Concentric circles

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THE MANUFACTURING TECHNIQUE OF NATIONAL TREASURE NO.141: BRONZE MIRROR WITH TWIN KNOPS AND FINE GEOMETRIC DESIGN

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[ABSTRACT]

This paper examines the appearance and casting defects of National Treasure No. 141, 'Bronze Mirror with Twin Knops and Fine Geometric Design,' which is in the collection of the Korean Christian Museum at Soongsil University, in order to investigate issues of manufacturing technology, manufacturing sequence, and the type of mould used.

It was revealed that a sand-based mould, made of hardened moulding sand, was used; the design of the mirror was carved onto the surface of this mould. The presence of casting defects such as corner scab and rat tail indicates that the mould strength was relatively low.

The circles comprising the mirror's design were drawn using a compass and it appears that the bisection of angles was used. The concentric circles of the outer section were drawn together using a multiple-toothed implement, while each circle dividing the different areas of decoration was drawn separately using a compass. It was observed that the rim was not carved using a sweep cutting edge, but formed after the outer section had been carved. The space for the knops was also formed after the designs of the inner section had been carved. The front side of the mirror and the rim were polished after casting. Finally, evidence of wear was found on the knops, which indicates that the Bronze Mirror with Twin Knops and Fine Geometric Design had indeed been used.

[KEYWORDS]

Bronze Mirror with Twin Knops and Fine Geometric Design, mould, manufacturing technology, sand-based mould

I INTRODUCTION

National Treasure No. 141 – Bronze Mirror with Twin Knops and Fine Geometric Design (hereafter referred to as NT 141) – which is in the collection of the Korean Christian Museum at Soongsil University, is regarded, on account of the detailed and elaborate nature of its geometric design, as a key artefact illustrating the high quality of bronze manufacturing techniques in Bronze Age Korea. It is surprising that such a bronze mirror could have been made using the manufacturing techniques available at the time. Various possibilities have been suggested and numerous experiments have been carried out, but the manufacturing technique of NT 141 has yet to be revealed.[1] Detailed investigation of the mirror was therefore carried out in conjunction with the conservation process which took place between July 2007 and August 2008.[2] The present paper aims to examine, based on the results of this investigation, the techniques used to manufacture this fine bronze mirror.

II INVESTIGATION METHOD

NT 141 was examined in detail through photography and the use of a stereomicroscope; a digital camera was used to make image recordings. The recorded images were then measured quantitatively using an image analyzer. The measurement of circles, such as those dividing the different areas of decoration or the concentric circles located in the mirror's outer section, was carried out as follows: three points were selected from the circumference of the circle, a new circle which passed through these three points was redrawn, and the radius of the new circle was measured. Vernier calipers and a thickness gauge were amongst the tools used to carry out measurement. Certain parts of the mirror were found to have been deformed due to defects which occurred during casting. In addition, it should be noted that measurement took place following the re-attachment of dislocated pieces; the values obtained may therefore differ slightly from the original dimensions of the cast mirror. Finally, as the back (the

decorated side) of the mirror was not perfectly flat, a slight error may exist in its measurement.

III RESULTS OF THE INVESTIGATION

01 MIRROR FORM

As seen in Figure 1, NT 141 has a horizontal diameter of 212.1mm and a vertical diameter of 212.8mm. The front of the mirror is flat while the back has two knops and is decorated with a geometric design. The decorations on the back of the mirror can be divided into three ring-shaped zones: inner, middle and outer. The outer zone contains vertical rows of triangles filled with slanting lines, in between which lie four pairs of concentric circles.[3] The middle zone was also decorated using triangles filled with slanting lines. Finally, the inner section of the mirror was divided into four panels, each of which was again decorated using triangles filled with slanting lines. The two knops are located slightly above the center point of the mirror and knop core prints can be found on either side of the knop holes. The inner zone of the mirror was found to be relatively thicker than the outer zone, thereby making the mirror convex in form. The rim of the mirror is semicircular in cross section, and evidence of chamfering was observed around the front edge (Figure 2).

The bronze mirror currently consists of 19 fragments, with a missing section extending vertically between the two knops. Missing sections are also located along the upper parts of the rim, to the left and right. The lower part of the outer zone also contains a missing section.

02 CASTING DEFECTS

Casting defects occur when casting conditions are not ideal, and as each casting defect has a corresponding reason, the investigation of these casting defects may allow us to infer casting conditions. A number of such casting defects can be found on NT 141. Some of the main casting defects are presented in Figure 3. The rim above Circle 1 (for ease of description, each concentric circle has been given a number (1~8), beginning with the upper left concentric circle) contains an imprint of the outer section and rim (hereafter Defect 1) due to parts of the mould having become detached (Figure 3-1). This defect starts at the rim, continues along the lower left part of the back of the mirror, and goes on to the front. This defect had previously been covered by restoration material and therefore had not been discovered. A corner scab defect occurred along the mirror's outer section and rim, between Circle 1 and Circle 2 (hereafter Defect 2), leading to the original decoration being erased (Figure 3-2). Circle 2 was found to contain an imprint of a piece of the mould detached from the outer section and rim (hereafter Defect 3) (Figure 3-3). Defects 1 and 3 were found to cover the surface of Defect 2 when moved to their original positions, thereby indicating the area from which they were detached (Figure 3-7, 3-8). Several rat-tail defects which extended to the rim were identified on the mirror's surface. The lower part of the mirror (Figure 3-4) and the area to the left of Defect 1 (Figure 3-5) were observed to be at the stage just prior to scab formation; this had occurred due to the expansion of the mould which led to a decrease in the thickness of the casting. A defect resulting from the inclusion of sand detached from the mould was also found on the front side of the mirror, parts of which were located directly underneath Defect 3 (Figure 3-6).

(Figure 1)
NT 141, the Bronze Mirror with Twin Knops and Fine Geometric Design after conservation treatment

(1) Back

(2) Front

(Figure 2)
Cross section of the Bronze Mirror prior to conservation treatment

(1) Upper part

(2) Lower part

(Figure 3)
Casting defects

(1) Defect containing design (Defect 1)

(2) Corner scab defect (Defect 2)

(3) Defect containing design (Defect 3)

(4) Rat-tail defect and scab on the lower part of the outer section and rim

(5) Casting defect located on the upper part of the back of the mirror

(6) Casting defect located on the upper part of the front of the mirror

(7) Location of Casting defects 1, 2, 3

(8) Original position of Casting defects 1 and 3

Based on the presence of corner scabs and rat-tail defects, it appears that there was too much moisture or too little clay in the mould.[4]

03 MOULD

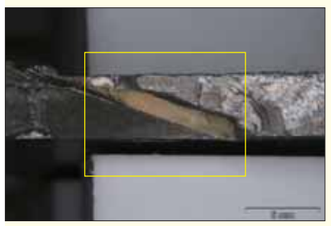
1) Material

Various suggestions have previously been put forth regarding the material of the mould. Among the possibilities has been the use of an earthen mould onto which the mirror design was incised,[5] the use of a stone mould onto which the mirror design was carved directly,[6] and finally the use of a cast made of beeswax (which in turn was made from a stone mould containing the mirror design) which was then covered with the material used to make the final mould.[7]

An attempt can be made to infer the material of the mould by examining the casting defects which can be observed on the mirror. Defect 1, located on the rim, continues along the edge of the mirror and onto the front (Figure 4), and sand inclusions which appear to have come from the mould are present in between the front and back of the mirror, as can be seen in Figure 4-1. As mentioned above, this part was found to have been detached from the outer zone area of Defect 2, and was also identified as containing evidence of a curved design, as well as traces of sand (Figure 4-2, 4-3). In addition, sandy material was also observed within Defect 3 [illustrated above in Figure 3], Figure 4-4 and the lower part of the rim (Figure 4-5, 4-6).

This indicates that the use of a stone mould is unlikely. However, we cannot exclude the possibility that casting took place using a lost wax process. In this case the final mould could have also been made of earth. Therefore it is necessary that we focus on the structure of the mould, rather than its material. In the case that space for the core print was cut into the stone mould and the core installed (the cores were used to make the knop holes in the mould), the wax-cast made through this process would have contained evidence of damage around the knop hole, as a result of removing the core. However, as can be seen in Figure 5, the design around the knops does not contain any evidence of damage. In addition, if this were the case, the redrawn line which can be seen on the knop core print could not have existed.

(Figure 4)
Distribution of moulding sand

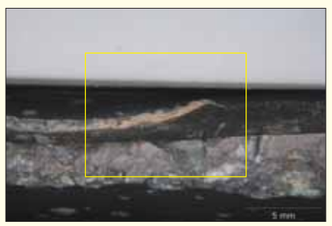


(1) Cross section of mirror

(2) Close-up of (1)

(3) Boundary between moulding sand and mould

(4) Moulding sand in Defect 3



(5) Scab on rim (Defect 4)

(6) Close-up of (5)

(Figure 5)
Designs around the boundary of the knops

(1) Left knop

(2) Right knop

(3) Trace of the right knop's core print

(4) Re-drawn line on the core print

Even in the case that the mould was made without detaching the knop core from the original cast, the infill between the core and the stone mould would have disintegrated upon separating the knop core and wax-cast from the stone mould. Therefore, the boundary between the core print and the surrounding design could not be as clear as is in fact the case.

Another possibility is that the knop holes were made after the wax-cast was completed. However, in this case, the core print would not have been required at all, and therefore would not have left a trace. Based on the above findings, NT 141 was manufactured using a sand-based mould of hardened moulding sand.

2) Type

With regard to the manufacture of bronze objects, there exists the question of whether an open or closed mould would have been used.[8] Even in the case that an open mould was used, the manufacture of bronze mirrors would have been possible by polishing the parts which had contracted during the solidification process.

Clues regarding the type of mould used can be obtained from the sand inclusions found in the defect located on the mirror's rim [Defect 1, see Figure 3]. When pieces of the mould become detached during the casting process, they float to the top as their density is lower than that of the molten metal. Therefore, in the case that an open mould was used, such mould debris should only be found on the front of the mirror. However, as debris was identified on both the front and the decorated back of the mirror, distributed in a diagonal direction, it is possible to confirm that an open mould was not used.

The type of phenomenon described above occurs when detached mould pieces floating to the top become trapped on either side of a closed mould. It can therefore be assumed that the type of mould used in the case of NT 141 was a closed mould.

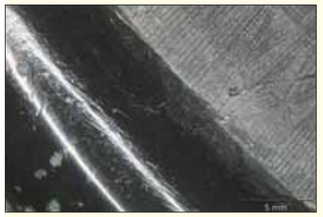
Though chamfering identified on the front side of the mirror, it cannot be known if such a feature had been present on the actual mould or if it occurred after casting, during the polishing process.

3) The Possible Use of Multiple Materials

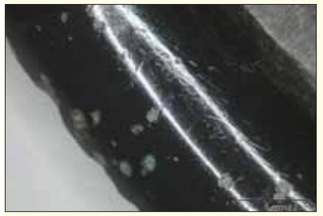
One other possibility regarding the mould is that the design of the mirror was carved onto a clay layer which was added to a stone mould.[9] This may be suggested based on observations that have been made on the use of the stone mould for a bronze mirror with multiple knops, currently in the collection of Soongsil University, which is said to have come from Yeongam, Jeollanam-do.

As discussed above, the mould of NT 141 was made of sand. Upon removing the earth caught in the lower right part of the rim (Defect 4), which had come from the matrix surrounding the buried mirror, it was possible to observe particles from the mould (Figure 4-5, 4-6). It is possible to observe that the distribution of mould remains nearly reaches the uppermost part of the rim. As traces of moulding sand can be observed, it can be said that at least up to this point, the type of mould used was a sand mould. In addition, as can be seen in Figure 6, rat-tails which were formed by a defect in the mould extend continuously from the outer zone of the mirror to the rim. This indicates that the entire surface which came in contact with the molten alloy was made using the same material – moulding sand.

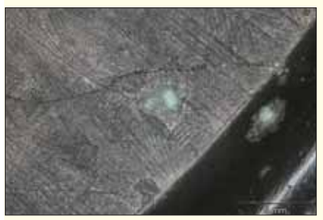
(Figure 6)
Distribution of rat-tail casting defects



(1) Defects on the lower left side



(2) Defects on the lower left side of the rim



(3) Defects on the lower right side

(4) Defects on the lower right side of the rim

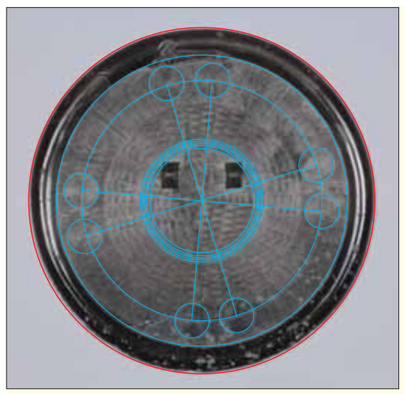
04 DECORATION

1) Appearance and Drawing Method

The circles which divided the respective decoration zones were re-drawn using an image analyzer, by selecting three different points on the circumference of each original circle. The results of this are presented in Figure 7. The re-drawn circles were found to be identical to the original circles, and the center points of the circles were also found to be nearly identical. However the circle that was drawn using three points from the circumference of the rim did not conform to the actual outline of the latter, with some sections falling outside and other sections lying within the mirror's outline. The center point of the rim circle was also located separately from that of the other circles. When a circle was drawn at the point where the centers of the other circles met (hereafter Center Point O), and passed the outermost point of the rim [the red circle in Figure 7], it was possible to observe that the upper edge of the mirror coincided with the boundary of the red circle, while the side and lower edges of the mirror did not extend to this boundary. It is assumed that this is because, although the mirror was originally planned and drawn out as a circle, the outline of the rim was carved unevenly or unevenness occurred during the process of polishing which took place after the mirror was cast. Based on the fact that the boundary between the rim and the outer zone forms an even circle, it is more likely that this unevenness in the outline of the rim resulted from manufacturing processes which took place after casting. The circles of the inner section were also found to have a similar center point where re-drawn using the image analyzer. However, this center point did not match that of the cross which divided the inner section into four panels. In addition, the vertical line of the cross did not form a right angle with its horizontal line; the angle between the vertical line and the horizontal line to the left was found to be 85°. As the lines forming the cross were not perfectly straight, the measurement of the angle took place by connecting the end points of the lines to the Center Point O. The unevenness of these lines is thought to derive from the fact that the back of the mirror is not perfectly flat but slightly convex. This means that the mould for the back of the mirror would have been slightly concave, making the drawing of the geometric designs a difficult task.

2) Concentric Circles in the Outer Zone

In the case of the eight concentric circles located in the outer zone, the center point of each was established by re-drawing the outermost circle, based on the above-described method of selecting three points. An attempt was then made to draw another circle which passed through the centers of the concentric circles and had Center Point O as its center (Figure 7). However, it was impossible to draw such a circle which passed through all of the centers of the concentric circles. Therefore, the angle between each of the concentric circles was obtained using Center Point O. The results of this are presented in Table 1. The angle between concentric circles forming pairs was found to range between 21.5° to 22.3° and the angle between the four pairs of concentric circles was found to range between 89.3° to 90.5°. As it is difficult to achieve this degree of closeness to a right angle based on the naked eye alone, it can be assumed that knowledge of how to bisect an angle existed at the time. In addition, in the case of the concentric circles forming pairs, the angles were found to fall slightly short of the 22.5° which can be obtained through the bisection of angles. It is difficult to know at present whether this was due to errors which occurred during the process of bisecting angles, or if the center point of each concentric circle hand, in fact, was established by selecting a point which lays at a certain distance from a nearby circle.



(Figure 7)
Re-drawn boundary lines and concentric circles

(Table 1)
Angle between the concentric circles

Concentric circle	Angle (°)	Concentric circle	Angle (°)
1-2	21.9	1-3	89.3
2-3	67.4	2-4	89.7
3-4	22.3	3-5	90.5
4-5	68.3	4-6	89.9
5-6	21.6	5-7	90.2
6-7	68.6	6-8	90.1
7-8	21.5	7-1	90.0
8-1	68.5	8-2	90.4

3) Carving Method

The radii of the concentric circles in the outer zone can be obtained by selecting three points on the circumference using an image analyzer – in doing so, a circle can be drawn and its center point established. Through this method, the radii of the 21 circles which comprise each concentric circle (excluding the two to three curved lines in the center) were obtained. Table 2 presents a list of the radius measurements, and Figure 8 presents the distribution of these values.

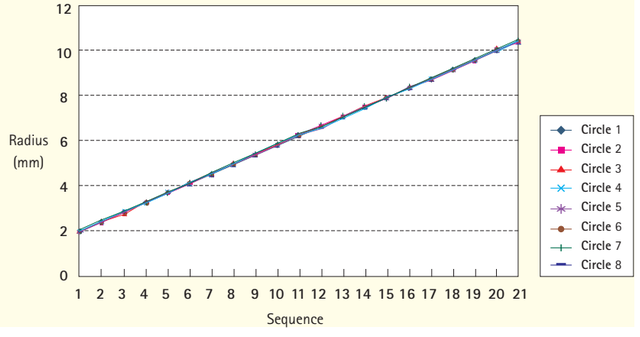
The distribution of the radius values of the 21 circles which form each concentric circle was found to be similar in nature, thereby suggesting that the concentric circles had been drawn at the same time using a multiple-toothed implement. In addition, the circles near the curved lines (which had been drawn by hand) were found to have been slightly modified or contained erased parts, as can be seen in Figure 9. One possible explanation for this is that in drawing the circles with a compass, the holes left by the compass spike were later filled in using moulding sand, some of which became trapped in the incised circles, therefore, these zones had to be re-drawn by hand later. The possibility that the compass spike hole would have been erased by infilling it with earth or sand has previously been suggested by others as well.[10]

Figure 10 presents the circles located just outside the inner zone of the mirror. The points where the starting and end point of each drawn circle met can be observed near the top of the circles, but interestingly enough, these meeting points do not form a straight line from the Center Point O (Figure 10-1, 10-2). This would not be the case if the circles had been drawn simultaneously using a multiple-toothed implement. In addition, the meeting point of a circle can also be observed to the lower right hand side of the inner zone (Figure 10-3, 10-4). Therefore, it should be assumed that the circles located just outside of

(Table 2)
Radius of concentric circles (unit: mm)

Circle / Sequence	Circle 1	Circle 2	Circle 3	Circle 4	Circle 5	Circle 6	Circle 7	Circle 8	Average	Standard deviation
1	1.87	1.83	1.85	1.81	1.95	1.96	1.86	1.87	1.87	0.05
2	2.38	2.33	2.34	2.31	2.36	2.34	2.35	2.38	2.35	0.02
3	2.92	2.86	2.73	2.85	2.87	2.85	2.87	2.87	2.85	0.05
4	3.34	3.29	3.25	3.29	3.30	3.30	3.22	3.29	3.29	0.04
5	3.73	3.68	3.67	3.69	3.72	3.67	3.71	3.68	3.69	0.02
6	4.21	4.14	4.13	4.15	4.17	4.13	4.13	4.13	4.15	0.03
7	4.63	4.56	4.52	4.56	4.58	4.54	4.55	4.53	4.56	0.03
8	5.16	5.09	5.04	5.10	5.13	4.99	5.09	5.08	5.09	0.05
9	5.64	5.55	5.53	5.58	5.61	5.54	5.56	5.52	5.56	0.04
10	6.08	6.02	5.98	6.05	6.07	6.01	6.01	5.99	6.03	0.04
11	6.52	6.46	6.40	6.47	6.50	6.39	6.43	6.41	6.45	0.05
12	6.94	6.86	6.83	6.90	6.93	6.83	6.88	6.82	6.88	0.05
13	7.41	7.32	7.36	7.35	7.39	7.26	7.32	7.29	7.34	0.05
14	7.90	7.82	7.77	7.84	7.92	7.81	7.80	7.78	7.83	0.05
15	8.42	8.31	8.23	8.32	8.39	8.28	8.30	8.26	8.31	0.06
16	8.78	8.68	8.62	8.72	8.75	8.64	8.69	8.64	8.69	0.06
17	9.18	9.05	8.99	9.09	9.15	9.02	9.06	9.02	9.07	0.07
18	9.60	9.46	9.40	9.53	9.56	9.43	9.50	9.45	9.49	0.07
19	10.00	9.87	9.76	9.86	9.94	9.84	9.89	9.82	9.87	0.07
20	10.35	10.22	10.15	10.25	10.33	10.22	10.26	10.19	10.25	0.07
21	10.71	10.56	10.50	10.60	10.70	10.57	10.63	10.58	10.60	0.07

(Figure 8)
Distribution of radius values from the concentric circles of the mirror's outer zone



(Figure 9)
Concentric circles

Top left:
(1) Center of Concentric circle No. 1

Top right:
(2) Center of Concentric circle No. 2

Bottom left:
(3) Center of Concentric circle No. 3

Bottom right:
(4) Center of Concentric circle No. 4

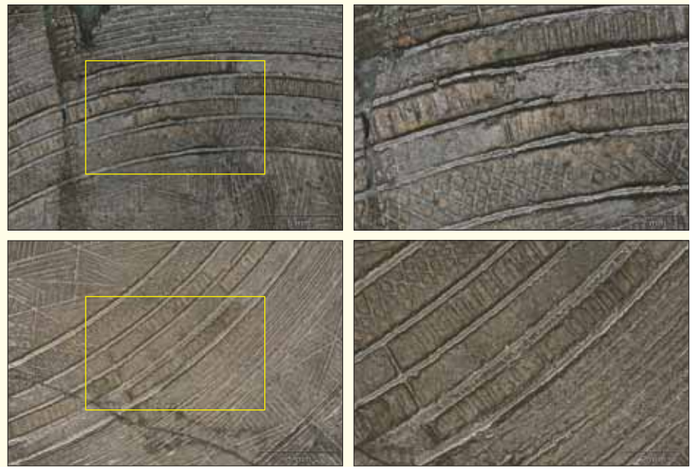
(Figure 10)
Circles located just outside the inner zone of the mirror

Top left:
(1) Area above the inner zone

Top right:
(2) Close-up of (1)

Bottom left:
(3) Area below the inner zone

Bottom right:
(4) Close-up of (3)



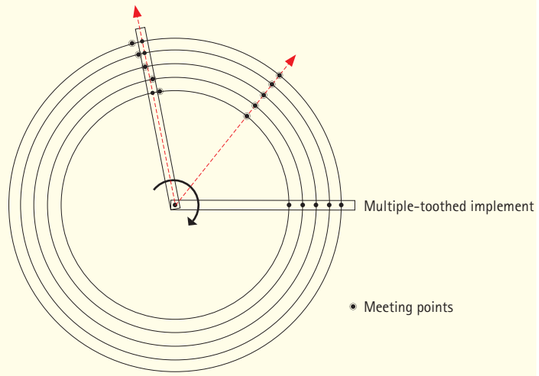
the mirror's inner zone were drawn individually using a compass. All of this is presented schematically in Figure 11 which demonstrates visually how the meeting points of the circles located just outside the inner zone are not aligned according to a straight line starting at Center Point O. Experimental reproductions of bronze mirrors have been carried out in which the entire decoration on the back of the mirror was carved into the mirror mould by using a sweep cutting edge which contained the shape of the back.[11] In such cases, the difference in height between the boundary where the mirror's outer zone and the rim meet and the highest point of the rim (i.e. the area where the mould was carved the deepest) was found to be constant. NT 141 was similarly examined, with the thickness of the rim and boundary of the outer zone measured according to units of 10°. Figure 12 presents the differences in the thickness measured. Even when values which represent casting defects and areas that have experienced conservation are excluded, it can be observed that the thickness was

(Figure 11)
Schematic drawing of circle meeting points and actual meeting points of circles located outside the inner zone of the mirror

The meeting points of circles and straight line drawn from Center Point O

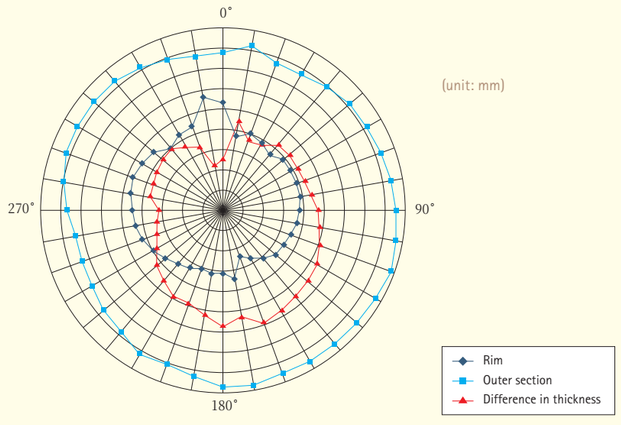
Meeting points not aligned in a straight line: multiple-toothed implement not used

Multiple-toothed implement used: meeting points aligned in a straight line



Meeting points and the use of a multiple-toothed implement [Clockwise from the upper left hand corner]

(Figure 12)
Thickness of the outer zone and rim and the distribution of differences in this thickness



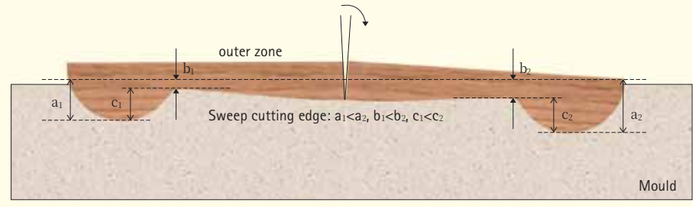
not even. If a stamp mould had been used, as illustrated in Figure 13, and if that stamp mould had been pressed unevenly, leading to differences in the thickness in the left and right parts of the rim ($a_1<a_2$), the right side of the outer zone should be thicker than its left side ($b_1<b_2$), and the difference in thickness between the outer zone and the rim should also be greater on the right than on the left ($c_1<c_2$), as schematically demonstrated. However if we look at Figure 13-2 which shows the left and right cross-sections of NT 141 upside-down, it is possible to confirm that the thickness of the left outer zone is greater than that of the right ($b_1>b_2$). Therefore, it appears that in forming the rim, a sweeping cutting edge was not used. The fact that the center point of the inner circle of the rim (i.e. its boundary with the outer zone) coincides with the center points of the other circles, makes it also unlikely that the rim was carved out using a pre-existing pattern. In other words, it appears that the rim was first drawn onto the mould and then carved out. As for the other areas of the mirror back, it is difficult to know how the designs were made. However, the use of a sweep cutting edge would have made it easier to establish the center point, thereby facilitating the drawing of circles which were later added on. It is therefore likely that a sweep cutting edge was used which did not include the shape of the rim.

4) Carving Sequence

The lines which divide the respective decorative zones were judged to have been carved first, followed by the fine design lines decorating each zone. The sequence in which the carving of decorative designs took place is presented in Table 3. This carving sequence was analyzed and divided according to the four sections of the mirror – the inner zone, middle zone, outer zone and rim – and it was concluded that the lower the position within each column, the later the designs had been carved. However, it should be noted that across the different columns, row position does indicate relative carving sequence; in the case where carving sequence could be established

(Figure 13)
Diagrammatic cross-section showing possible use of a sweep cutting edge

(1) Changes in cross-section thickness when a sweep cutting edge is used



(2) Cross-sections of the outer zone and rim (left and right)

across different columns, this relationship was marked using a double line. In the instance that the carving sequence within a specific decoration section could not be established, the carving actions were presented side by side. For example, the knop and core print would have been carved separately, but their sequence cannot be established.

Of course, in carving the decorations, it would have been natural, generally, to begin with the inner zone and continue towards the outer zone, as this would have prevented designs which were already carved from being damaged during subsequent carving actions. Interestingly enough, in the case of the core print of the right knop, the dividing line was redrawn later, as is shown in Figure 5-4. As this line goes beyond the trajectory of the original circle, it is assumed that it was redrawn by hand, rather than with a compass, in an effort to restore the original design.

In carving the decorations of the mirror, the first step would have been to carve out the center of the mould in order to make a concave space for the convex mirror back. It has been identified that, if the rim and outer zone had been formed together using a sweep cutting edge (i.e. if the rim had been formed prior to carving the lines of the outer zone), the designs of the outer zone, located adjacent to the rim, would have tended to extend further and encroach upon the rim where it meets the outer zone.[12]

However, in the case of NT 141 (Figure 14), the decorative lines of the outer zone located near the boundary where it meets the rim do not demonstrate any differences in height, as can be seen in Figure 14-1. Therefore, in the case of NT 141, it appears that the rim was carved subsequent to the decorations of the outer zone. In addition, if we continue to adopt the above reasoning, it can be said that the knops were carved after the decorations of the inner zone, since none of the patterns of the inner zone extend to the knop (Figure 14-2).

Finally, it can be observed that some of the triangles located in the lower right side of the outer zone were not in-filled with slanting lines (Figure 14-3~14-5). This illustrates that the slanting lines were added after the triangle motifs were drawn, but it is unclear why these patterns were left unfinished.

5) Polishing

As the main objective of a mirror is to reflect the image of objects, the front surface of the mirror must be smooth.[13] However, the surface of metal objects manufactured through casting are too rough to be used as mirrors and therefore must be additionally polished. Figure 15 presents the polished states of the mirror's surface. Since corroded parts and flaws are present, the surface of the front of the mirror appears rough. However, the smooth surface of other parts indicates that the front of the mirror was originally polished. The rim was not as finely polished as the front of the mirror, and its boundary with the outer zone was not polished at all. It is likely that this was in order to prevent the designs of the outer section from being erased during polishing. The fact that Defect 4 remained on the rim, as well as the fact that traces of rat-tail defects are still present, indicates that the polishing was not heavily carried out.

(Table 3)
Manufacture sequence of each section

<table>
<tr><th>Section
Sequence</th><th colspan="3">Inner zone</th><th colspan="2">Middle zone</th><th colspan="3">Outer zone</th><th>Rim</th><th>Gating system</th></tr>
<tr><td rowspan="8">Earlier
↓
Later</td><td colspan="9">Carve out main space</td></tr>
<tr><td colspan="9">Section dividing lines</td></tr>
<tr><td colspan="2">Cross-shaped line</td><td>Radiating lines</td><td colspan="2">Radiating lines</td><td colspan="2">Radiating lines</td><td>Concentric circles</td><td></td><td></td></tr>
<tr><td colspan="2">Dividing straight lines</td><td rowspan="3">Slanted lines</td><td rowspan="3">Triangles</td><td rowspan="3">Triangles</td><td rowspan="4">Slanted lines</td><td rowspan="4">Slanted lines</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td colspan="2">Triangles</td></tr>
<tr><td colspan="2">Slanted lines</td></tr>
<tr><td>Knop</td><td>Core print</td><td></td><td>Slanted lines</td><td>Slanted lines</td></tr>
<tr><td colspan="6"></td><td>Rim</td><td></td></tr>
<tr><td colspan="6"></td><td></td><td>Gating system</td></tr>
</table>

(Figure 14)
Line decorations which demonstrate carving sequence

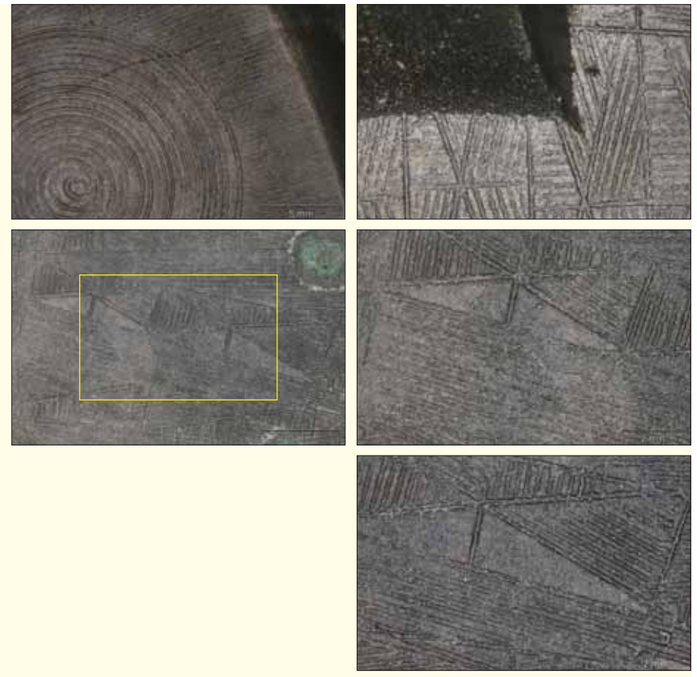
Top left:
(1) Detail of a circle in the outer zone near the rim (visible in the top right corner)

Top right:
(2) Inner section of right knop

Bottom left:
(3) Undecorated triangle pattern from the outer zone

Center right:
(4) Close-up of (3)
(left undecorated triangle pattern)

Bottom right:
(5) Close-up of (3)
(right undecorated triangle pattern)



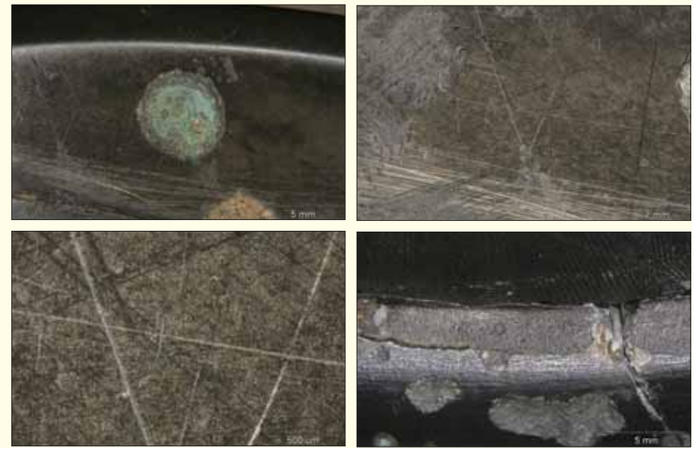
(Figure 15)
Polished state of each section

Top left:
(1) Front of the mirror and edge

Top right:
(2) Front of the mirror

Bottom left:
(3) Close-up of the front of the mirror

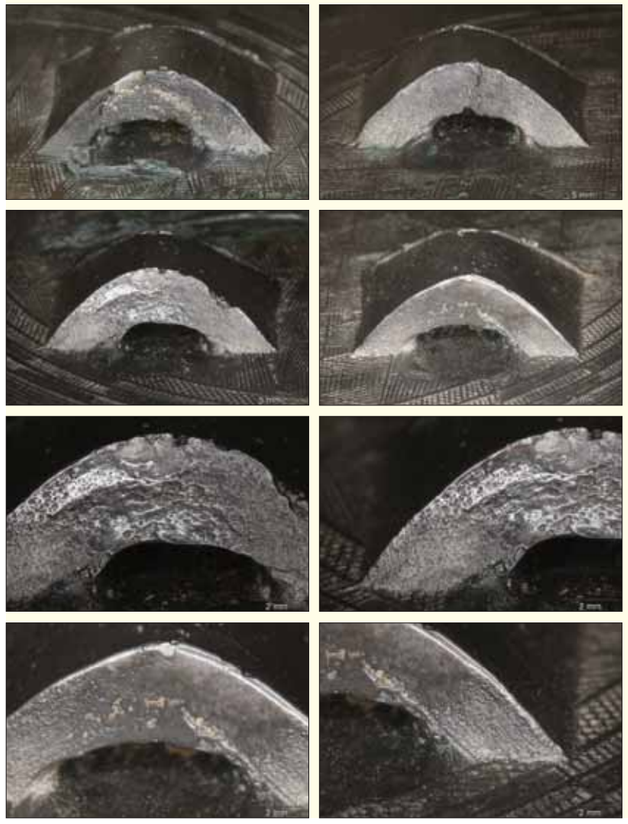
Bottom right:
(4) Detail of the rim



6) Possibility of Use and the Appearance of the Knops

Whether or not the mirror had been used was determined by inspecting the degree of roughness of the edges of the knops. If the mirror had been hung using a cord fastened to the knop, the friction caused by the cord would be expected to result in differing degrees of surface roughness, compared to the parts of the knop which were not rubbed by the cord. Figure 16 presents the inward-facing and outward facing surfaces of the knops; the latter were found to demonstrate similar degrees of roughness to those on the inward-facing sides. On the other hand, the outward facing surfaces of both knops were found to be smooth from the center to the upper part of the knops, unlike the edge surface which was rough. This smooth surface would not have been possible when the knop sections were originally cast, and therefore can be regarded as being the result of wear due to friction. The fact that such a smooth surface exists only on the upper surfaces of the knops indicates that the mirror was hung using a single cord inserted through the holes of both knops. The mirror would have hung at an angle, as is suggested by the nature of the wear. Observation of the knop hole from the side confirmed that it was oval in shape, as illustrated in Figure 17. The space between the knop hole and the edge of the knop was found to go in slightly, and this area was separated from the edge of the knop by an arc-shaped line (Figure 16). This shows that the core print section on the mould, where the core print of the core was located, was made by carving an arc-shaped space (in cross-section) and installing an oval core. The

(Figure 16)
Traces of wear on the knops



Left: (1) Inward-facing side of the left knop
Right: (2) Inward-facing side of the right knop

Left: (3) Outward-facing side of the left knop
Right: (4) Outward-facing side of the right knop

Left: (5) Area of wear on the outward-facing side of the left knop
Right: (6) Area of wear on the outward-facing side of the right knop

Left: (7) Area of wear on the outward-facing side of the left knop
Right: (8) Area of wear on the outward-facing side of the right knop

gap between this arc-shaped space and the core print was found to have been packed with infill material, and it appears that this infill was slightly pushed out. On the other hand, observation of the knop from above shows that the area where the core print was originally placed was pushed out slightly (Figure 5-1~5-3). It is assumed that the evaporation of moisture caused the infill to shrink and its area was pushed out after casting.

IV CONCLUSION

The present paper has attempted to consider certain aspects of the manufacturing technique of National Treasure No. 141, the Bronze Mirror with Twin Knops and Fine Geometric Design. It was identified that a sand mould, made of hardened moulding sand, had been used, and that this mould had not been strong, resulting in casting defects such as scabs and rat-tail defects.

The designs of the mirror appear to have been drawn using a compass and the bisection of angles; the designs were finely executed even though the surface of the mirror was not completely flat. The concentric circles of the outer zone were made using a multiple-toothed implement, and the circles which divided the different zones of decoration were drawn, one by one, using a compass. The rim does not appear to have been formed using a sweep cutting edge, but was rather carved after the outer zone had been decorated. Polishing was carried out subsequent to casting, and the knops contained traces of wear which indicate use.

It should be noted that the above represents only a fraction of the manufacturing techniques involved in the production of NT 141. In addition, they require discussion and examination through further studies. It is hoped that the understanding of the casting process of this National Treasure will lead to further in-depth studies on the manufacturing techniques of ancient bronze objects and that many researches will contribute to this worthy endeavor.

(Figure 17)
Appearance of the knop

(1) Knop hole of the left knop
(2) Knop hole of the right knop

NOTES

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