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IMPURITIES OF THE SURFACE LAYER OF THE EXPLOITED ETP GRADE COPPER RAILWAY TRACTION SCRAP AND ITS INFLUENCE ON THE CHEMICAL COMPOSITION AFTER METALLURGICAL SYNTHESIS

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The recycling possibility of exploited ETP grade copper railway traction scrap has been evaluated in terms of reusing the materials of high Cu content for new traction equipment dedicated for modern railway and tram overhead lines based on CuNi2Si and CuZn37Ni1Si0,5 alloys. Firstly, the conducted research was focused on the qualitative and quantitative assessment of residual impurities of the scrap materials of carrying ropes and overhead contact lines. The main research part was the metallurgical synthesis and the impact of the said impurities on the chemical composition and selected properties of copper manufactured from scrap material.

Keywords: copper, scrap, recycling, chemical composition, electrical and mechanical properties

INTRODUCTION

Being the fastest growing transport sector both passenger and freight in Europe and in the world [1-3] forces constant modification of the existing railway lines and construction of the new ones. Up until now most solutions regarding materials used in railway transportation (apart from steel used as construction materials) were ETP grade copper and its alloys, mostly aluminium or silicon bronzes [4-5]. Pure copper of high electrical conductivity [6] was used e.g. for contact lines and carrying ropes whereas bronzes for various types of overhead contact line equipment such as clamps of various geometry. Copper alloys were used for contact lines production much later [7-9]. The newly designed railway lines of increased current and mechanical carrying capacity were developed with alloy materials which ensured increased operational properties such as high electrical conductivity, increased heat and corrosion resistance, reduced own weight, etc. These properties may be provided by two groups of alloys and thus novel railway equipment is manufactured with CuNi2Si and CuZn37Ni1Si0,5 alloys [10-13].

New materials dedicated for railway equipment are manufactured on the copper matrix (mostly ETP grade copper) which directly influences the production cost. That is why this research aimed at replacing pure copper with exploited copper scrap as charge material for metallurgical synthesis process.

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EXPERIMENTAL PROCEDURE
Research materials

The conducted research assumed the use of exploited traction scrap in the form of contact lines and carrying ropes manufactured of ETP grade copper originated from modernized railway lines. Surface of such materials is covered with a thick layer of impurities resulting from years of operation in diverse environment. Contact lines and carrying ropes are the main elements of the overhead contact system which are directly responsible for the transmission of the electric current. In order to ensure low transmission losses the material used for these applications should be characterized with high electrical conductivity. Chemical composition of such materials is strictly defined with proper standards and internal regulations of individual countries which have to be followed by manufacturers all over Europe [14-16]. The defined chemical composition of ETP grade copper used for the manufacturing of contact lines and carrying ropes was presented in Table 1.

Table 1 **Chemical composition of Cu-ETP [14,17]**

Cu	Ag	Bi	O	Pb	Other
Min. / wt. %	Max. / ppm				
99,9	150	5	400	5	300

Surface analysis

Surface analysis of the impurities was conducted with Hitachi SU-70 scanning electron microscope (SEM) which allowed for the surface topography observations combined with the Energy Dispersive X-ray (EDX) analysis of their chemical composition. What is more a linear analysis of the cross-section of the samples to assess the impurities penetration into the structure of copper was conducted. In order to quantify the thickness of the impurities layer on the surface Olympus GX51 microscope was used.

Metallurgical synthesis and analysis of the chemical composition

Metallurgical synthesis was conducted with 450 g of charge material using resistance furnace set to 1 150 °C for 60 minutes in a crucible made of isostatically pressed high grade graphite which would reflect industrial conditions as close as possible [18]. Obtained materials were subjected to chemical composition analysis with spark emission spectrometer Foundry-Master Xpert using full element copper analysis.

Analysis of the electrical and mechanical properties

Electrical properties of the obtained ingots were defined using SigmaTest 2.069 device. Samples prior testing were placed in an air-conditioned laboratory for 24 hours at ambient temperature in order to stabilize their thermal state. Mechanical properties were defined in Vickers hardness test in accordance with the PN-EN ISO 6507 standard at the cross-section of the ingots with the use of Tukon2500 automated hardness tester.

RESULTS AND DISCUSSION

Surface analysis

The obtained results proved that there is a large impurities layer at the exploited traction scrap materials. Depending on the analysed element and the place of analysis the impurities thickness vary. The measurements examples of the samples taken from carrying rope and contact line scrap material were presented at Figure 1.

The conducted analyses of the scrap carrying rope showed even distribution of the impurities at individual wires, especielly those of external layer. The thickness of the layer ranges from 13 and 25 µm. Considering contact

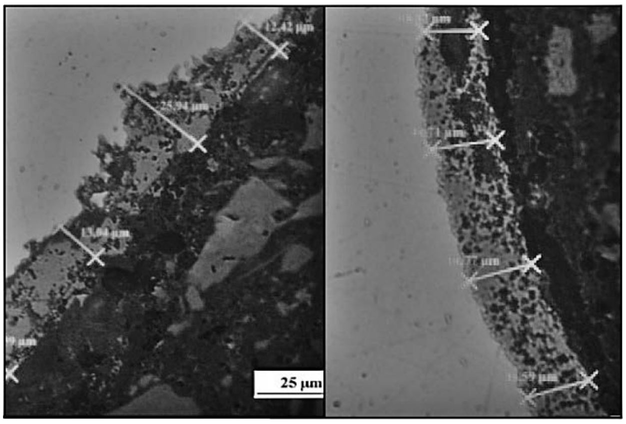

Figure 1 Exemplary measurements of the impurities thickness at the surface of carrying rope (left) and contact line (right)

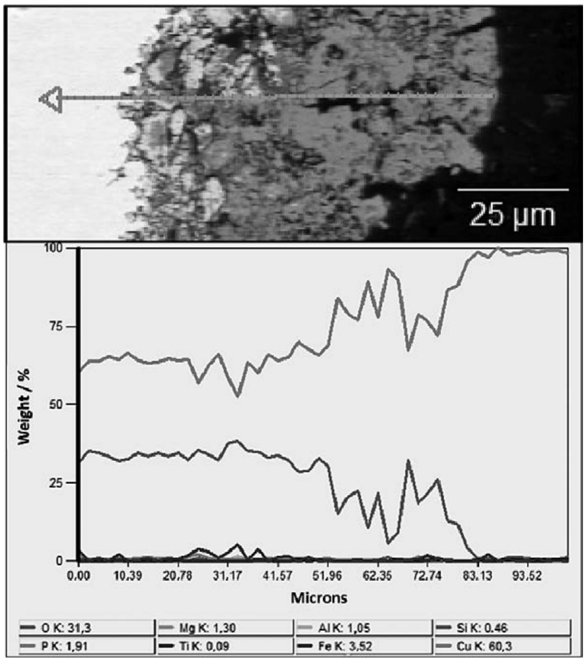

Figure 2 Linear analysis of the impurities layer

line of scrap origin the lowest accumulation of the impuriteis was noted at the operational part of the material which was approx. 5 µm and the highest was recorded at the groove and was equal to approx. 15 µm. The conducted analysis of the surface chemical composition of various areas of the tested samples showed similar impurities in both cases. An example of a single measurement area of the scrap sample identified impurities such as Mg, Al, Si, K, Ti, Fe.

Table 2 **Quantitative analysis of the identified at the surface elements / wt. %**

Mg	Al	Si	K	Ti	Fe
0,52	4,85	7,99	0,68	0,51	9,69

Elements such as Fe, Si and Al were confirmed to be of highest accumulation at the surface of the tested scrap materials. These elements are especially harmful in terms of physical properties of the materials as they deteriorate them in copper and copper alloys. Additional research was carried out to determine the influence of the impurities layer on the base material. An example of a linear analysis of chemical composition directed towards the interior of the material was presented at Figure 2.

The linear analysis of the chemical composition directed towards the interior of the material shows the actual nature of the surface layer impurities. The identified elements mainly residue at the outer surface and the main impurity is copper oxide formed over many years of operation of the metallic elements.

Metallurgical synthesis and analysis of the chemical composition

Consecutive part of the results analysis consisted of chemical composition tests of the obtained in the metallurgical synthesis process ingots (Figure 3).

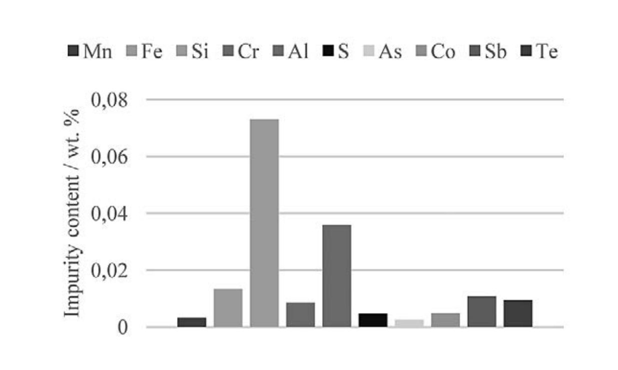

Figure 3 Chemical composition of the obtained from scrap material copper ingots

The chemical composition analysis clearly indicated that the surface impurities of the charge materials of scrap origin during metallurgical synthesis contaminated the copper matrix. Similarly to the conducted surface analysis a strong contamination of copper with elements such as Si, Al and Fe was recorded and their cumulative content exceeded 1 000 ppm.

Analysis of the electrical and mechanical properties

The unintentional addition of these elements affects copper properties of the obtained ingots of scrap origin which in theory should reach parameters similar to technologically pure copper. In this particular case a significant decrease of electrical conductivity was recorded (down to 54 MS/m) and the measured Vickers hardness of the tested samples fluctuates around approx. 41 HV10.

CONCLUSIONS

Taking everything into account it may be stated that the surface impurities layer identified on scrap material significantly contaminates the materials obtained during metallurgical synthesis. The presented results show the addition of unfavourable impurities elements of around 1 600 ppm which drastically exceeds the acceptable standards of ETP grade copper. The results concerning the impurities layer revealed the effect of atmospheric corrosion pitting coming from almost 40 years of operation of the railway line in various conditions with simultaneous current and mechanical carrying capacity. The surface impurities did not diffuse into the interior part of the tested materials, thus keeping it at a relatively high chemical purity level, which is undoubtedly a positive aspect of the conducted research. Metallurgical synthesis research conducted with the materials of railway scrap origin proved higher amount of elements which might possible contaminate the structure of the metallic material.

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Note: The translator responsible for English language: Paweł Strzępek, AGH University