separately made pedestals were permanently attached to the statues through mechanical processes (Craddock and Hook 2007, 75–80).

In the Sri Lankan case, there are a few examples of piece-mould casting that are not included in this sample. Important examples, are a life size hollow cast image discovered from Nandimithra Vihara, Pallama in Puttalam District (Herath 2005, 27–32) and the above mentioned hollow cast seated Buddha figure from Badulla. However, according to Wikramagamage (1990: 160) this statue can be attributed to the Andhra-Anuradhapura school. Thantilage on the basis of alloy composition claims that this image differs from the indigenous Mahavihara School’s sculptures and also does not fit with the locally available ore source of Seruwawila (Thantilage 2008).

While there is evidence for hollow and solid cast Buddha images dating from the Anuradhapura period, by the eighth or ninth century, hollow-cast Bodhisattva (three out of four in this study) images were standard.

According to Reedy, Mahayana and Vajrayana Buddhist images were often cast hollow in order to leave space, once some clay core had been removed, for sacred objects to be inserted as part of a consecration.

Figure 18  XRF Spectra on traces of gilt (MMA 1987.142.65) © MMA.

Figure 19  Silver inlaid Urna of Buddha Statue (MMA: 2010. 67) © MMA.
ceremony (Reedy 2007). One of the standing Buddha images in this study (MMA: 1993.387.8) shows through x-radiography three core cavities and surviving core material still visible in the belly area of the statue. According to Reedy, the core material comprised of very black organic material and sand, similar to that found in the above mentioned standing Buddha with the broken neck in the Department of Archaeology. Core material was used to improve the ability to absorb gases from the hot metal during casting (Reedy 2007).

The radiographs indicate that in hollow cast statues, armatures varying in thickness, size and shape were used irrespective of the small size of the statues. This study has revealed armatures ranging from solid metal rods and dowels, hollow metal tubes and twisted wires in several figures. An interesting finding from this study was the use of simple armatures in some small figures which did not require armatures. In addition, unnecessarily complex armatures were used in medium size statues including the Bodhisattva image (MMA: 1994.509) with the twisted wire armature. This is the first time such a complex armature including twisted wire has been recorded in a Sri Lankan bronze. Armatures of varying thickness, size, and shape were found in the Cambodian sculptures studied by Brice Vincent, a French research scholar at the Metropolitan Museum. However, a twisted wire system was not seen in the Cambodian sculptures.

The earliest surviving bronzes in Sri Lanka are solid cast representations of Buddhist guardian figures from the Deegavapi stupa. As these figures were not meant for public veneration and usually placed in inaccessible locations, they were less finely finished and even flat on the reverse in some relatively small figures. Conventionally, Lokapalas were deposited in stone receptacles with 9 or 25 compartments and placed inside stupas, under large stone images, or under monastery porches. The presence of Brahmanical guardians provided protection, and because they were placed under the feet of the images to be safeguarded, at the same time, illustrated the superiority of Buddhism.

Table 3  SEM-EDS analysis of Durga figure (MMA: TR 340.3.2012).

| Sample site | Cu  | Fe  | Sn  | Pb  | Zn  | As  | Ni  | Ag  | Au  | Hg  | Co  | Sb  | Total | Notes          |
|-------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|----------------|
| arm         | 96.1| 0.18| 2.4 | 0.51| nd  | 0.52| 0.04| 0.08| nd  | nd  | 0.02| 0.1 | 100.0 | low tin bronze |
| tang        | 75  | nd  | 24.8| 0.4 | nd  | nd  | nd  | nd  | nd  | nd  | 0.02| 0.1 | 99.9  | quenched high- tin bronze |

Amounts shown are in weight percent; nd = not detected
Unlike the older guardian figures however, the MMA and Aukana Lokapalas are considerably larger in size. That they are indeed a matched set is supported by technical, as well as the more obvious stylistic features. Considering the size and quality of other Lokapalas known from sites such as Puliyankulama, Vijayarama and Aukana, the Metropolitan Museum figures probably reflect a very high level of patronage.

Mahayana Lokapala figures and after the ninth and tenth centuries Buddha figures seem to have been made as solid-cast sculptures. It can be said that most bronze images in Sri Lanka were solid cast from the 9th century onward, with the exception of Bodhisattva figures and the rare 10th century hollow cast Buddha image (MMA: 1993.387.8). This development is probably due to new influences arriving from South India towards the end of the Anuradhapura period. Practices differed in Northern India, where numerous Hindu and Buddhist images were hollow cast. The restriction to solid figures was codified in the Sariputra, a Sinhalese text describing canons of proportion and other guidelines for sacred sculptures, in which the casting of hollow statues to be used for worship was explicitly forbidden (Schroeder 1992, 513). The change appears to have taken place gradually and was naturally not adopted by all workshops at the same time (Schroeder 1992, 172).

Generally, late Divided Kingdoms and Kandy period figures unlike in the Anuradhapura or Polonnaruva periods, were mostly large in size and solid cast, gilded or painted bronzes. The 65 cm high, Kandy style gilded standing Buddha statue (MMA: 2010.68a, b) was cast in three pieces.

Conclusion

The earliest direct evidence for the production of copper alloy sculpture is uncertain. However, extensive technological studies of tin bronze sculptures revealed that bronze casting was well developed throughout the four different periods. The images are well designed and highly skilled creations, generally, metal of low porosity and few casting defects are observed in most of the radiographs, indicating that the castings of the sculptures have been generally of good quality attesting to a high level of craftsmanship. For example, the only scientifically dated gilded standing Buddha is evidence that a high level of casting technology flourished during the 4th - 6th centuries AD and probably even before this time in Sri Lanka. The direct lost wax technique was used with remarkable skill as a local technique.

While both a vertical and a horizontal casting orientation was observed in the used of the lost wax technique. In my view, the horizontal casting position was mostly used for lower level beings and deities in the Buddhist pantheon such as, yaksha, figures and Lokapala guardian deities. In studies conducted by me to date, Buddha and Bodhisattva statues are invariably cast in a vertical position. Guardian figures and the later Lokapalas represent a distinct type of sculpture with a protective function. A study focusing on other existing groups of these sculptures would be of great interest particularly in view of the new evidence of their casting orientation.

In addition larger Buddha statues, which mostly date to the later periods, are for the most part solid cast in keeping with restrictions codified in the Sariputra shilpa text.

This study has revealed that armatures used in hollow cast bronze sculptures in Sri Lanka range from solid metal rods and dowels, to hollow metal tubes to twisted wires. A Bodhisattva statue from this study is the only evidence to date of the use of twisted wire armatures in bronze sculptures.

Gilding on ten figures in the study, particularly those from later periods, was done through fire gilding, also known as amalgam gilding and bear traces of gilding in association with mercury.

The four figures subjected to microstructure analysis confirmed the existence of considerable differences in composition, thermal history, and state of preservation in bronzes from different historical periods.

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