‘*Atiqot* 62, 2010

The Metal Objects from Fassuṭa

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Among the artifacts recovered in the excavations at Fassuṭa (see Gershuny and Aviam, this volume) were six metal items that were sampled and examined. The chemical analysis of all six artifacts was conducted by a SEM-PROBE instrument with WDS.[1] Metallographic analysis was conducted on four artifacts by cutting a minute solid metal sample close to the surface. The two spearheads were found heavily corroded near the surface and therefore were drilled for chemical analysis only.

The metallurgic and metallographic results are presented below and their archaeological significance is discussed. All the examined items were found as part of a funerary assemblage in Tomb 1, dated by the excavators to the transitional MB I–II (see Gershuny and Aviam, this volume).[2] Details of the examined artifacts, the location of sampling and the mechanical and thermal treatment they underwent after casting, as seen in their metallography, are given in Table 1. The chemical composition of each of the metal items is presented in Table 2. Table 3 contains comparative data of the chemical composition of similar items from other sites.

The chemical analysis reveals that five of the six metal items were made of tin bronze,

Table 1. Typology and Metallography of the Metal Items from Tomb 1

Type	Sampling Method and Location	Metallography	Fig. No. (Gershuny and Aviam, this volume)
Shaft-hole axe	Cut: center bottom	Hammered and annealed Grain size: 20μm, coring	Fig. 13:1
Tanged dagger	Cut: blade center	Hammered and annealed	Fig. 13:2
Spearhead	Drilled: mid-rib		Fig. 13:3
Spearhead	Drilled: mid-rib		Fig. 13:4
Toggle pin	Cut: center	Hammered and annealed	Fig. 13:5
Ring	Cut: whole thickness	Hammered and annealed Grain size: 20μm	Fig. 13:6

Table 2. The Chemical Composition of the Metal Items from Tomb 1

Type	Fe	Co	Ni	Cu	Zn	As	Sb	Sn	Ag	Bi	Pb	Au	S	Method
Shaft-hole axe	0.73	tr.	0.03	90.03	tr.	4.34	0.11	0.02	0.01	n.d.	4.35	0.02	0.34	EPMA
Tanged dagger	0.24	0.02	0.06	94.75	0.01	0.46	0.02	3.68	0.05	n.d.	0.48	0.02	0.19	EPMA
Spearhead	0.21	0.01	n.d.	91.55	0.01	0.27	n.d.	7.68	0.02	0.01	0.13	0.05	0.06	EPMA
Spearhead	0.43	tr.	0.02	92.06	0.02	0.61	tr.	6.65	0.02	0.02	0.07	n.d.	0.09	EPMA
Toggle pin	0.16	n.d.	0.05	90.73	n.d.	0.87	0.08	6.75	0.04	0.02	0.68	0.01	0.18	EPMA
Ring	0.40	0.01	0.05	94.39	n.d.	0.74	0.04	3.70	0.07	tr.	0.43	0.02	0.14	EPMA

tr. = traces; n.d. = not detected; EPMA = SEM-PROBE with Wavelength Dispersive Spectrometer namely, copper alloy with tin in quantities of 3.7% to 7%. Only one item, a shaft-hole axe, is made of copper with 4.3% arsenic and 4.3% lead. In order to ascertain whether these differences are accidental or significant, the Fassuṭa items will be discussed in a broader typological context, based on the comparative data presented in Table 3. For a detailed discussion of comparative MB I–II analyses and objects, see Khalil 1980 (for Jericho); Shalev and Northover 1993 (for Shillo); Shalev 2002 (for Kabri); Shalev 2007 (for Gesher); Kan-Cipor Meron 2003 (for Rishon Le-Ẓiyyon).

The Shaft-Hole Axe

The shaft-hole axe (see Gershuny and Aviam, this volume: Fig. 13:1) belongs to a large group of over 20 such items that have been found to date (Gerstenblith 1983:91; Miron 1992:71–74). Its distribution is more limited

Table 3. Comparative Data of Chemical Composition of Metal Types from Fassuta and Other Sites

Site	Fe	Co	Ni	Cu	Zn	As	Sb	Sn	Ag	Bi	Pb	Au	S	Method
Shaft-Hole Axe														
Fassuṭa F-37	0.73	tr.	0.03	90.03	tr.	4.34	0.11	0.02	0.01	n.d.	4.35	0.02	0.34	EPMA
Gesher I-62	2.27	0.03	0.37	93.71	n.d.	3.47	0.03	0.03	0.03	n.d.	0.04	0.02		EPMA
Spearhead														
Fassuṭa F-45	0.43	tr.	0.02	92.06	0.02	0.61	tr.	6.65	0.02	0.02	0.07	n.d.	0.09	EPMA
Fassuṭa F-21	0.21	0.01	n.d.	91.55	0.01	0.27	n.d.	7.68	0.02	0.01	0.13	0.05	0.06	EPMA
Gesher	0.65	0.02	0.65	94.46	n.d.	1.62	0.02	n.d.	0.08	n.d.	0.49	0.01		EPMA
Gesher	0.62	n.d.	0.11	97.22	0.01	0.74	0.03	0.01	0.09	n.d.	1.17	n.d.		EPMA
Tanged Dagger														
Fassuṭa F-46	0.24	0.02	0.06	94.75	0.01	0.46	0.02	3.68	0.05	n.d.	0.48	0.02	0.19	EPMA
Kabri K-12	0.32	0.01	0.06	72.10	0.03	0.87	0.07	8.20	0.17	n.d.	0.10	n.d.		AAS
Shillo 15091	0.15	n.d.	0.01	88.70	0.04	n.d.	tr.	10.83	0.03	tr.	0.21	tr.		EPMA
Toggle Pin														
Fassuṭa F-31	0.16	n.d.	0.05	90.73	n.d.	0.87	0.08	6.75	0.04	0.02	0.68	0.01	0.18	EPMA
Jericho 114/105	0.20	n.d.	n.d.	91.00	n.d.	n.d.	n.d.	7.50	n.d.	n.d.	n.d.	n.d.		XRF
Rishon Le-Ẓiyyon RL25	0.09	0.01	0.04	92.44	n.d.	0.20	tr.	7.07	0.02	tr.	0.08	0.02	0.03	EPMA
Ring														
Fassuṭa F-48	0.40	0.01	0.05	94.39	n.d.	0.74	0.04	3.70	0.07	tr.	0.43	0.02	0.14	EPMA
Rishon Le-Ẓiyyon 2152	0.24	n.d.	0.02	50.00	0.08	2.00	0.13	7.34	0.02	n.d.	0.13	n.d.		AAS
Jericho 81/74	0.39	0.06	0.11	91.00	0.02	4.40	0.01	1.56	0.05	tr.	0.09	n.d.		AAS

Tr. = traces; n.d. = not detected; EPMA = SEM-PROBE with Wavelength Dispersive Spectrometer than that of the duckbill-shaped axe; it extends throughout modern Israel, between Tell el-ʻAjjul in the south and Ẓefat in the north, and as far as southern Lebanon (Gubel 1986:150). Isolated items were also found at both ends of the Fertile Crescent: one in Hama in Syria (Fugman 1958:69; Pls. 20–24) and the other in Tell ed-Dabʻa in Egypt (Bietak 1968: Fig. 9–11).

The metallurgic and metallographic analysis makes it possible to reconstruct the manufacturing process of this type of axe as follows:

1. It was cast in a closed mold with a (probably ceramic) core used to produce the socket void. Fragments of a two-piece steatite mold for casting this type of axe were found in Megiddo, Byblos (Miron 1987:68, Fig. 5), and Tell ed-Dabʻa (Philip 1995:71). The mold was made of two slabs of steatite that were connected by means of at least two holes. The casting sprue was conical in shape and was next to the edge of the blade, like that present in similar molds of the duckbill-shaped axe (Miron 1992:52). It is possible to cast metal in this kind of stone mold, but the duration of the mold would be rather short due to the thermal shocks and burning during consecutive castings. Therefore, the steatite mold could have been used for casting wax models that were later encased in clay, which after heating became disposable. This method would make it easier to cast the axe with the socket hole. Connecting and fashioning the core in the hollow situated across the width of the stone mold requires a great deal of expertise. However, on a model made of wax, it is quite easy to carve the socket hole and fill it afterwards with clay as part of the same overall clay investment and not as a separate core that needs to be connected and adjusted during each operation, as in a double stone mold.

2. After the casting had cooled, the mold was opened (if a stone was used) or broken (if a clay investment was used) and the metal axe was removed from it. The metal cone that filled the sprue opening of the casting was detached from the front of the blade and saved to be re-melted. The surface of the axe was polished and then heated and hammered, especially in the area of the blade, in order to achieve a higher degree of hardness. The annealing temperature of the item from Fassuṭa did not reach 600°C, and therefore, the metal was not completely homogenized. Consequently, micro-coring is discernable in the metallographic examination of the metal's micro-structure.

3. A wooded stick for the handle was inserted into the axe socket after the manufacturing process was completed. In several cases, metal nails that were apparently used to secure the axe to the handle were preserved along the width of the top of the socket (e.g., Philip 1995: Figs. 1, 2). No nails were found on the item from Fassuṭa.

To date, all chemical analyses of this type of axe have indicated the use of tin-bronze metal composition of 14%–15% tin, with up to 9% lead (Guy 1938:161; Birmingham 1977:115; Philip 1991:94; Rosenfeld, Ilani and Dvorachek 1997: Table 1: 93/15). In contrast, the shaft-hole axe from Fassuṭa, like the one from Gesher (Shalev 2007: Table 7.3:4), was made of arsenic copper (4.34% As), with lead (4.35% Pb), without tin, and it is thus a continuation of a local tradition (Shalev 1988). Tests for hardness of similar items (Branigan, McKerrell and Tylecote 1976:18) indicate that the arsenic alloy in those instances does not fall short in its quality from that of the tin-bronze.

A large amount of lead (between 4% and 6%) was found in many of the items belonging to this type, as well as in the duckbill-shaped axes (Shalev 2000:281; 2002:310–311). This is without doubt an intentional addition, both to the axes made of tin-bronze and those made of arsenic copper. In laboratory tests conducted by J.P. Northover in the Materials Department at Oxford University, it was found that despite lead's property of complete segregation during the crystallization of the cast metal, its addition does have an effect on the metal. For example, an addition of up to 2% Pb significantly reduces the viscosity level of copper with 10% Sn. An amount of lead greater than this does not significantly influence the viscosity level of the metal. However, up to 12% addition of Pb does not at all impair the forging capability and level of hardness of the bronze. It is interesting to note that in the Middle Bronze Age, levels of lead at 4% or more are only found in this type of axe and in the duckbill-shaped axe. Hence, it can be concluded that lead was intentionally added to ease the relatively thick casts whose forging after casting was relatively limited to the blade tip area.

The Tanged Dagger

The tanged dagger from Fassuṭa (see Gershuny and Aviam, this volume: Fig. 13:2) was made of bronze with a substantially less amount of tin (Sn 3.7%) than that detected in the socketed spearheads described below. Judging by its shape, the dagger was used for slicing and not stabbing, as evidenced by the width of the blade, its thickness and the rounded blunt tip. It belongs to a group of daggers that are similar in shape and varied in their dimensions. This type is known especially from tombs dating to the latter part of the Middle Bronze Age (MB IIB) at Kabri, Afeq, Tel Lakhish and Tell el-ʻAjjul (Shalev 2002:311). These daggers reflect a simple, local manufacturing tradition that mainly utilized scraps of discarded and/or broken metal pieces that were remelted, without the ability or an attempt to maintain a consistent level of alloy. The dagger from Fassuṭa was probably cast, like the rest of these items, in an open mold and afterward underwent cycles of annealing and intensive hammering.

The Socketed Spearheads

The two socketed spearheads from Fassuṭa (see Gershuny and Aviam, this volume: Fig. 13:3, 4) also belong to a large group of items that are well-known in the Middle Bronze Age in Israel. Their distribution is similar to that of both the duckbill-shaped and the thin axes (Gerstenblith 1983:91–92). The metallic composition of these two items is almost identical and it is similar to other spearheads from Megiddo and Afeq (Guy 1938:161; Shalev 2000:283). Both were produced from medium tin-bronze (6.7%–7.7% Sn), without lead, and contain small amounts of arsenic and iron present as impurities. In MB II, socketed spearheads were also made of copper containing small amounts of arsenic (up to 1.6% As, and up to 1.5% Pb). The typological and metallurgic analysis of the items from Fassuṭa, along with the metallographic analysis of similar items from Gesher (Shalev 2007), allows us to propose a possible reconstruction of the manufacturing process. This process would appear to have been essentially similar to that described by Guy (1938:164) and replicated in an experiment recreating the production of socketed points (Buchholz and Drescher 1987:47, Fig. 7).

1. The spearhead was probably cast, like the axe, in a closed mold, with a core to form the socket void, although no mold fragments for a spearhead have been found. The mold could have been made of clay, invested around a wax model or any other flammable or perishable material. The conical sprue through which the liquid metal was poured was probably connected to the tip of the blade.

2. After removing the casting from the mold and detaching the casting sprue, the spearhead was completely homogenized by reheating to a temperature that exceeded 600°C and afterward underwent intensive hammering and annealing. The blade underwent final hammering, which reduced its original thickness by more than one third. As a result of this, the degree of hardness at the end of the blade was at least twice as much as that of the socket area. Final cold work is visible in the metallography of the blade from Gesher (Shalev 2007), probably aimed at obtaining an effective blade hardness higher then 115Hv (i.e., Shalev 1996:13). This left the socket in a much softer state than the blade, without any signs of final hammering, probably in order to facilitate a tight connection to the wooden handle, which was fastened by means of a thin rope, the remains of which are still visible on the socket of the long spear from Gesher (Garfinkel and Bonfil 1990:140–141).

The Toggle Pin

The toggle pin from Fassuṭa (see Gershuny and Aviam, this volume: Fig. 13:5) was made of bronze with an amount of tin similar to that used to produce the socketed spearheads, but with a slightly higher level of arsenic and lead impurities. Reconstruction of the production process of these toggle pins, as well as their typology and use, have been intensively discussed (i.e., Kan-Cipor Meron 2003:57–62). The pin from Fassuṭa, like similar toggle pins from Jericho (Khalil 1980:134–135) and Rishon Le-Ẓiyyon (Kan-Cipor Meron 2003:58–59; RL25, RL26 in Tables 5–9), underwent intense hammering and annealing after being cast. The metallography of the Fassuṭa toggle pin, as with an example in the Rishon Le-Ẓiyyon cemetery (Kan-Cipor Meron 2003: RL25), shows overheating during the annealing process, still preserved in the core of the pin, and final hammering, which affected mainly the pin surface, reaching there a hardness of 188Hv. While this item was being worked, a decorated bead was added, which served as a thickened head for the pin. X-ray photographs of a similar item from Jericho (Khalil 1980: Pls. 56, 57) clearly show that the head of the pin was cast separately and secured to the body by hammering the end of the pin.

The Ring

The simple ring (see Gershuny and Aviam, this volume: Fig. 13:6) is also made of tin-bronze, like most of the other metal items. The amount of tin measured (3.7%) is identical to that detected in the dagger. The impurities (such as arsenic and lead in relatively low levels of c. 0.5%) are detected in the dagger described above, as well as in the toggle pin. Most of the MB II rings and earrings that have been examined to date from Rishon Le-Ẓiyyon (Kan-Cipor Miron 2003:102) and from Jericho (Khalil 1980:123–124) were also made of tin-bronze. The amount of arsenic detected in these items ranges between 0.5% (like in the ring from Fassuṭa) to as much as 4.4% (in the ring from Jericho). A metallographic examination of the ring from Fassuṭa also indicates intense hammering and annealing after the casting, and thus it can be assumed that the production process was to a large extent similar to that of the toggle pin.

CONCLUSIONS

In conclusion, it can be said that the metallurgical profiles of the group of six metal objects from Fassuṭa Tomb 1 well fit the accumulated knowledge of archaeometallurgy of MB I (also termed MB IIA). The archaeological context and dating of the material from Fassuṭa (the end of MB I and the beginning of MB II) demonstrate a similarity between the type of objects that are made of tin-bronze (sometimes with lead) or arsenical copper (sometimes with lead as well) and the metals from Tell ed-Dab‘a (Philip 2006). Despite the fact that most of the items, including those that were produced from scrap pieces of recycled metal, contain not less than 3.7% tin, there are still objects that continue the long tradition of the Intermediate Bronze Age of alloying copper with arsenic. All of the metal artifacts, with the exception of the shaft-hole axe, were made with a similar technique from the same kind of raw material. The relatively high level of impurities and the high variability in the amount of tin may be indicative of recycling metal as the primary raw material. The shaft-hole axe is typologically earlier than the rest of the items and was produced from different material. Despite the fact that it was made of copper arsenic, the addition of lead, and the manner in which it was worked after casting, indicate a very close similarity between it and the same axes that were made of tin-bronze.

The overall geographic and chronological distribution patterns of metals during the Middle Bronze Age in the Ancient Near East is a broad research topic that needs to combine the results from all analyzed sites into a meaningful synthesis (Shalev, forthcoming).

NOTES

[1] The artifacts were analyzed at the Department of Materials at Oxford University, with the help of Dr. J.P. Northover. For a technical description of the measuring method and the sensitivity limits regarding each one of the elements, see Shalev and Northover 1993.

[2] This period is also termed MBIIa–b, (e.g., Bunimovitz 2000, Garfinkel and Cohen 2007, and see also Gershuny and Aviam, this volume: n. 2.

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