BRIEFING NOTE
THE RECYCLING OF COPPER ROTOR MOTORS

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INTRODUCTION

In recent years, various products containing metallic copper composites have appeared on the market with the intent of taking full advantage of copper's properties. A composite is usually defined as a structure obtained by assembling two or more materials (in this case metals) in contact or very close proximity. By retaining their individuality, they contribute to the maximization of the overall performance of the assembly through their distinct, but complementary mechanical, physical, and chemical properties.

Common examples are numerous including among others, cooking pans of a copper/stainless steel sandwich or similarly lined bottoms, copper/stainless steel clad roofing sheets, squirrel cage copper/iron/silicon rotors for electric motors, copper-sheathed aluminium and steel electric wires, and copper wires with embedded niobium/titanium superconducting filaments.

Although most of these products have not yet arrived at the end of their service life, it is important to evaluate their recycling potential and to outline possible recycling schemes.

One difficulty in recycling metallic composites lies in the fact that the strong bond between the constituents and their rather similar plasticity makes a mechanical separation virtually impossible. Therefore pyrometallurgical and, to a lesser extent, hydrometallurgical techniques have to be employed.

This briefing note focuses on the pyro-metallurgical recycling of copper squirrel cage rotors used in electrical motors (Copper Rotor Motors or CRM). Like conventional electrical motors, after adequate sorting of the different metals, they can be easily recycled with existing technologies. This can achieve an almost 100% recovery of copper in a highly purified state and the formation of a valuable iron-silicon slag suitable for a variety of applications after granulation, including materials suitable for infrastructure construction. The same technology holds also for other copper/steel and copper/stainless steel composites. Indeed, in the latter, a large fraction of the nickel contained in the steel is recoverable separately.

The squirrel cage rotor consists of a grooved stack of magnetic iron-silicon laminates (typically 2 to 3% silicon). The grooves are filled with a highly conductive metal. Historically aluminium was pressure die cast into the grooves. Recent advances in design however substitute copper due to its superior electrical conductivity. This improved design enables the fabrication of a smaller rotor with an equivalent mechanical power.

![Picture 1: Copper rotor motor or CRM](image)
This leads to a significant overall reduction in weight and volume of the motor, which compensates by an appreciable margin both the higher density and the higher price of copper.

The typical copper and aluminium content in a rotor as a function of its power, is given in Table 1 for several 400 V/50 Hz motors. The high copper content—with an average relative copper content of around 25%—means that for technical and economic reasons, the rotors must be recycled within the copper recycling circuit and not within the steel scrap circuit. It should also be noted that the amount of copper in the windings of the stator is at least as high as the copper in the rotor and that the proportion of copper rises with increasing power. The copper content in the stator is approximately proportional to the power (kW)^0.75.

Table 1: Copper in CRM

<table>
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<th>Power (kW)</th>
<th>1.5</th>
<th>3.0</th>
<th>7.5</th>
<th>15.0</th>
<th>22.0</th>
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<td>Iron weight (kg)</td>
<td>6.3</td>
<td>7.5</td>
<td>16.9</td>
<td>30.0</td>
<td>30.3</td>
</tr>
<tr>
<td>Copper weight (kg)</td>
<td>2.3</td>
<td>3.2</td>
<td>5.2</td>
<td>6.4</td>
<td>5.2</td>
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<tr>
<td>Relative copper weight (%)</td>
<td>27</td>
<td>30</td>
<td>24</td>
<td>18</td>
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The question now is where and how to best recycle electric motors.

Technical and economic reasons lead to recycling electric motors within the copper industry.

Recycling copper in the steel making industry is ineffective and affects the quality of the resulting steel.

Once copper enters a steel melt, pyro-metallurgical processes are ineffective at eliminating it. The reason is the higher affinity of iron for oxygen. The only practical method of reducing copper content in steel is by dilution. Copper as an alloying metal hardens steel and deteriorates the surface quality during hot rolling. The content of copper as an unavoidable impurity is limited to only 0.25 % in almost all steel qualities. Therefore, steel scrap has very strict limitations concerning the copper content. Nevertheless, there are some steel grades and trademark brands containing copper. Good corrosion resistance and/or high mechanical strength characterize such steels. One widely known example of such weathering steel is the popular COR-TEN steel.
which can be alloyed with copper up to 1.5 %. Current alloying practice is supposedly the direct injection of copper into the melt, as apparently no master alloys are offered on the market.

On the contrary, as will be described below in the copper metallurgy section, iron can be easily separated from copper. Due to its higher affinity for oxygen than copper, iron is essentially oxidized during smelting and converting and transformed in a silicate-based slag, which can be recycled for construction and road works.

Note that the situation is less problematic for rotors containing aluminium: on one hand the aluminium content is much lower by a factor three in comparison to copper, and on the other, aluminium is routinely used to deoxidize steel melts.

Economically, the recycling of the CRM in the copper industry makes sense as well.

In reference to the LME copper price, the discount for the copper contained in rotor scrap is approximately 25%. This means that the value of the copper is higher by almost one order of magnitude in comparison to the steel of the cage. This becomes clear by considering a steel scrap price of some 200 €/ton and an LME copper quotation of some 6,500 €/ton. For one ton of rotor scrap of which 25% is copper, the steel value would be at the best around 150 € and for copper around 1,300 €.

Practically speaking, the recycling path for the CRM is essentially similar to the one used for conventional motors with copper wire coils. It consists of two distinctive processes:

- The extraction of the copper (usually mixed with iron and steel fragments forming the so-called meatballs) from the decommissioned and shredded systems, like end of life vehicles and appliances. Figure 1 shows the simplified scheme of the scrap sorting circuit.
- The pyro-metallurgical separation of copper and iron eventually leads to high purity cathodes and iron silicate based slag. Figure 3 shows the simplified refining process of copper scrap.

As indicated, for the first process, electrical motor containing systems like vehicles and appliances are increasingly fragmented mechanically with hammers and shredders following the manual removal of fluids or specific subsystems like wire harnesses and radiators. An initial sorting with strong magnets separates the magnetic iron fragments and the non-magnetic light materials (glass, polymers, et cetera) as well as most of the non-ferrous metals (stainless steel, aluminium, copper, et cetera). Both fractions have to be processed further for a better sorting of the different materials and a more efficient recycling. This is obvious for the non-magnetic fraction. It holds also for the steel fragments, because of their contamination with non-ferrous metal parts, which are embedded in the fragments or which just stick to them. The truly critical parts are the armature copper windings that were not fully removed from the rotor and stator iron bodies. These iron/copper fragments are usually designated as “meatballs”—a term which is also suitable to the CRMs.

**Picture 3:** Mixed scraps with “meatballs”
In previous processes, the meatballs had to be picked out manually. This is now being carried out more and more by automated methods. In recent years, new sorting lines have been developed combining chemical identification of the major constituents of the fragments and controlled pneumatic sorting. The fragments are placed on an endless conveyer belt and pass under analytical sensors, currently using x-ray fluorescence (XRF) spectroscopy. New tools are under development such as laser induced breakdown spectroscopy (LIBS), which may possibly allow for better spatial resolution and chemical sensitivity. At the end of the belt, a row of valves can deliver controlled high-pressure air jets for ejecting out of the main steel stream one or two fractions of contaminants. Figure 2 shows the main steps of a modern sorting line.
It is important to note that these analytical techniques only analyse the surface of the sample with an information depth below one mm. In order to sort the shredded scrap efficiently, sufficient copper must be apparent to the probing beam—either x-rays or laser light. Otherwise, meatballs will be considered as pure iron fragments and will thus deteriorate the quality of the iron scrap. At this stage, the layouts of the two kinds of rotors may make a difference: obviously copper is more apparent in a conventional rotor with its windings than in a CRM. Thus, both rotor designers and shredder plants have to make as much copper surface apparent as possible. For the latter, increasing the brittleness of iron by using so-called cryogenic shredding could improve the fragmentation of the rotors. It should also be determined whether automatic visual inspection should supplement chemical analysis.

Nevertheless, it is clear that a truly pure iron fraction is unlikely to ever be achieved, due to the presence of small electrical motors or bits of copper that are too small or hidden and which will not be detected or ejected. The code given by the Institute of Scrap Recycling Industries (ISRI) to the shredded and sorted scrap with electric motors is **Shelmo** *(shredded electric motors)* which means mixed copper bearing material from ferrous shredding including motors without cages, and **Zebra**, which stands for scrap still containing other kinds of high-density non-ferrous metals. The objective of scrap yards is to sort out as much copper as possible and to provide the steel mills with the best quality scrap. On one hand, as already explained, the copper contained in the iron has no value, and in fact being a nuisance. Thus, delivering high quality steel scrap increases the premium on the price which can go from some 5 to 25 €/ton. On the other hand, collecting as much copper as possible for the copper refiners strongly increases the benefit of the sorting operation.

After sorting, the iron scrap goes to the steel mills. There, it is—after inspection, and possibly mixed with higher quality steel scraps—directly melted in electric arc furnaces. The only refining treatment is the removal of gaseous or highly volatile impurities.

The recycling of copper scrap is more complex, but it leads ultimately to a quality identical to one of primary copper obtained from ore. Copper scrap refining starts with a three-step pyro-metallurgical process producing anodes for electrolytic refining in tank houses.

Firstly, low-grade copper inorganics (fumes, dross, slag, et cetera) and metallic scrap like the meatballs are melted in shaft furnaces or Isa smelters under reducing conditions in respect to copper. The main products are impure black copper serving as a collector for most non-ferrous metallic elements, flue dust charged with...
some volatile metallic elements, as well as slag resulting mainly from the oxidation of iron in presence of some fluxes like sand and lime. The presence of iron in the scrap is an asset, because its exothermic oxidation reaction contributes to the heat needed to melt the charge. The slag may also contain some copper and other valuable minor elements. Thus, the flue dust and slag have to be processed to recover all the non-ferrous elements, as well as the off-gas to eliminate hazardous organic compounds. The two following refining furnaces (converting furnace and anode furnace) are charged with the upgraded copper coming from the previous furnace and with higher quality metallic copper scrap like alloys and low purity copper.

**Figure 3: Recycling flow-chart of copper scrap**

The converting furnace is either a conventional Pierce-Smith converter, or the more recent top blown rotary converter (TBRC). It upgrades the black copper through an oxidation and slag forming process to remove most of its 20% content of other elements. The crude or blister copper obtained consists now of approximately 97% copper. In the anode furnace, the impurity level is still reduced by a similar process to less than 1%.

For the recycling, CRMs have to be considered as low-grade scrap—even if the copper and iron components are rather pure—and charged into the starting furnace. They could also be recycled in a pyro-metallurgical copper production plant using sulphide ore. The process bears some similarities with the refining processes. The only restriction is that the meatballs are fed into a bath-smelting furnace and not into a flash smelter.

Both processes produce anodes of comparable purity, and thus the last common step is electrolytic refining of copper up to 99.99%, with the possibility of recovering further very valuable elements in the slime like gold and silver.

As a conclusion, there is, worldwide, enough capacity to recycle efficiently, with well-proven technologies, mixed copper/iron scrap such as meatballs. In Europe, there are several secondary copper smelters (Aurubis—Lünen in Germany, Boliden in Sweden, Metallochimique in Belgium, and Montanwerke Brixlegg in Austria) reclaiming copper from electronics and appliance scraps and accounting for a total capacity exceeding 300,000 tons per year. CRM can also easily be handled by primary copper smelters together with copper concentrates.
It is also possible that a very small fraction could be directly melted for the production of iron containing copper alloys that go to speciality niche markets.

Recycling copper scrap is a field of on-going improvements. The aim is to increase the useful recovery rate of all elements contained in the scrap and to reduce the energetic and environmental burden.

Concerning CRMs, their recycling is similar to that of conventional rotors—the only challenge for the design of the rotor and for the fragmentation at its end of life is that enough copper surface is visible to enable an efficient sorting of the shredded fragments. As shown on the picture below, the copper rings at both ends of the rotor are clearly visible.

**Picture 4: CRM ends**
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INTERVIEWS

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Andritz Maerz GmbH (D)  Bernhard Hanusch
Bundesvereinigung Deutscher Stahlrecycling- und Entsorgungsunternehmen eV (D)  Detlef Cohrs
Metallo-Chimique NV (B)  Inge Hofkens
Montanwerke Brixlegg AG (A)  Robert Stibich
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