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Analysis of Medieval Mail Armour – Archaeological Remains from the Prilep Monastery Treskavec

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Abstract:-In this paper, archaeological material, found in the Treskavec monastery, in Priler, Macedonia, was analysed. In fact, the material is a large fragment of mail armour, made of rings, which, according to archaeological findings, dates from the end of the 13th or the beginning of 14th century. The ring samples were inspected by SEM, metallographic, EDX and X-ray analysis, and the obtained information was used to determine the chemical composition, metallographic characterization, corrosion analysis, as well as the metallurgical processes by which the rings were produced.
Keywords:-mail armour, metallographic characterisation, corrosion, archaeology

I. INTRODUCTION

The subject of interest in this paper is the material used in the mail armour, property of the Museum of the city of Prilep, Macedonia. This unique artefact is located in the museum since 1973. It was originally found in the Treskavec monastery, within a distance of 10 km from Prilep [1]. From archaeological point of view, the monastery is an exceptional structure. It was built in the 13th century, on the remains of an early Christian temple, and it was restored in the 14th century [2].

In the past, during the medieval period, mail armours were frequently used. They were made with rings, connected at the ends by rivets. It is thought that this specimen was deposited in the monastery, because in those times, mail armours and various types of weapons were frequently deposited in monasteries [3].

On Fig. 1 the appearance of a preserved section of the mail armour from the Treskavec monastery is shown, and on Fig. 2, a detail of the same armour is presented.

The appearance of mail armours dates back to the Iron Age. Parts of mail armours were found in archaeological sites in Denmark, Great Britain, Slovakia, Romania, etc. It is considered that the oldest specimen from the Kiev area dates back to the 5th century BC [4].

The mail armour production was time-consuming and demanded a lot of skill, metallurgical knowledge and, of course, iron resources [5]. In the beginning, this type of armour was rare. The required skills include knowledge of the wire drawing process and technology, as well as rivet connecting. Production on a larger scale begins from the 2nd century BC. Because of the variety of desirable properties, such as low weight, adjustability, easy storage and maintenance, the mail armour has been used for centuries [5].

Considering the fact that the mail armours have remained unchanged for centuries and were possibly used for longer periods before they were deposited, the chronological origin of the Treskavec specimen is not precisely determined [2]. However, it is almost certain that it originates from the end of the 13th or the beginning of the 14th century [3, 6].

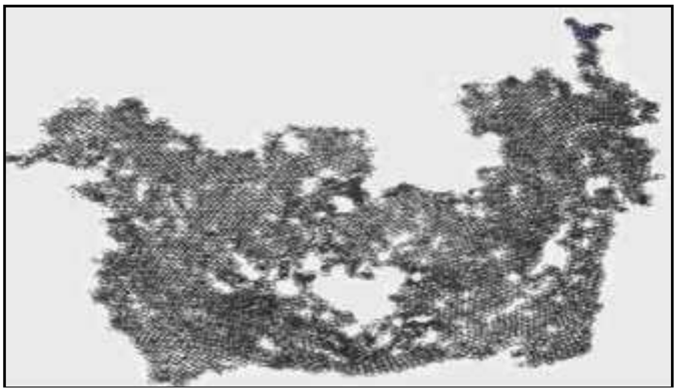


Fig.1. Appearance of a preserved section of the mail armour from the Treskavec monastery

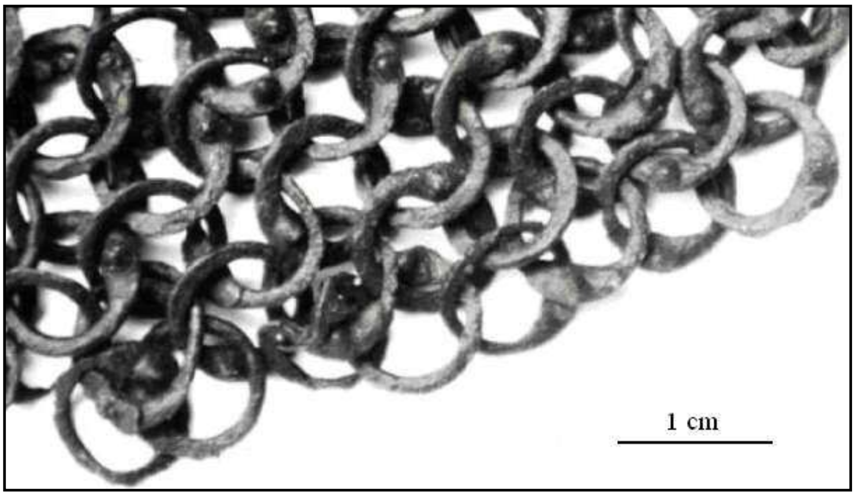


Fig.2. Detail of the mail from the Treskavec monastery

II. EXPERIMENTAL

In the aim to further study the mail armour material, several of the rings, shown on Fig. 3, were subjected to analysis.

First, the dimensions of the rings were determined. Then, several types of analysis were performed: X-ray, metallographic, SEM and EDX [7-10]. The analysis was done to characterize the mail armour material qualitatively and quantitatively, and above all, to determine the chemical composition of the material and to define the metallurgical processes used for the manufacture of the mail armour specimen.

A

b **c**

Fig.3. Appearance of the rings used in the mail armour a) no magnification b) magnification 25% c) magnification 180%

III. RESULTS AND DISCUSSION

The analysis of the samples has shown that the ring have identical dimensions. The rings are manufactured from a wire – the metal material, by means of drawing, was shaped into a wire with a cross-section of 1 mm. Using wire bending, the wire was shaped into a circle-shaped ring. The rings have an outside diameter of 1 cm and thickness of 1 mm. The last 6 mm of the wire length were flattened, by means of forging, and thus forming an widened area. The maximal central widening is approximately 2 mm. The ends were overlapped in the forming of the ring and the center of the widened area was perforated, so a rivet may be put [3].

The specimen represents a relatively well preserved, larger section of the mail armour. Its dimensions are 59x44 cm (Fig.1). It is manufactured from rings (Fig.3), linked with rivets in the following manner: each ring is connected to 4 other rings, which forms the mail structure.

X-ray analysis was performed on several samples. On Fig.4, the sampling of the rings for X-ray analysis is shown: in the areas 1, 2 and 3. The analysis results are given in Table 1.

Excluding the oxygen, which has penetrated the samples as a result of corrosion, it can be stated that, in the time when they were manufactured, the rings most likely contained a minimum of 75% Fe, about 9,5% Si and 8,5 % Mg, with 3,2 % Ca and 1% of Al, S and Cl impurities.

On Fig.5 and 6 the SEM photographs of the rings are presented. On Fig.5, a SEM photograph of the entire ring is given, with width of the photograph of 20,57 mm. Fig.5 was used to determine the average width of the ring, which is 9,81 mm. Also, on Fig.5 the corroded sections of the ring can be clearly observed. The darker sections are Fe and the lighter – the corroded material.

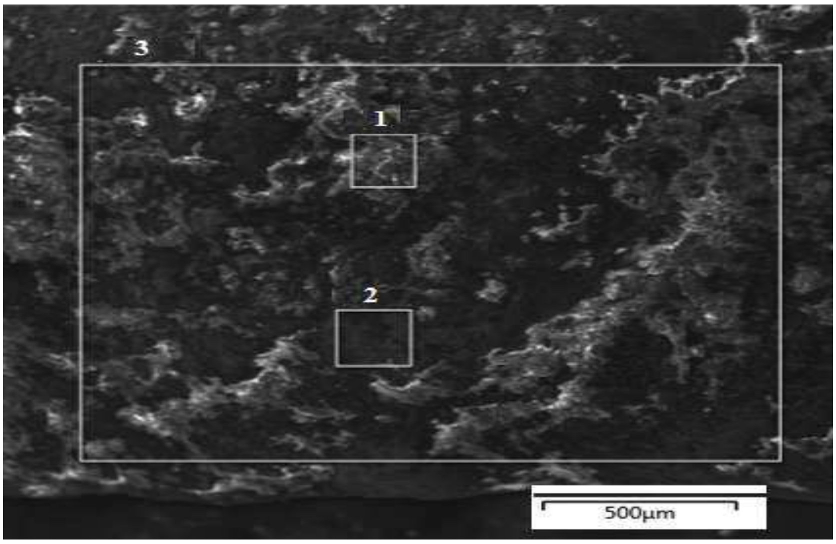


Fig.4. Sampling for X-Rey analysis

Table I. Chemical composition, wt %

Chemical composition, wt %											
Position	**Fe**	**Si**	**Mg**	**Na**	**Ca**	**S**	**K**	**Al**	**Cl**	**O_2**	**Total**
1	14,1	14,2	11,1	-	2,7	0,9	0,7	-	1,2	55,2	99,9
2	53,5	2,9	2,7	1,6	1,5	0,5	0,4	0,4	0,3	36,0	99,9
3	43,8	5,5	5,0	-	1,9	0,6	0,5	0,6	0,4	41,5	99,8

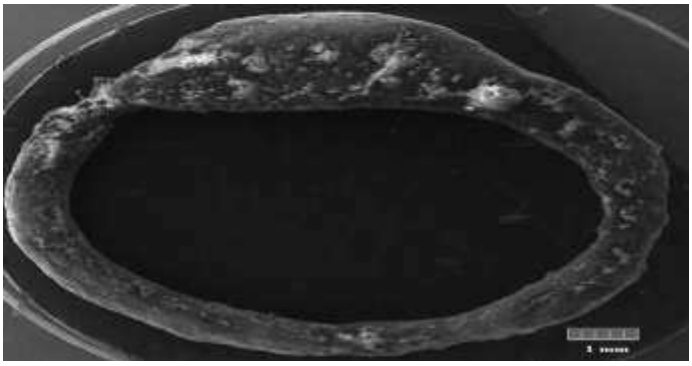
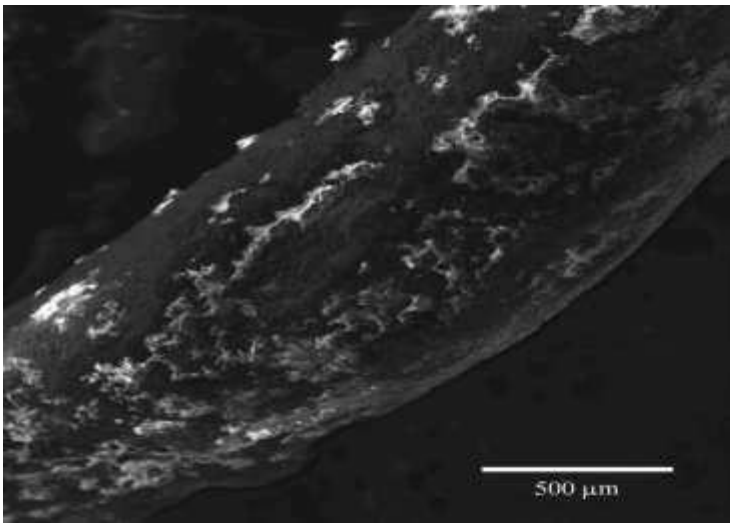
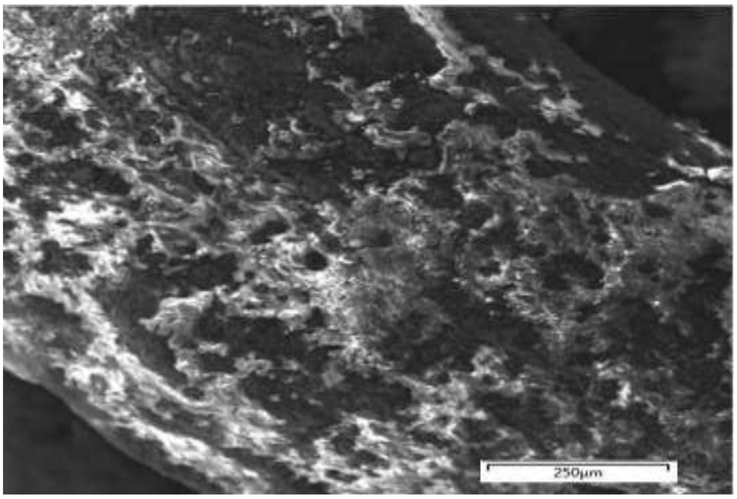


Fig.5. SEM photograph of the sample, photograph width 20,57 mm

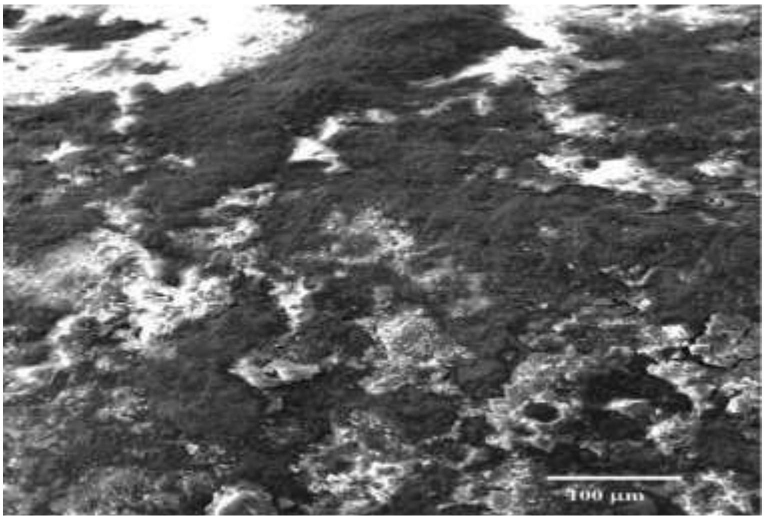
On Fig.6 SEM photographs of the sample are shown. The width of the photographs is different – on Fig.6.a is 1,94 mm, on Fig.6.b is 1,52 mm and on Fig.6.c is 697 μm. The magnification is noted on the photographs.



a



B



c

Fig.6. SEM photographs of the sample with magnification of a) 142, b) 182, c) 464

An EDX analysis of the ring samples was also performed. The distribution of some of the elements is given on Fig.7.

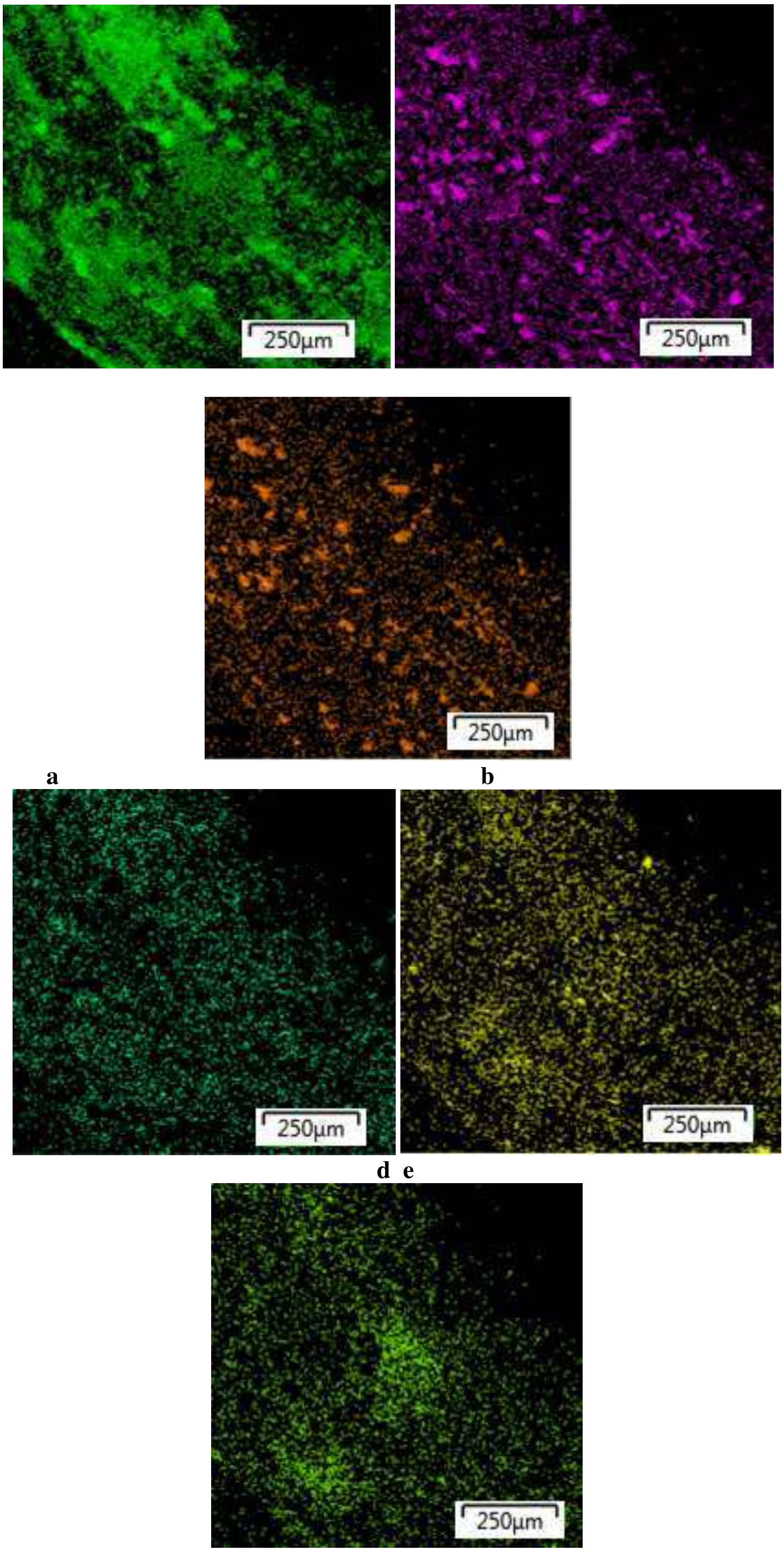


Fig.7. Distribution of elements in the samples a) Fe, b) Si, c) Mg, d) K, e) Ca, f) Cl

As can be seen, Fe has the most uneven distribution, with larger groupings through the sample (Fig.7.a), Si and Mg have a more even distribution and are grouped in smaller areas (Fig.7.b and c), whereas the remaining three elements – K, Ca and Cl, are small and evenly distributed throughout the sample (Fig.7.d, e and f).

The sample microstructure of the samples is shown on Fig.8, with x5 magnification. Sections of 4 different rings are presented. It can be seen that the ring is manufactured by means of bending of a material that was previously plastically deformed by drawing (Fig.8.a, Fig.8.c). The sample given on Fig.8.a is, in fact, a lower left section, which is relatively well preserved. Corroded areas can also be observed, which are especially pronounced on the surface of the ring.

The metal grain has an uneven size; the smaller grains are centrally positioned, which indicates on deformation by drawing, with minimal intercept value L = 10 μm, i.e. with minimal grain diameter value D_{min} = 15 μm, calculated according the Saltykov expression [11, 12]:

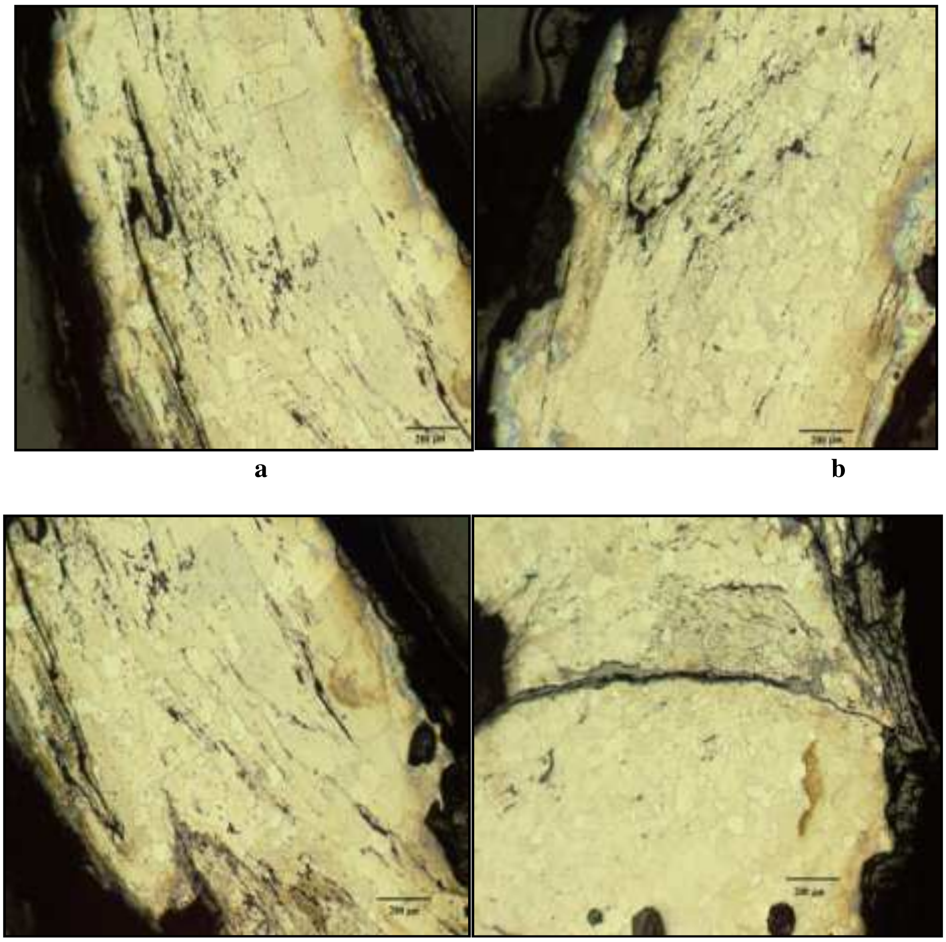
$$D = 1{,}5 \cdot L \quad , \tag{1}$$

where L – intercept, μm, calculated as a mean value of Lx and Ly, i.e. segment lengths in x and y directions

$$L = \frac{L_x + L_y}{2} \quad , \tag{2}$$

and D – volume diameter of the metal grain, μm.

On the other hand, the maximal grain size value, expressed as D in 14 times larger than the minimal, i.e., D_{max} = 210 μm.



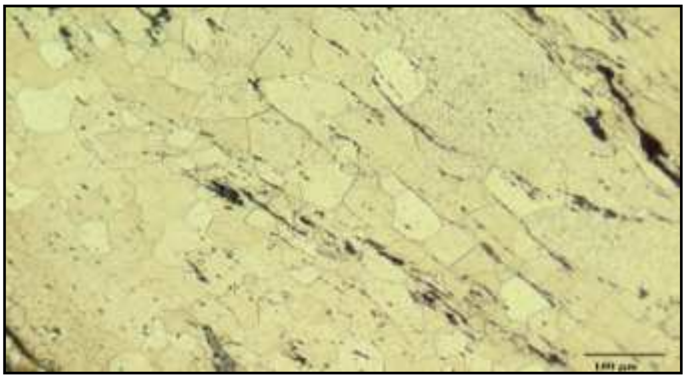
a b

c d

Fig.8. Ring microstructure, magnification x5,
a) bottom left section, b) upper left section, c) upper right section, d) right central section

The second sample (shown on Fig.8.b) indicated increased degree of corrosion, especially on the outer side of the ring, on which a part of the ring exterior is almost entirely deteriorated [13]. The grains are smaller and more even in size, with mean value of the volume diameter of the grains of D_{mean} = 65 µm. On the third sample (Fig.8.c), the corrosion caused thickness reduction of the ring of 45%, and the metal grains are similar in size and evenness to the first sample (Fig.8.a). On Fig.8.d the microstructure of a ring with a crack is shown. The metal grains are smaller in comparison to the other samples, with D_{mean} = 45 µm, and are relatively evenly distributed. The crack appeared in the section of the ring with small grain structure, but, because of the bending procedure, this area has the largest residual mechanical stress which, in the course of time, with intergranular corrosion, were most likely the cause of the cracking [14, 15].

Characteristic details of the microstructure of the rings, with magnification x10, are given on Fig.9. On Fig.9.a section of the ring interior, with small areas of corrosion shaped like thin stripes, along the grain boundaries, is shown. Larger corroded areas located in the internal section of the ring are given on fig.9.b. Fig.9.c represents the microstructure of the ring, from the right central side (Fig.8.d), with greater magnificatin; it can clearly be seen that the intergranular corrosion, which is one of the causes for the cracking, has progressed towards the interior of the ring.



A

B

c

Fig.9. Microstructure of the rings, magnification x10, a) central section, b) secttion with corrosion on the interior side, c) intergranular corrosion

IV. CONCLUSIONS

Archaeological specimens – rings from a metal mail armour, originating from the Treskavec monastery were investigated, via SEM, metallographic, EDX and X-ray analysis.The chemical composition of the samples is 43,8% Fe, 41,5% O_2, 5,5% Si, 5% Mg and Ca, S,Al, K and Cl impurities. If it is presumed that the presence of O_2 is due to the long-term exposure to atmospheric corrosion, at the time of the manufacture, the samples had a minimum of minimum 75% Fe, about 9,5% Si and 8,5 % Mg, with 3,2 % Ca and 1% of Al, S and Cl impurities.

Fe is unevenly distributed in larger areas, whereas Si and Mg are more evenly distributed and grouped in smaller areas; the remaining three elements – K, Ca and Cl are small and evenly distributed throughout the sample.The metal grains have irregular size, with minimal mean volume diameter of 15 μm, to a maximal mean volume diameter of 210 μm. The smaller grains are located in the interior, whereas the larger grains are located on the exterior of the rings, as a result of the plastic deformation from the wire drawing process.

The analysis have shown that the samples are significantly corroded on the surface and partialy in the interior. On some locations, cracks have appeared, as a result of the intergranular corrosion and the residual stress, resulting from the shaping process performed by bending.

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