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Bronze Jewellery from the Early Iron Age urn-field in Mała Kępa. An approach to casting technology

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Abstract

This study characterizes the bronze jewellery recovered from the Lusatian culture urn-field in Mała Kępa (Chełmno land, Poland). Among many common ornaments (e.g. necklaces, rings, pins) the ones giving evidence of a steppe-styled inspiration (nail earrings) were also identified. With the dendritic microstructures revealed, the nail earrings prove the implementing of a lost-wax casting method, whereas some of the castings were further subjected to metalworking. The elemental composition indicates the application of two main types of bronze alloys: Cu-Sn and Cu-Sn-Pb. It has been established that the Lusatian metalworkers were familiar with re-melting the scrap bronze and made themselves capable of roasting the sulphide-rich ores.

The collection from Mała Kępa has been described in terms of its structure and composition. The investigations were made by means of the energy dispersive X-ray fluorescence spectroscopy (ED-XRF), scanning electron microscopy (SEM) coupled with an energy dispersive X - ray analysis system (EDS) and optical microscopy (OM). In order to fingerprint an alloy profile of the castings with a special emphasis on the nail earrings, the data-set (ED-XRF, EDS) was statistically evaluated using multidimensional analyses (FA, DA).

Keywords: Non-Destructive Testing, Investment casting, X-ray fluorescence spectroscopy, Archaeometallurgy, Lusatian culture

1. Introduction

During excavations made between 1956-1958 by the Toruń District Museum at site 1 in Mała Kępa (Dąbrowa Chełmińska commune, Bydgoszcz county) the Early Iron Age cemetery of the Chełmno group society of the Lusatian culture was recovered. It has been preserved in a form of an urn-field with 122 cremation graves. Besides numerous ceramic vessels, metal artefacts giving evidence of bronze valorisation manifested as grave offerings (e.g. necklaces, rings, pins) were also identified. According to the archaeological data obtained so far, the urn-field in Mała Kępa was established around 900BC and was used for over 450 years (Ha B1/B2 - Ha D3) [1, 2].

The jewellery investigated here was manufactured by two techniques: (1) the investment casting method and (2) a plastic working. Since the Lusatian metalworkers were fully aware of the alloying limitations, they applied the plastic working as a deliberate treatment for improving mechanical properties of the castings (e.g. necklaces), while the lost-wax method was used rather to cast small objects (e.g. nail earrings) and those more advanced in shape, like decorative pendants [3-8].

2. Materials and methods

2.1. Materials

As the funeral rite practiced by the Chełmno group of the Lusatian culture required burning the dead member body together with the grave offerings, the majority of artefacts investigated here is thermally deformed and defragmented (Fig. 1). Among numerous body ornaments (e.g. earrings, necklaces) including items of clothing (e.g. pins), the ones preserved in unrecognizable form (e.g. wire, lumps) were also selected.

Fig. 1. The investigated collection (by courtesy of the Toruń District Museum)

2.2. Methods

The elemental composition was established by means of the X-ray fluorescence spectrometry with energy dispersive X-ray fluorescence (ED-XRF) spectrometer Spectro Midex equipped with a molybdenum X-ray lamp of an excitation energy of 44.6kV and a Si Drift Detector (SDD) with a resolution of 150eV. For the nail earrings the elemental composition was completed by the SEM-EDX investigations using a SEM microscope Hitachi S 3400N equipped with the EDS spectrometer by Thermo Noran. The mechanical removal of the corrosion products (reaching the metallic core level) followed by surface degreasing using acetone were prior to the ED-XRF investigations.

The microstructure of the nail earrings was observed with a Nikon Eclipse LV150 optical microscopy (OM) equipped with a Nikon Digital Sight DsFi1 microscopic camera and it was completed by the SEM investigations.

The macrostructure observations were made using a Nikon SMZ 745Z stereoscopic microscope (OM) equipped with the Nikon Digital Sight DsFi1 microscopic camera.

3. Results

The results were divided with a special emphasis on the nail earrings and necklaces. The rest of the artefacts were taken as a comparative background and therefore discussed in further parts of this work. The averaged and normalized results of the elemental composition determined for the jewellery, including 39 artefacts (ED-XRF) are summarized in Table1.

3.1. Nail earrings

While the MaKa_27 is preserved almost in a full form, the MaKa_28 underwent strong defragmentation and lost its original circle-like shape (Fig. 2). The nail earrings do not, however exhibit many surface casting defects (e.g. blows or drops) what could be due to the proper pattern design and casting practice.

Fig. 2. The nail earrings with reconstruction of an original form

The nail earrings were cast in tin-bronze. In fact, the castings contain the levels of tin (7.2wt% and 13wt%) suggesting that the alloys could have been kept in their as-cast condition [9].

When looking at the macrostructure of the nail earrings, it is almost evident that such ornaments could be manufactured only using a lost-wax casting method. With dendrites and well-developed grain boundaries (partially degraded by corrosion), the microstructures are typical for the cast structures (Fig. 3, 4). Moreover, the large and hexagonal grains are indicative of slight forging followed by annealing.

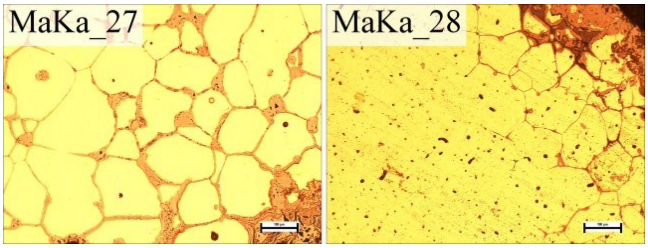

Fig. 3. The OM images of the nail earrings microstructure

The nail earrings exhibit a dendritic α-phase containing tin dendrites forming a solid solution with copper. Whereas the inclusions brought to the MaKa_28 by Pb were captured in the interdendritic phase and appear white, no significant inclusions can be found in the MaKa_27 matrix (Fig. 4, Table 2).

The high amounts of iron (22wt%) and sulphur (22wt%) in the EDS microareas of the MaKa_28 should be noticed. While the elements such as Ag, As and Sb tend to agglomerate as impurities on the grain boundaries, Fe, Pb and S usually form $Cu_{2-x}Fe_xS$-inclusions in the tin–bronze matrix [10]. It is commonly assumed that copper containing sulphur was produced by the smelting of chalcopyrite ore [9] and therefore it is likely that sulphide-rich ore was used to manufacture the MaKa_28 nail earring.

Table 1.
The elemental composition (wt%) of the jewellery by means of ED-XRF

Signature	*Artefact*	*Grave no*	Fe	Co	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb	Bi
MaKa_1	*Necklace*	*20*	0.086	0.056	0.42	92	0.14	0.48	0.62	5.0	0.95	0.030	0.070
MaKa_2	*Necklace*	*95*	0.042	0.065	0.23	88	0.13	0.31	0.17	10	0.38	0.88	0.025
MaKa_3	*Necklace*	*102*	0.088	0.072	0.23	88	0.13	0.36	0.16	10	0.35	0.85	0.037
MaKa_4	*Pin*	*89*	0.21	0.061	0.17	87	0.13	0.12	0.083	7.9	0.093	4.3	0.28
MaKa_5	*Rod coil*	*89*	0.15	0.091	0.10	87	0.12	0.19	< 0.020	12	< 0.051	0.28	0.021
MaKa_6	*Necklace*	*89*	0.056	0.059	0.14	91	0.12	0.15	0.14	4.7	0.094	3.3	0.37
MaKa_7	*Lump*	*89*	0.84	0.088	0.15	79	0.16	0.37	0.15	8.5	0.23	10	0.66
MaKa_8	*Earring*	*89*	0.084	0.080	0.079	86	0.13	0.26	< 0.020	13	< 0.051	0.083	0.015
MaKa_9	*Earring*	*89*	0.077	0.075	0.081	87	0.12	0.24	0.025	12	< 0.051	0.062	0.023
MaKa_10	*Earring*	*89*	0.19	0.073	0.24	87	0.12	0.23	0.10	10	0.15	2.1	0.079
MaKa_11	*Earring*	*89*	0.067	0.099	0.24	87	0.12	0.30	0.12	10	0.18	1.6	0.31
MaKa_12	*Earring*	*89*	0.090	0.072	0.084	87	0.13	0.24	0.023	12	< 0.051	0.12	0.023
MaKa_13	*Earring*	*89*	0.072	0.087	0.10	87	0.16	0.30	< 0.020	11	< 0.051	0.98	0.011
MaKa_14	*Earring*	*89*	0.32	0.11	0.12	84	0.18	0.24	< 0.020	12	< 0.051	3.4	0.033
MaKa_15	*Earring*	*89*	0.21	0.080	0.077	82	0.11	0.36	0.041	16	< 0.051	0.39	0.035
MaKa_16	*Earring*	*89*	0.48	0.056	0.27	90	0.13	0.43	1.4	3.5	2.2	1.3	0.034
MaKa_17	*Earring*	*89*	0.17	0.075	0.062	88	0.15	0.23	0.082	11	< 0.051	0.30	0.039
MaKa_18	*Earring*	*89*	0.20	0.071	0.10	89	0.13	0.37	0.027	10	< 0.051	0.27	0.042
MaKa_19	*Necklace*	*80*	0.11	0.066	0.34	88	0.12	0.053	0.034	11	< 0.051	0.058	0.010
MaKa_20	*Pin*	*80*	0.080	0.062	0.20	92	0.13	0.33	0.18	6.4	0.52	0.36	0.021
MaKa_21	*Ring*	*38*	0.36	0.11	0.34	70	0.17	1.7	0.26	22	1.2	4.0	0.13
MaKa_22	*Ring*	*38*	0.013	0.077	0.16	92	0.18	0.99	0.17	5.2	0.63	0.78	0.028
MaKa_23	*Pin*	*78*	0.037	0.058	0.10	89	0.12	0.051	0.085	10	0.064	0.29	0.080
MaKa_24	*Plate*	*84*	0.041	0.064	0.52	93	0.12	0.36	0.50	3.8	1.4	0.27	0.015
MaKa_25	*Salta leone*	*103*	0.068	0.070	0.36	82	0.12	0.61	0.10	16	< 0.051	0.82	0.24
MaKa_26	*Earring*	*40*	0.10	0.056	0.20	98	0.11	0.041	0.35	0.28	0.98	< 0.020	0.0056
MaKa_27	*Nail earring*	*95*	0.12	0.096	0.25	91	0.12	0.35	0.071	7.2	0.13	0.18	0.037
MaKa_28	*Nail earring*	*95*	0.21	0.10	0.39	84	0.17	0.28	0.37	13	0.65	1.0	0.032
MaKa_29	*Wire*	*95*	0.053	0.074	0.26	90	0.13	0.30	0.18	8.0	0.44	0.42	0.022
MaKa_30	*Bracelet*	*91*	0.060	0.087	0.17	89	0.13	0.12	0.090	10	0.052	0.71	0.11
MaKa_31	*Bracelet*	*91*	0.056	0.069	0.19	89	0.12	0.20	0.090	9.2	0.14	0.42	0.062
MaKa_32	*Bracelet*	*91*	0.15	0.086	0.20	86	0.11	0.20	0.078	12	< 0.051	0.65	0.12
MaKa_33	*Band*	*91*	0.25	0.067	0.16	90	0.13	0.17	0.11	6.9	0.11	2.1	0.047
MaKa_34	*Plate*	*96*	0.047	0.054	0.43	94	0.11	0.97	1.4	1.3	1.6	0.33	0.020
MaKa_35	*Plate*	*96*	0.36	0.067	0.68	91	0.17	2.1	1.1	1.6	2.6	0.26	0.067
MaKa_36	*Plate*	*96*	0.057	0.071	0.40	95	0.12	0.46	0.93	1.4	1.4	0.070	0.036
MaKa_37	*Lump*	*72*	0.30	0.070	0.11	77	0.12	0.13	0.10	22	< 0.051	< 0.020	0.011
MaKa_38	*Lump*	*72*	0.056	0.096	0.16	85	0.13	0.40	0.11	11	0.22	3.0	0.16
MaKa_39	*Lump*	*72*	0.25	0.069	0.10	80	0.13	0.17	0.086	19	< 0.051	< 0.020	0.016

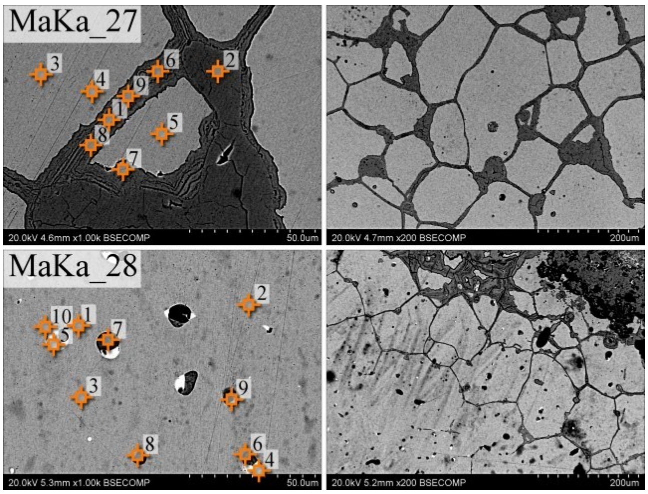

Fig. 4. The SEM images of the nail earrings microstructure with the EDS microareas spots

Table 2.
The elemental composition (wt%) of the nail earrings by means of SEM-EDS

Microarea	O	S	Fe	Cu	Sn	Pb
MaKa_27 (1)	14	...	...	86	...	...
MaKa_27 (2)	13	...	...	87	...	...
MaKa_27 (3)	...	...	...	95	5.0	...
MaKa_27 (4)	...	...	...	95	5.0	...
MaKa_27 (5)	...	...	...	94	6.0	...
MaKa_27 (6)	15	...	...	82	3.0	...
MaKa_27 (7)	16	...	...	78	6.0	...
MaKa_27 (8)	15	...	...	78	7.0	...
MaKa_27 (9)	16	...	...	76	8.0	...
MaKa_28 (1)	...	...	...	92	8.0	...
MaKa_28 (2)	...	...	...	91	9.0	...
MaKa_28 (3)	...	...	...	90	10	...
MaKa_28 (4)	...	...	...	8.0	...	92
MaKa_28 (5)	...	...	...	5.0	...	95
MaKa_28 (6)	...	22	22	76	...	...
MaKa_28 (7)	...	22	3.0	75	...	...
MaKa_28 (8)	...	22	3.0	75	...	...
MaKa_28 (9)	8.0	...	...	12	...	80
MaKa_28 (10)	3.0	...	...	7.0	...	90

The microstructures observed on cross-sections are coherent and indicative of implementing a 3-step manufacturing process: (1) casting by a lost-wax method followed by (2) annealing and finished with (3) slight forging to a final shape.

3.2. Necklaces

The necklaces belong to the same typological category of the band ornaments and are indicative of Ha D (Fig. 5). This category tends to concentrate in the Upper and Middle Odra and Warta basins reaching the regions of Cuyavia and Eastern Pomerania.

Fig. 5. The necklaces MaKa_1-3 with close-up on the decoration

While the MaKa_1-3 and MaKa_19 were cast in tin-bronze, the MaKa_6 was made in tin-lead-bronze. A suggestive indication for the casting use lies in the numerous inclusions brought to the alloys. Thus it can be assumed that the bronze in-use had been molten and relatively rapidly solidified [11].

The macrostructures are indicative of implementing an intense metalworking. With no visible casting seams left on their surfaces, the necklaces are suggestive of using a lost-wax casting method prior to the plastic working.

In conclusion, an identical *chaîne opératoire* was applied during manufacturing all the necklaces: (1) casting of a square in a cross-section rod using a lost-wax method, (2) elongating the rod by hammering and annealing with potential water quenching in order to avoid brittle phases, (3) one-way twisting the rod around its own axis followed by (4) forming the circle-shaped ears at the flattened endings and finished with (5) [10].

4. Discussion

Since long-term tradition of emphasizing the cremation funerary rite by the Chełmno group society required the grave offerings to be combusted with a corpse before burial act was done (Fig. 6a), the majority of jewellery recovered from the urn-field in Mała Kępa did not resist high-temperature corrosion. In general, this type of damage tends to spread equally into the entire surface of the metal to form a final corrosion layer (usually of uniform thickness) with mill-scale and intergranular products. It can be seen from Fig. 6b that after exposed at high-temperature atmosphere, the mill-scale formed on the outer surface of the MaKa_27. It can also be seen in Fig. 6b that intergranular corrosion products accumulated alongside grain boundaries of the artifact. The intergranular corrosion led to a significant reduction in tensile strength and ductility of the metal whereas the mill-scale brought to the MaKa_27 by high-temperature corrosion reduced the aesthetic quality of the artifact, which in fact is desirable in the case of exhibition and presentation purposes.

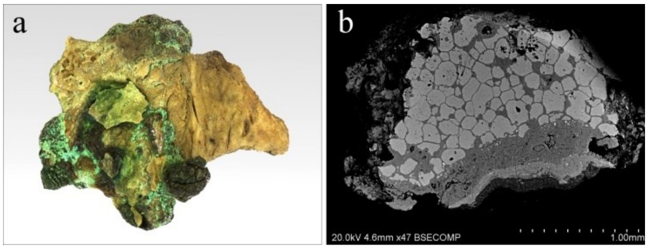

Fig. 6. a) Cremated human bone with incorporated bronze drops b) Mill-scale formed on the MaKa_27 with visible intergranular corrosion products

The elemental composition results lead to the conclusion that the jewellery from the urn-field in Mała Kępa had been cast with the emphasis on tin- and tin-lead-based bronzes (Table 3). The alloys contained numerous impurities of Ni, As, Ag and Sb and thereby impacting the technological properties.

Table 3.
The characteristics of the alloys

Alloy			
Type	%	*Class*	%
Cu	8	*N/A*	8
Cu-Sn	64	*Binary*	64
Cu-Sn-Pb	22		
Cu-Sn-Sb	3	*Ternary*	28
Cu-Sb-As	3		

Interestingly, some of the artefacts have reached relatively low-tin levels of less than 2wt% Sn (MaKa_26 and MaKa_33-35) suggesting that bronzes in-use had been recycled [9].

It is only 2wt% Pb that is required for optimal casting fluidity, however more than 2wt% has been noticed in several alloy profiles (i.e. MaKa_4, MaKa_6-7, MaKa_21). Although lead improves fluidity and castability, it also brings a deleterious effect to the ductility of the alloys [9]. Nevertheless it was probably an additive used by the Lusatian metalworkers not for economic but rather technological reasons. This, indeed, is the case of the Chełmno group metalworkers where lead-contaminated alloys become common, alongside mainstreamed tin-bronzes [6, 8].

In order to fingerprint the alloy profile of the nail earrings, the EDS data-set (Table 2) was statistically evaluated using a factor analysis (FA) with a maximum likelihood (ML) extraction method completed by a Varimax rotation with two factors to include in a model. All available elements (O, S, Fe, Cu, Sn and Pb) were used to determine the FA model.

The first factor determined by Cu, Sn and Pb impacts a significant intergroup diversity within the Pb inclusions (captured in the MaKa_28 Cu-matrix) and the remaining EDS microareas (Fig. 7), which in fact tend to share the FA space generated by the first factor (α-Cu solution, α-Cu-Sn eutectic and

Cu-sulphides). Correlated strongly with the second factor, S and Fe clearly separated the MaKa_28 Cu-sulphides. It may be explained by using the sulphide-rich ore to manufacture the MaKa_28 nail earring, as it has been already suggested.

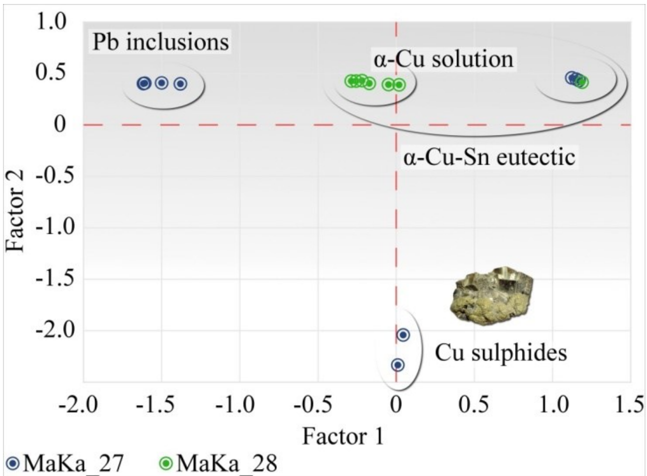

Fig. 7. The FA projection of the nail earrings EDS microareas

As the sulphide-rich ores cannot be reduced directly but need to be oxidized, then it became essential for the Lusatian metalworkers to implement roasting prior to smelting. The roasting had taken place at about 350°C in an oxidizing atmosphere and thereby the resulting ore was partially oxidized and desulphurised [9, 11, 12]. This is in agreement with the presence of sulphur inclusions and above-average iron weight fractions (0.21wt%) in the alloy profile of the MaKa_28.

After being cast, the castings underwent annealing cycles improving their ductility and thereby enabling further plastic deformation [9]. Both the nail earrings were manufactured according to the same technological process, using a similar tin-bronze alloy and final shaping by the process of slight forging.

In the case of the MaKa_2 and MaKa_3 alloy profiles, the distribution of the minor and trace elements is fairly uniform (Fig. 8). The values of a relevant standard deviation (RSD) lend unequivocal support to these observations. Obviously, the necklaces were made with the same *chaîne opératoire* using consistent tin-bronze alloy and final shaping with intense forging, as may be expected if they were worked together in the same casting workshop. This, indeed, reflects the cultural changes initiated during HaD in Central Europe by the Northern Barbarians practicing their own and original style of bronze manufacturing [13].

Both necklaces contain relatively low amounts of arsenic and antimony (0.31wt% - 0.38wt%) with the total sum of impurities averaging 2wt%. Since two cycles of re-melting and hot-working in air can impact the loss of As and Sb content until less than 1wt% is left, it is likely that re-melting of scrap bronze and subsequent smelting could have been indeed applied here [11].
Furthermore, evaluating the ornaments by means of a discriminant analysis (DA) with regard to the level of the implemented plastic forming yields some interesting conclusions. Based on the macrostructural observations the ornaments used here have been arbitrally classified into two groups (weak or intense plastic working). The DA model was dedicated to the artefacts preserved in a well-distinguishable form and it was determined using all avaible elements (ED-XRF), excluding Cu. A greater tendency shared by the ornaments treated with intense plastic forming to contain relatively higher amounts of iron and cobalt is responsible for the significant (Wilk's lambda Λ_W=0.03) intergroup discrimination (Fig. 9).

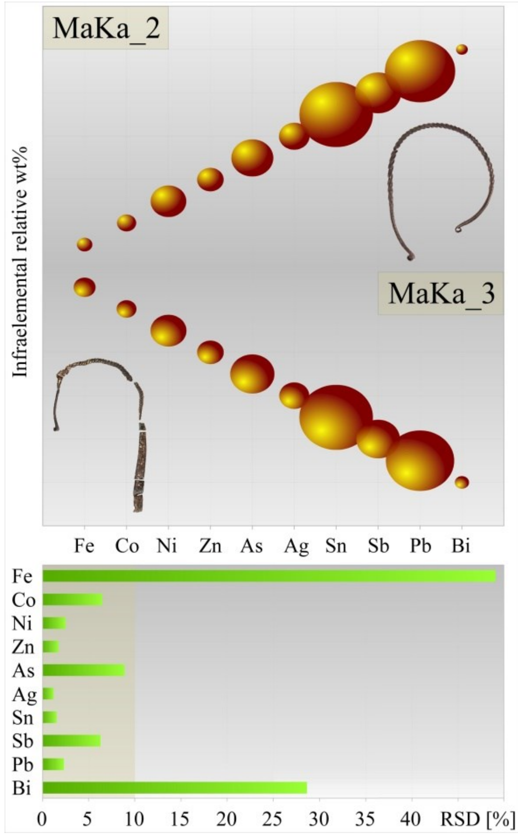

Fig. 8. The alloy profiles of necklaces MaKa_2 and MaKa_3 with corresponding values of RSD (Sn content given as Sn·10^{-1}wt%)

Therefore, taking into account the manner the ornaments were formed, it is almost certain that the smelting process had impact on the differences in the iron content. Cobalt, having both provenance and technology marking potential, may have also contributed to the intergroup discrimination apparent in the DA scatterplot [12, 14]. While the ornaments where intense metalworking was implemented average Fe around 0.08wt% (with Co about 0.06wt%), the Fe content in those which underwent weak plastic forming amounts to approximately 0.2wt% (with Co about 0.1wt%).

This points to the alloying technology approaches taken by the Lusatian metalworkers, one that suggests implementing short refining process and the other with the more sophisticated process involving slagging off [14]. It must also be stressed here that the first scenario is in a good relation to the necklaces cast in re-melted scrap bronze (MaKa_2 and MaKa_3), while the second is in agreement with the sulphide-rich ore used for manufacturing the MaKa_28.

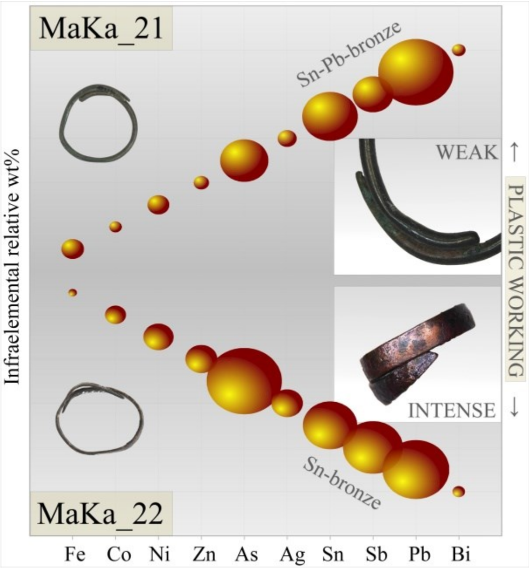

Fig. 9. The DA scatterplot related to level of the plastic working

The macrostructure of the MaKa_21 and MaKa_22 suggests that both rings were made with different *chaîne opératoire*. The DA model (Fig. 9) and alloy profiles (Fig. 10) lend strong support to this observation. While the MaKa_21 was manufactured from a rod cast in tin-lead bronze alloy, the MaKa_22 was made using a tin-bronze ingot and it does seem like it was the the final shape that determined the Sn and Pb content in the bronze alloys. For the MaKa_21 being regular in a cross-section alongside all its length and it became essential for the Lusatian metalworkers to improve the fluidity and castability of the casting (Sn=22wt% and Pb=4.0wt%), whereas the MaKa_22 was intended to intense plastic working and thereby it was cast in well-ductile tin-bronze (Sn=5.2wt% and Pb=0.78wt%). This gave rise to conception that the Chełmno group metalworkers could have been fully aware of the advantages (fluidity and castability) and disadvantages (ductility) of alloying the tin-lead bronze. It is symptomatic that the band ornaments recovered from the casting workshop in Kamieniec render such conception even more likely [6, 8]. It is meaningful that both rings were deposited into grave no 38 within the oldest zone of the urn-field in Mała Kępa (with open-ring-like grave agglomeration) and thus it is almost evident that the Chełmno group metalworkers were familiar with such metallurgical know-how during the Late Bronze Age already.

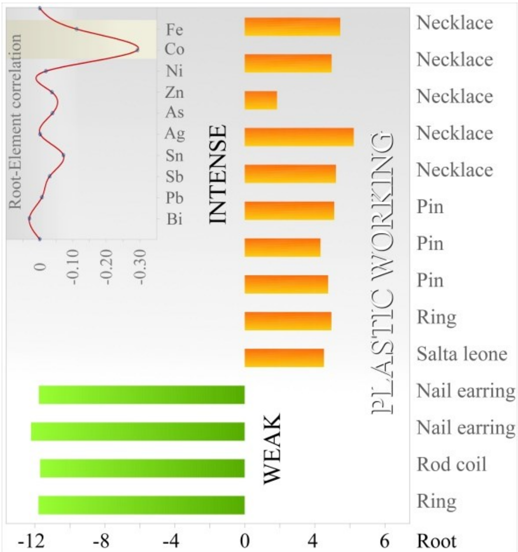

Fig. 10. The alloy profiles of rings MaKa_21 and MaKa_22 with close-up on the castings (Sn content given as Sn·10^{-1}wt%)

A comparison of alloy profiles of the nail earrings recovered from the Cuyavia-Chełmno land region (Table 4) brings out an interesting point about the provenance of this ornaments. So far, nine nail earrings have been recorded in the northern province of the Lusatian culture (Mała Kępa, Krusza Podlotowa, Kolonia Dębice, Brześć Kujawski and Gustorzyn).

Table 4.
The elemental composition (wt%) of the nail earrings from the Cuyavia-Chełmno land region [18-21] as amended

Site	*Type*	Fe	Co	Ni	Cu	Zn	As	Ag	Sn	Sb	Pb	Bi	Ag/Ni	Co/Ni	Ni/Zn	Ag/Sb	Ag/Pb	Sb/Pb	Co/Bi
Mała Kępa	*IIc*	0.12	0.096	0.25	91	0.12	0.35	0.071	7.2	0.13	0.18	0.037	**0.3**	**0.4**	**2**	**0.5**	**0.4**	**0.7**	**3**
Mała Kępa	*IIc*	0.21	0.10	0.39	84	0.17	0.28	0.37	13	0.65	1.0	0.032	**1**	**0.3**	**2**	**0.6**	**0.4**	**0.7**	**3**
Krusza Podlotowa[*]	*IIc*	0.12	0.052	0.08	90	*N/A*	0.15	0.085	9.0	0.07	0.47	0.052	**1**	**0.7**	*N/A*	**1**	**0.2**	**0.1**	**2**
Brześć Kujawski	*Sokolniki B*	0.43	0.000	0.11	83	0.60	0.000	0.000	14	0.18	0.000	0.000	**0.00**	**0.00**	**0.2**	**0.00**	…	…	…
Gustorzyn	*Sokolniki B*	0.39	0.000	0.23	91	0.63	0.000	0.000	6.7	0.000	0.22	0.000	**0.00**	**0.00**	**0.4**	…	**0.00**	**0.00**	…
Gustorzyn	*Sokolniki B*	0.27	0.000	0.29	79	0.67	0.000	0.000	18	0.000	0.94	0.000	**0.00**	**0.00**	**0.4**	…	**0.00**	**0.00**	…
Gustorzyn	*Sokolniki B*	0.53	0.000	0.26	79	0.66	0.000	0.000	18	0.000	0.000	0.000	**0.00**	**0.00**	**0.4**	…	…	…	…
Gustorzyn	*Sokolniki B*	0.20	0.000	0.31	91	0.85	0.000	0.000	7.2	0.080	0.35	0.000	**0.00**	**0.00**	**0.4**	**0.00**	**0.00**	**0.00**	…

[*]The alloy profile of the nail earring from Krusza Podlotowa is completed by Au (Au=0.038wt%)

Except the findings from Kolonia Dębice (single find) and Krusza Podlotowa (unclear context) the other nail earrings are of confirmed context and associated with the burial (Mała Kępa and Gustorzyn) and settlement (Brześć Kujawski) deposition.

A deeper look at the alloy profiles may reveal some meaningful differentiation between the IIc type nail earrings and those of the Sokolniki B type. It is remarkable that the profile of the Sokolniki B type seem to bear a pattern of fresh bronze alloy. Moreover, the copper used for alloying the nail earrings from Brześć Kujawski and Gustorzyn does not present any impurities of Co, As, Ag and Bi (and also Sb in general), while the profiles for Mała Kępa and Krusza Podlotowa are completed by significant amounts of these elements. Hence, the alloy profile of the Sokolniki B may be considered rather as a foreign pattern. This striking differentiation brings the possible metallurgical provenance of the nail earrings recovered from the Cuyavia-Chełmno land region. While the IIc type seem as a local product of the Tarnobrzeg culture, the Sokolniki B type is commonly connected with the workshops of the Milograd culture [19, 22]. The clay moulds destructs recovered from the casting workshop in Zawada (Tarnobrzeg county) render such possibility even more likely [17]. Although the moulds destructs are not compatible with IIc type it is a distribution of the IIc type (Fig. 11) that suggesting its true origin. What is symptomatic, the Brześć Kujawski type pottery is associated with the nail earring findings from Brześć Kujawski and Gustorzyn but it is not surprising when taking into account that this type of pottery is thought to be originated from the Forest-Steppe zone [18, 19].

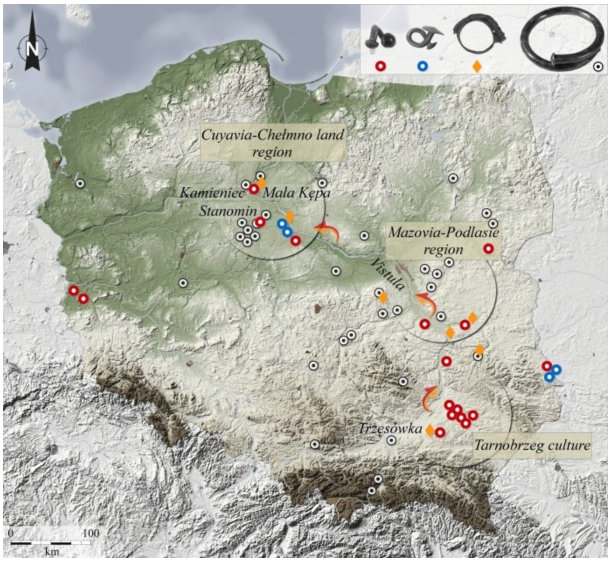

Fig. 11. Map of distribution the nail earrings of IIc (⭘) and Sokolniki B type (⭘) with Trzęsówka type rod coils (♦) and classic Stanomin anklets (⦿) [19, 22] as amended

Despite some differences (especially brought by the presence of Au), the similarity between alloy profiles of the nail earrings from Krusza Podlotowa and Mała Kępa can still be meaningful. Also worth mentioning is that some Au amounts are quite frequently observed in so-called Stanomin anklets [20] which are in fact considered to be the intermediate goods. If indeed, a model concerning the south-eastern redistribution of the Stanomin anklets by the Mazovia-Podlasie societies is still to be uphold then it is possible that at least some of the IIc nail earrings may have been manufactured in the workshops of the Tarnobrzeg culture using metal source originated from Cuyavia and were further distributed to the North. Interestingly, this model is in a good relation to findings of the Trzęsówka type rod coil ornaments recovered from the Mała Kępa and Brześć Kujawski (Fig. 11, 12).

Fig. 12. The bronze jewellery from the urn-field in Mała Kępa originating from the Tarnobrzeg culture

However, it must be stressed here that the small size of the data-set obviously necessitates caution in interpreting these results and therefore until more data is collected (especially from the south-eastern Poland) it would be too risky now to establish clearly and unequivocally the metallurgical (and thus cultural) origin of the nail earrings used by the Cuyavia-Chełmno land societies.

5. Conclusions

The metallographic results of the jewellery from the urn-field in Mała Kępa are a supportive indication of implementing the lost-wax casting method and further metalworking. In the case of bronze alloying, the jewellery show an emphasis on tin- and tin-lead-based alloys. It has been established that processes of slight plastic working and annealing were both applied during manufacturing the nail earrings. It is also likely that some of the ornaments, the necklaces in particular, underwent intense plastic working.

As far the corresponding necklaces recovered from Cuyavia (e.g. Stanomin) were commonly made of circle bronze rods [2], it is plausible that emphasizing the non-circled (squared) and one-way twisted necklaces recovered from the urn-field in Mała Kępa may be related to the local pattern of the Chełmno group. It must be emphasized here that compatible (designed for casting squared rods) clay moulds destructs were recovered from the nearby casting workshop in a defensive settlement at Kamieniec [15] and thus it cannot be excluded that at least some necklaces (or even wider - ornaments) deposited in the urn-field were made in Kamieniec. It might be that during the Ha D the Lusatian metalworkers from Chełmno land continued to work with close relation to the earlier stylistic patterns. It does seem then as if technological flow-in had not broken the Chełmno group cultural boundaries down and therefore led to a somewhat stylistic backwardness in this area [13].

It may be assumed that the necklaces MaKa_2 and MaKa_3 were intended to meet a specific style and alloy standard with possible weight standardization. This gave rise to hypotheses that perhaps such necklaces could have been circulated as a form of commodity money (*Gerätegeld*). Interestingly, this model is welldocumented by the bronze sickle hoards deposited during the Late Bronze Age in northern Central Europe [13, 16].

It is the alloy profile of the jewellery from Mała Kępa that suggests it was common enough for the Lusatian metalworkers to carry on re-using bronze scrap circulating in the area of their activity. This, indeed, is the case for northern province of the Lusatian culture lacking sources of metal ore, where re-melted bronze scrap was in fact contaminating further bronze alloys.

The steppe-styled ornaments and to a wider extent the military accessories are commonly thought to be indicative of the Nomads penetration in Central Europe, but when looking at the alloy profiles of the nail earrings and their distribution in Poland then it is very plausible that the Tarnobrzeg group of the Lusatian culture could have been an interregional production center of the IIc type, whereas the Sokolniki B type may be indicative of Steppe-Forest zone cultural infiltration (Milograd culture). Consequently, the presence of the nail earrings in Mała Kępa may have led towards the model of exchange contacts between societies of the Cuyavia-Chełmno land region through the South-Eastern cultural passageway. It would also seem meaningful that importing or local imitating of the steppe-styled objects by the Lusatian metalworkers was still a relatively new phenomenon tied into the increasing presence of the Nomads in Central Europe or rather their strong cultural impact on the northern province of the Lusatian culture during Ha D [6, 17-19].

Although this study can only touch the problems highlighted hereinbefore, an archaeometallurgical approach to the casting technology of the bronze jewellery from the urn-field in Mała Kępa may provide a valuable contribution to the understanding of the Early Iron Age metallurgy practice and dynamics in the northern province of the Lusatian culture.

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