Deliverable Report

Deliverable Title:

Definition of the pre-treatment required by the aluminium scrap

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[1] PU = Public
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Technical References

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V	Date	Author (Affiliation)	Actions& Approvals
V1.0	23/03/2022	Giovanni Sbrega (PRO) Ruggero Zambelli (RAFF)	Template filled up with section titles and rough content proposal.
V1.1	20/07/2022	Giovanni Sbrega (PRO)	Pre-treatment procedure definition for PVP, Scoots, production scrap
V1.2	21/07/2022	Ruggero Zambelli (RAFF)	Pre-treatment procedure definition for rims, scrap from zorba stream
Final	27/07/2022	Manel da Silva, Hannah Arpke (EUT)	Review and finalisation

Summary

The present document describes the method followed by the different alloy producer PROFIL, RAFF and ASAS to pre-treatment at industrial scale the different fractions of scrap coming from Zorba stream, selected by COMET and tested by EUT in WP1.

Scrap is the raw material of Al recycling. The different amount of impurity depends on the origin of the scrap itself. The level of contamination could be evaluated by means of the metal yield which indicates the portion of a scrap consignment which becomes useable metal after proper melting.

Oxidation and presence of foreign materials are the causes of a lower metal yield of scrap, however, to maximize the efficiency and profitability of the remelting process, the presence of deleterious impurities in recycled Al alloys have to be mitigated by preliminary operations and treatments. The scrap characteristics can be changed before the melting and the principal preliminary process applied to Al scrap are hereafter discussed, such as sorting, comminution, and thermal treatments.

All of these operations are performed to improve the scrap quality in terms of recyclability and metal yield.

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Scrap pre-treatment is also required to improve melting efficiency and is mandatory when it contains free element (for example Iron) or high present of organic material like paint, oil, plastic or rubber attached.

By properly removing all the presence of organic material, it is possible to obtain:

- a high level of metallic yield;
- a reduction in the formation of dross;
- a reduction in the consumption of energy used during their melting.

This deliverable contains information on the origin and constitution of scrap supplied by COMET, the methods of classification of scrap, a summary of the various scrap pre-treatment systems. The document also describes the general procedure for processing scrap by casting, extrusion and rolling.

Deliverable 3.1 should be a guide to consider in the development of SALEMA technology to treat the scrap and the subsequent use to produce partially recycled aluminium alloys in WP3.

Disclaimer

Abbreviations

Abbreviation / Acronyms	Description
LIBS	Laser Induced Breakdown Spectroscopy

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1. Introduction and Background

One of the main objectives of the SALEMA project is to develop new, high-performance, partially recycled aluminium alloys for electric vehicles. In other words, the feedstock of these alloys shall partially consist of secondary aluminium alloys recycled from well-identified scrap sources. In WP3 we study the best methods of treatment and melting of scrap to obtain high performance alloys by using low quality scrap, recovering CRMs from them.

1.1. Objectives of task and deliverable

Within WP3, Task 3.1 has the objective to define the pre-treatment that produces lower dross formation and reduces the energy consumption for the scrap used to produce the different alloys. The deliverable of Task 3.1 contains technical results about:

Scrap classification methods

Pre-treatment set up and adopted for casting, extrusion and rolling

Procedure for scrap processing for casting, extrusion and rolling.

2. Scrap

2.1. Scrap classification

Standards EN 13920 proposes an exhaustive classification of the aluminium scrap. This norm also gives references about the metal yield and the number of foreign elements expected for each category of scrap.

Table 1 - Classification of Al scrap from EN 13920 Standard

EN 13920 Part No.	Scrap	Metal Yield Lower Limit (%)	Metal Yield Avg. Value (%)	Oxides (%)	Foreign Material (%)
2	unalloyed aluminum	0.95	-	-	-
3	wire and cable	≥0.95	97.7	1.3	0.5
4	single wrought alloy	≥0.95	97.2	1.8	1.8
5	two or more wrought alloys—same family	≥0.88	97.2	1.0	2.0
6	two or more wrought alloys	≥0.88	94.0	0.8	5.2
7	Casting	≥0.9	83.4	6.2	10.4
8	Shredded (not separated)	≥0.9	-	-	-
9	shredded (separated)	≥0.9	84.5	5.4	10.1
10	used beverage cans	≥0.88	94.0	0.8	5.2
11	Al-Cu radiators	-	-	-	-
12	Turnings single alloy	≥0.9	95.3	3.7	1.0
13	mixed turnings	≥0.9	84.0	3.3	12.8
14	coated packaging	≥0.28	71.5	3.8	24.7
15	de-coated packaging	≥0.8	86.1	12.9	1
16	dross	≥0.3	55.7	44.3	-

It defines the foreign material as:

1. metals other than aluminium and aluminium alloys
2. non-metallic materials such as earth, dust, insulation and glass

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3. combustible non-metallic materials such as rubber, plastic, fabric, wood and other chemical or organic substances
4. larger pieces (brick-size) which are non-conductors of electricity such as tyres, pipes filled with cement, wood or concrete.

Limits for foreign materials are not generally defined, however some categories of EN 13920 include equivalent limits in the range from 2 – 5 %. A summary of limitations on foreign materials is shown in table hereafter:

13920-3	The scrap shall be free from attachment devices, steel core wires, coiling spools of any material, bundling material and other components of electric lines other than aluminium cables and wires. The scrap shall not be coated and shall be free from burned wire, oil, grease, dust, plastics and any other type of foreign material.
13920-4	The scrap shall be free from oil, grease, powder, plastics and any other type of foreign material.
13920-5	The scrap shall not contain more than 5 % (mass fraction) of oil, grease, dust, plastics and any other type of foreign non-metallic material as a total. The scrap shall be free from foreign metallic materials.
13920-6	The scrap shall not contain more than 5 % (mass fraction) of oil, grease, dust, plastics, calcareous deposits and any other type of foreign non-metallic material as a total. The scrap shall be free from pieces of alloys of the 2xxx or 7xxx series and free from foreign metallic materials.
13920-7	The percentage of volatile substances shall not exceed 2 % (mass fraction). The total percentage of other non-metallic foreign material shall not exceed 2 % (mass fraction). The total percentage of foreign metallic material, either free or attached, shall not exceed 2 % (mass fraction).
13920-9	The sum of the percentages of oil, grease and other non-metallic materials in the scrap shall not exceed 2 % (mass fraction). The scrap shall be free from metallic foreign materials.
13920-10	The scrap shall not contain more than 2 % (mass fraction) of moisture and not more than 5 % (mass fraction) of total volatile substances. The scrap shall be free from any other foreign material, e.g. free iron and lead, and shall exclusively consist of beverage cans. It shall be free from burnt or oxidized cans and aluminium foil.
13920-11	The scrap shall consist of non-oxidized pieces free from moisture, oil, grease, dust, plastic, iron, brass and any other foreign material.
13920-12	The scrap shall be unoxidized and the following tolerances apply to the delivered mass: 0.5 % (mass fraction) of magnetic iron, 5 % (mass fraction) of moisture and oil, 3 % (mass fraction) of fines passing through a 20 mesh sieve (0.71 mm opening), after drying. The scrap shall not contain any other foreign materials.
13920-13	The scrap shall be unoxidized and the following tolerances apply to the delivered mass: 0.5 % (mass fraction) of magnetic iron, 5 % (mass fraction) of moisture and oil, 3 % (mass fraction) of fines passing through a 20 mesh sieve (0.71 mm opening), after drying. The scrap shall not contain any other foreign materials.
13920-15	The scrap shall not contain free iron. The scrap shall not be heavily oxidized by the adopted decoating process. The scrap shall not contain fines less than 1mm in size and shall be free from non-metallic materials.

Table 2 - Summary of the EN 13920 limits on foreign materials

The metal yield is also defined under EN 13920-1 and can be measured by melting small amounts of fine metal scrap in a laboratory furnace using a crucible. The metal yield is usually lower than the metal content due to the other impurities being included in the metal scrap (e.g. oxide, fine dirt attached to the scrap). The metal yield according to standard EN 13920 varies from 80 – 90 % (except category 13920-14 scrap from post-consumer aluminium packaging and 13920-16 scrap consisting of skimmings, drosses, spills and metallic which have a lower metal yield). The metal yield shall be calculated as a mass after melt (m4) and the mass after determining the moisture content (m2), according to the scheme and the equation below:

$$m\,[\%] = (m4/m2) \times 100$$

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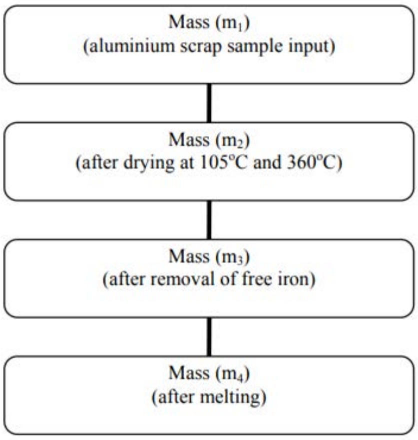

Figure 1 - Metal yield scheme calculation

In the case of aluminium scrap, metal content would include metals other than aluminium. The reason for not excluding other metals is that they are in some cases desired when scrap is used for aluminium production. Oxides generated by 'normal' oxidation of macroscopic aluminium would also be included. Dust should, however, not be counted towards the metal content because it is undesired and will usually not contain much metallic aluminium.

Another classification is proposed by the Institute of Scrap Recycling Industries (ISRI) to assist scrap users in the buying and selling of their materials and products.

Aluminium scrap can also be modelled depending on the product, the time, and the rate at which material becomes available for recycling. In example it is often categorized as “new scrap” from production processes and “old scrap” from post consumer use. New scrap has its origin during the manufacturing process of the material (shavings, off-cuts, moulded parts, etc.) and its quality and composition is usually known. Thus, it can be melted down without any preliminary treatment. Old scrap refers to those products collected after disposal from consumers, thus at the end of their life, (e.g., cables, pots, radiators, etc.). This raw material is more contaminated than new scrap and preliminary treatments of the scrap are generally necessary. The categories differ not only in their origin and chemical composition, but in the amount of entrapped oxides and foreign materials too.

2.2. Scrap market

Aluminium is a strategic material to realising the EU’s industrial green transition, the decarbonisation. In order to achieve the EU’s sustainability and industrial leadership goals a robust, complete and competitive European aluminium value chain is required.

Recycling and resource efficiency represent major opportunities for the global Aluminium industry to lower emissions across the value chain and increase its competitiveness over the rest of the energy intensive sectors. Recycling all available aluminium scrap and closing the loop are key to achieve the full potential of the industry. If we would be able to collect different kind of scrap separately and treat them separately, we could increase recycling efficiency and recycling content in the final products. This would be a first step in reducing the carbon footprint of the product.

We are experiencing an increasing difficulty in sourcing scrap. The entire aluminium value chain is trying to increase recycling content of its product and therefore the need of this raw material, our

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energy bank is increasing. Nevertheless, export of scrap continues to increase, especially to Asian countries. Now the Waste Shipment Regulation is being revised and we know that the EU Commission's proposal aims at reducing waste exports to non-EU countries. However, we are seeing a lot of End of Waste material leaving Europe. Therefore, we risk that only scrap classified as waste will remain in Europe, continuing to lose large quantities of material with high energy content, which allows us with little effort to drastically reduce carbon emissions and help achieve the European decarbonization targets.

The EU cannot build its economic and sustainability ambitions on dependencies. The EU must protect its values and ambitions by strengthening its domestic industries, limiting its dependence on non-EU countries. Only in this way we can avoid that world events of this magnitude will heavily influence our economy.

In the European market the companies that offer aluminium scrap are very different in size. There are small family companies that can supply 25-50 MT for month and big companies that can offer until 1.000 MT for month, sometimes also more. Some companies are specialized in supplying one kind of aluminium scrap, others offer many. There are companies that process aluminium scrap before selling and there are many trading companies, they only buy and sell. The largest companies that manage aluminium scrap in the European market are located in Germany, France and UK, main sectors are automotive, packaging, building. Germany, France and UK export around 2.000.000 MT of aluminium scrap for year. Important markets are also Holland, Spain and Italy: in these areas we find big plants for processing scrap before sales. In the east of Europe we have other important areas for aluminium scrap in Poland and Romania.

Outside Europe the most important market is certainly the USA, which exports around the same total volume of Germany, France and UK together. Main sectors are automotive, packaging and building. The Middle East is one of the fastest growing aluminium markets in the world, where the recycling market is mainly driven by exports of industrial waste. Aluminum scrap generated in the Middle East is around 500.000 MT per year.

Aluminium scrap comes on the market in various types and alloys. Below are the photos of the main types that are offered :



Figure 2 - From left to right: aluminium clean mixed old alloy, aluminium blind, aluminium copper radiator



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Figure 3 - From left to right: aluminium radiator cutting 1000/2000 series, aluminium sheets and cutting 2000/3000/5000/6000/7000/8000 series, aluminium used beverage cans

Figure 4 - From left to right: aluminium turnings, aluminium lithographic sheet, mixed aluminium castings

Figure 5 - From left to right: aluminium foil, aluminium rims, mixed aluminium wire and cable

Figure 6 - From left to right: aluminium extrusion 6000 series, aluminium drosses and skimmings, zorba-shredded non ferrous scrap

Aluminium scrap is offered in different forms as shown hereby:

Figure 7 - From left to right: loose material, sheared material, shredded material

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Figure 8 - From left to right: bale loose, bales on pallet, thickened pieces

The final customers decide the best form considering their process, use and logistic organization.

2.3. Scrap provided by COMET

2.3.1.1. Scrap from Zorba stream: chemical composition

This evaluation consists in defining the right mix of scrap, selected by COMET and analysed by EUT in order to obtain a suitable chemical composition to produce extrusion, rolling but especially HPDC alloys.

Based on the analysis performed by EUT, scraps coming from Zorba are composed mainly by 5.000 series and 6.000 series, not suitable for producing HPDC alloys.

n=5	%Si	% Fe	%Cu	%Mn	%Mg	%Cr	%Ni	%Zn	Alloy
5xxx-1	0.44	0.19	<0.03	<0.03	0.39	<0.03	<0.03	<0.03	6060
5xxx-2	0.39	0.19	<0.03	<0.03	0.38	<0.03	<0.03	<0.03	6060
5xxx-3	0.44	0.18	<0.03	<0.03	0.40	<0.03	<0.03	<0.03	6060
5xxx-4	0.82	0.15	<0.03	<0.03	0.49	<0.03	<0.03	<0.03	6005
5xxx-5	0.41	0.25	<0.03	<0.03	0.66	<0.03	<0.03	<0.03	6063
5xxx-6	0.45	0.19	<0.03	0.05	0.34	<0.03	<0.03	<0.03	6060
5xxx-7	0.61	0.23	0.15	0.06	0.49	0.09	<0.03	<0.03	6017
5xxx-8	0.42	0.22	<0.03	0.08	0.44	<0.03	<0.03	<0.03	6060
5xxx-9	0.14	0.32	0.05	0.49	3.95	0.09	<0.03	<0.03	5086
5xxx-10	0.09	0.30	<0.03	<0.03	0.02	<0.03	<0.03	<0.03	1050
5xxx-11	0.18	0.23	<0.03	0.15	2.80	<0.03	<0.03	<0.03	5754
5xxx-12	0.42	0.16	<0.03	0.07	0.47	<0.03	<0.03	<0.03	6063
6xxx-1	0.34	0.16	<0.03	<0.03	0.47	<0.03	<0,03	<0,03	6063
6xxx-2	0.67	0.41	<0.03	0.45	0.64	<0.03	<0,03	<0,03	6081
6xxx-3	0.56	0.16	0.2	0.06	0.81	0.06	<0,03	<0,03	6061
6xxx-4	0.91	0.2	<0.03	0.55	0.63	<0.03	<0,03	<0,03	6082
6xxx-5	0.46	0.24	<0.03	<0.03	0.48	<0.03	<0,03	<0,03	6063

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6xxx-6	0.44	0.17	<0.03	<0.03	0.41	<0.03	<0,03	<0,03	6060
6xxx-7	0.35	0.18	<0.03	<0.03	0.33	<0.03	<0,03	<0,03	
6xxx-8	0.41	0.18	<0.03	<0.03	0.41	<0.03	<0,03	<0,03	6060
6xxx-9	0.93	0.16	<0.03	0.44	0.62	<0.03	<0,03	<0,03	6082
6xxx-10	0.92	0.21	<0.03	0.46	0.61	0.09	<0,03	<0,03	6082
6xxx-11	0.42	0.16	<0.03	<0.03	0.45	<0.03	<0,03	<0,03	6063
6xxx-12	1.05	0.27	0.12	0.1	0.3	<0.03	<0,03	<0,03	6016

Table 3 - Chemical composition, performed by EUT, by spark of OES spark with SPECTROMAXx equipment on the 24 samples chosen from COMET scrap

To achieve a high recycling rate in HPDC alloys, it is probably necessary to select also other types of scrap preferring scrap with a high content of CRM materials, in particular silicon metal present in the end-of-life scrap such as wheels or castings.

2.3.1.2. Alternative scrap: chemical composition

Alternative raw material proposed by COMET are relatively clean scraps in comparison to potential aluminium fractions from the Zorba stream. We can list them in 4 main types of scrap:

- rims/wheels;
- photovoltaic panels frames (PVP);
- frames of electric scoots and bikes;
- 6xxx and 5xxx alloys from production scraps.

Rims, photovoltaic panels and electric scoots and bikes are end-of-life products scraps.
For each kind of material Comet provided the measurements of the chemical composition by handheld XRF apparatus and some photos as showed hereafter.

Rims

RIMS	Mg	Si	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Al
RIM001	0,31	8,36	0,21	0,00	0,02	0,00	0,15	0,01	0,00	0,01	0,01	90,92
RIM002	0,41	8,17	0,14	0,03	0,02	0,01	0,16	0,01	0,01	0,01	0,01	91,03
RIM003	0,40	11,96	0,12	0,00	0,01	0,01	0,22	0,02	0,00	0,01	0,01	87,23
RIM004	0,15	11,87	0,17	0,00	0,00	0,02	0,18	0,01	0,01	0,01	0,01	87,59
RIM005	0,33	10,31	0,13	0,00	0,02	0,00	0,21	0,01	0,01	0,01	0,00	88,98
RIM006	0,45	9,13	0,07	0,02	0,02	0,01	0,10	0,01	0,00	0,01	0,01	90,17
RIM007	0,52	12,93	0,54	0,00	0,00	0,17	0,45	0,02	0,07	0,04	0,01	85,25
RIM008	0,15	11,82	0,09	0,00	0,03	0,00	0,22	0,01	0,00	0,02	0,02	87,65
RIM009	0,40	12,49	0,08	0,00	0,03	0,17	0,47	0,01	0,08	0,05	0,02	86,21
RIM010	0,35	8,72	0,08	0,00	0,03	0,00	0,32	0,02	0,01	0,02	0,01	90,44

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RIM011	0,34	12,59	0,21	0,00	0,00	0,01	0,16	0,01	0,00	0,01	0,01	86,65
RIM011	0,34	12,59	0,21	0,00	0,00	0,01	0,16	0,01	0,00	0,01	0,01	86,65
RIM012	0,40	8,65	0,11	0,02	0,00	0,00	0,22	0,01	0,00	0,01	0,01	90,57
Average	**0,35**	**10,58**	**0,16**	**0,01**	**0,01**	**0,03**	**0,24**	**0,01**	**0,02**	**0,02**	**0,01**	**88,56**

Table 4 - *Typical chemical composition of wheels as measured by handheld XRF apparatus*

Figure 9 - *End-of-life aluminium wheels dismantled from scrapped cars*

All these kinds of scrap contain high value of Silicon, so they match very well the purpose of SALEMA project, the reduction of the use of CRM in the production of aluminum alloys.

Aluminium alloy rims will be divided into whole and crushed with a dimension range of 20-100 mm.

The rims, supplied by COMET, must be previously cleaned individually from any counterweight (Zn or Pb) or brass valve, thanks to the manual selection of the scrap, so the supplied rims will probably be free of foreign elements and with a suitable chemical composition to produce the AlSi10MnMg alloy.

But in the case in the rims there was the presence of foreign metals either in alloy or free (Zn, Pb, etc.) an additional selection system must be provided.

Photovoltaic panels frames

PVP	Mg	Si	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Al
PVP001	0,52	0,10	0,01	0,00	0,00	0,04	0,23	0,01	0,01	0,00	0,00	99,09
PVP002	0,59	0,00	0,01	0,02	0,00	0,03	0,23	0,01	0,00	0,00	0,00	99,10
PVP003	0,67	0,00	0,01	0,00	0,00	0,02	0,24	0,01	0,00	0,00	0,00	99,04
PVP004	0,49	0,04	0,01	0,00	0,00	0,03	0,22	0,01	0,00	0,00	0,00	99,19
PVP005	0,60	0,47	0,02	0,00	0,00	0,03	0,27	0,00	0,00	0,01	0,00	98,61

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PVP006	0,53	0,07	0,01	0,00	0,01	0,04	0,23	0,00	0,00	0,00	0,00	99,10
PVP007	0,58	0,23	0,01	0,00	0,00	0,04	0,24	0,01	0,00	0,00	0,00	98,88
PVP008	0,58	0,20	0,02	0,00	0,00	0,03	0,28	0,01	0,01	0,00	0,00	98,87
Average	**0,57**	**0,14**	**0,01**	**0,00**	**0,00**	**0,03**	**0,24**	**0,01**	**0,00**	**0,00**	**0,00**	**98,99**

Table 5 - Typical chemical composition of PVP frames as measured by handheld XRF apparatus

Figure 10 - End-of-life aluminium frames from scrapped photovoltaic panels

Frames of electric scoots and bikes

Référence	Mg	Si	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Al
Sco001	1,02	0,67	0,06	0,00	0,12	0,03	0,42	0,02	0,30	0,05	0,00	97,30
Sco002	0,94	0,58	0,05	0,03	0,12	0,02	0,37	0,02	0,29	0,04	0,00	97,55
Sco003	1,02	0,41	0,04	0,03	0,09	0,04	0,36	0,01	0,27	0,08	0,00	97,65
Sco004	1,00	0,54	0,06	0,00	0,25	0,04	0,63	0,01	0,24	0,01	0,01	97,21
Sco005	1,11	0,88	0,06	0,00	0,08	0,03	0,29	0,01	0,31	0,02	0,00	97,20
Sco006	1,11	0,77	0,05	0,02	0,08	0,03	0,27	0,01	0,33	0,01	0,00	97,32
Sco007	1,06	0,95	0,07	0,04	0,09	0,01	0,27	0,01	0,37	0,01	0,00	97,13
Sco008	1,10	0,95	0,11	0,02	0,09	0,04	0,36	0,01	0,25	0,05	0,00	97,01
Sco009	1,10	0,45	0,04	0,00	0,18	0,06	0,67	0,01	0,34	0,02	0,00	97,14
Sco010	1,10	0,34	0,03	0,02	0,12	0,02	0,30	0,01	0,35	0,09	0,00	97,61
Average	**1,06**	**0,65**	**0,06**	**0,02**	**0,12**	**0,03**	**0,39**	**0,01**	**0,30**	**0,04**	**0,00**	**97,31**

Table 6 - Typical composition of electric scoots (and bikes) as measured by handheld XRF apparatus

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Figure 11 - End-of-life aluminium part from scrapped electric scooters

6xxx alloys from production scraps

6xxx	Mg	Si	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Al
PRO001	2,53	1,20	0,04	0,00	0,07	0,46	0,58	0,01	0,08	0,05	0,01	94,98
PRO002	2,61	0,00	0,03	0,00	0,07	0,51	0,34	0,00	0,04	0,01	0,00	96,39
PRO003	2,92	0,06	0,02	0,00	0,08	0,32	0,46	0,02	0,06	0,04	0,00	96,02
PRO004	2,69	0,00	0,02	0,00	0,07	0,58	0,39	0,02	0,04	0,07	0,01	96,12
PRO005	2,71	0,00	0,02	0,00	0,07	0,55	0,41	0,02	0,06	0,05	0,00	96,12
PRO008	0,48	0,15	0,01	0,03	0,00	0,03	0,24	0,00	0,00	0,01	0,00	99,05
PRO009	0,21	0,06	0,03	0,00	0,02	0,11	0,63	0,02	0,14	0,14	0,00	98,64
PRO010	2,74	0,34	0,03	0,00	0,07	0,36	0,49	0,02	0,07	0,04	0,00	95,84
Average	**1,95**	**0,22**	**0,02**	**0,00**	**0,05**	**0,33**	**0,43**	**0,01**	**0,05**	**0,05**	**0,00**	**96,88**

Table 7 - Typical chemical composition of production scraps as measured by handheld XRF apparatus (5xxx alloys)

5xxx alloys from production scraps

5xxx	Mg	Si	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Zr	Al
PRO006	0,78	1,32	0,04	0,00	0,18	0,84	0,41	0,01	0,12	0,22	0,01	96,09
PRO007	0,50	0,41	0,02	0,00	0,02	0,03	0,30	0,01	0,02	0,03	0,00	98,66
PRO011	0,64	0,19	0,02	0,00	0,00	0,04	0,30	0,01	0,01	0,00	0,00	98,79
Average	**0,64**	**0,64**	**0,03**	**0,00**	**0,07**	**0,30**	**0,34**	**0,01**	**0,05**	**0,08**	**0,00**	**97,85**

Table 8 - Typical chemical composition of production scraps as measured by handheld XRF apparatus (6xxx alloys)

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Figure 12 - Aluminium alloy-based production scraps

The registered chemical composition and a visual inspection of the material shown that:

- Rims/Wheels are made of AlSi10MnMg alloy with an Fe content; they don't seem particularly oxidized or corroded. A major fraction of the wheels has an unpainted, metallic surface. It may possess some surface treatment. A minor fraction of the wheels is painted in black color on its lateral areas
- Photovoltaic panels frames are made of 5005 alloy; they seems not corroded nor oxidized. A major fraction of PVP frames is painted in black color (that contain Ti);
- Frames of electric scoots (and bikes) are made of 6061 alloy; are painted in white or red color and possibly anodized or passivated before painting. Similarly, frames from electric bikes are painted in white color;
- 6xxx alloys from production scraps are mainly composed of 6063 and 6082 alloys, and 5xxx alloys from production scraps are mainly composed of 5005 and 5454 alloys. They are not passivated nor anodized, and not painted, certainly because they are the result of stamping and cutting operations. They seem to be not corroded nor particularly oxidized

2.3.2. Shape and size

The evaluation of the shape and size of the scrap supplied by COMET is necessary to define the pre-treatment of the same before being loaded into the furnace and being melted. The Zorba stock of COMET from which 5xxx and 6xxx series aluminium alloys have been selected consists of parts the size range of which is [20 mm; 100 mm].

Dimensions and shapes of the scrap that are too large or too small have a considerable influence on the production capacity, the metal yield and the energy consumption of the melting system, therefore on the choice of the type of furnace.

2.3.3. Presence of organic material

Also, the evaluation of the organic material content in the scrap supplied by COMET has a strong impact on the choice of the type of pre-treatment for the removal of this organic component and consequently also on the choice of the type of melting system of this scrap.

As regards to alternative scraps, one may expect a substantial organic and mineral content from paints on wheels, PVP frames and electric scoots' and bikes' frames; on these parts, some amount of oxide

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might be expected. On the contrary, one may expect no organic content and only some minute oxide content on production scraps.

3. Pre-treatment set up

3.1. Summary of pre-treatment

The objectives of all preliminary processes are to get a higher homogeneity and knowledge of the chemical composition of the scrap by removing non-aluminum parts, increasing the bulk density, and reducing the impurity content. This allows for a better scrap quality.

Figure 13 - From scrap mix to higher quality scrap by pre-treatment process

The principal pre-treatments used by the industry applied to Al scrap are hereafter reported.

3.1.1. Comminution

The scrap collected in the market is usually a mix that looks in a great variety of shapes and dimensions, so the comminution is needed and aimed to reduce this inhomogeneity. The objectives of this process are:

- To reduce the scrap size in fragment, with the dimensions required by the next process;
- To increase the bulk density;
- To disaggregate components that form assemblies.

The comminution can directly affect the melting rate with the scrap size [1], but the main advantage is the possibility to remove undesired materials as rubber, magnesium, and zinc parts from the Al alloy [2]

A variety of machines and equipment are available on the market, specifically rotary shears, rotary cutters, translator shears (guillotine, alligator), and rotary shredders.

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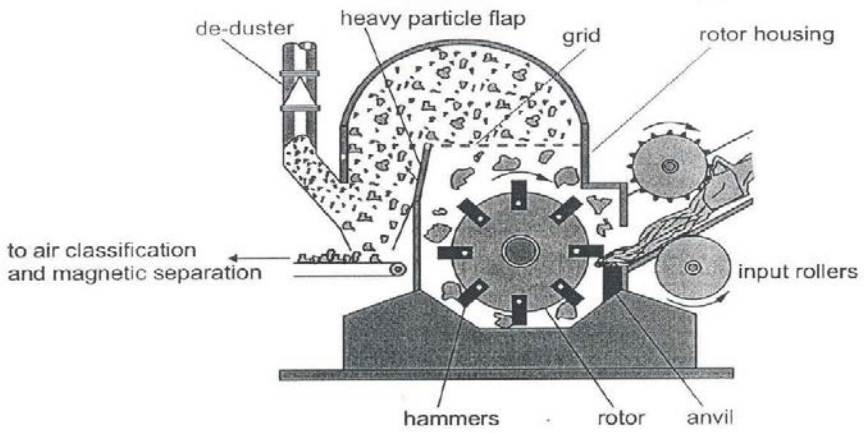

Figure 14 - Illustration of a typical shredder

3.1.2. Sorting

Several sectors and applications use aluminium alloy together with a lot of different materials, so the aluminium scrap inevitably contains residuals of other materials as rubber, plastic, or glass and other metals as steel, copper or zinc. To enhance recycling efficiency and reduce the presence of unwanted elements, the properly sorting of the scrap before melting it is critical. Different types of sorting technologies are available according to the type of the scrap and the desired separation (Table 2).

Method	Separator Type	Physical Parameter	Desired Separation	Technology
Consolidated methods	magnetic separator	magnetic susceptibility	ferrous fraction, nickel-based alloy	magnetic drum, overhead belt magnet
	air separator	mass	low density as paper, foam plastic	vertical zig-zag, air table, elutriator, air knives
	eddy current	conductivity	non-metal, and metal types	eddy current system, electromagnetic system
	dense media	density	non-metal and metal types	soak float, wet jig
	hand sorting	aspect	metal types and wrought-casting alloys	manual operation
	thermal	melting point	wrought-casting alloys	hot crush
Innovative methods	elemental composition	vapor phase, plasma, x-ray energy, γ-ray energy	alloy type	LIBS, XRF, PGNAA *
	image analysis	color and shape	alloy type	color, etch, 3D shape
	transmission	atomic number	alloy type	XRT *

* XRF: X-ray fluorescence, LIBS: laser-induced breakdown spectroscopy, PGNAA: prompt gamma neutron, activation analysis, XRT: X-ray transmission.

Table 9 - Classification of consolidated and innovative sorting methods showing the physically parameter and the desired separation (from: Metals 2018, 8,249)

The separators normally used by Al recycling industries aim to divide aluminium from other undesired materials, but now the innovative technologies and the research on this topic are oriented also to distinguish the alloy group and, if possible, the specific Al alloy. The main sorting technologies used in industry are hereafter described:

3.1.2.1. Magnetic Separation

Magnetic separation is a very common technology and it is extensively used in secondary Al industry. It aims to divide non-ferrous from ferrous scrap and a wide variety of separators are available to perform this job. Drum magnets and overhead belt magnets are the most common technologies used and they differ from one to another mainly for the plant layout. The material to be treated advances on a conveyor belt and it passes near a magnetic field generated by a permanent magnet. This field creates an attractive force to the ferromagnetic materials while non-magnetic particles are unaffected by the magnet. Thus, the sorted scrap by magnetic separation may still contain many non-magnetic contaminants.

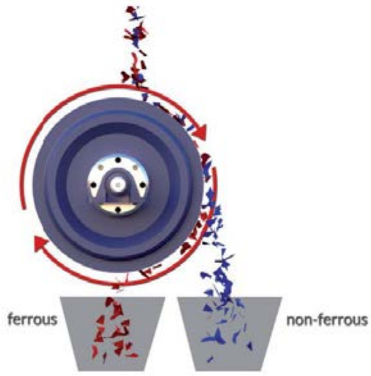

Figure 15 - Magnetic separator scheme

3.1.2.2. Air Separator

Plastics, rubbers, foams and other non-metallic materials are often light-weight and they can be separated using air classifier. Many different technologies are available, but they differ for slightly dissimilar mechanisms. A negative aspect of that has to be mentioned for this separation method is that the lightweight metallic products, such as beverage cans and shredded pieces of a smaller size could be loss.

3.1.2.3. Eddy Current Separation (ECS)

Eddy current separation works by exposing the material to an external magnetic field that repels the non-magnetic electrically conductive metallic particles. This system induces eddy currents in the metals. A time-variable magnetic field, following the Faraday law, generates electromotive forces perpendicular to the magnetic field. If this occurs within a conductive material, an eddy current depending on the material conductivity is generated by the induced forces.

This technology usually use a conveyor tape with a particular magnetic field in the head: when the scrap approach the magnetic field, non-ferrous metals are lifted and discarded to an appropriate collecting duct while the inert materials freely fall down to a container. Since eddy current depends on conductivity of the material, different metals will be thrown away at different distances and it is possible to separate them positioning the collectors at precise distances from the rotor [3] .

3.1.2.4. XRF Sorting System

X-ray fluorescence (XRF) generates a collimated or diverging beam of X-rays to the surface of the material. That excites the material, which then emits secondary X-ray fluorescence radiation. These secondary X-rays are captured by special detectors. The produced energy is characteristic of the elemental emission line and can be linked to the alloying element concentration by an appropriate calibration procedure. If the chemistry of a material meets the set ejection criteria a signal is sent to the ejection unit. This unit is composed of high-speed valves and air jets, operated by compressed air. If the set sorting criterion is met air jets are activated to reject selected material.

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3.1.2.5. LIBS Sorting System

Laser-induced breakdown spectroscopy (LIBS) uses a short and highly energetic laser pulse to ablate a very small amount of material from the surface. In this process a sensor first detects the presence of a particle which is then bombarded with a pulse. The pulse laser illuminates the surface of the metal producing an atomic emission, and the chemical information about the material can be obtained by a spectral detector. Using an optical fiber, a polychromator and a photodiode detector, which are all connected to a computer system, the resulting emission can be transferred to a sorting signal. The sorting signal then activates a mechanical device that forces the identified piece to be placed in a particular sorting bin. Since pulse lasers can only penetrate a small distance into the surface of a metal and therefore the scrap must be free of lubricants, paint, and other coatings. Nowadays, the new generation of LIBS sensor has found a good application for special alloys, i.e., in aerospace and marine applications.

3.1.2.6. Hand Sorting

Manual sorting of material types is still considerably widespread and it is still attractive in countries where the labor cost is low such as China, India and Brazil. The accuracy can achieve up to 99% when sorting non-ferrous automotive shreds, but if aluminium is quite easy to distinguish from other metals (manly zinc or copper) it is still difficult differentiate aluminum by alloy.

3.1.2.7. Dense Media Separator

The difference in density (Table 3) is very useful for the separation of Al scrap from undesired materials. Sink float separation is the most diffused sorting technology based on the density variation. Water-based slurries are used to generate a bath with a known specific gravity (SG) so that materials with different densities can be separated.

Material	Density (kg/dm^3)
Aluminum	2.6–2.9
Lead	10.7–11.3
Copper	7.5–9.0
Stainless steels	7.5–7.7
Brass and bronze	5.2–7.2
Zinc	5.2–7.2
Magnesium	1.7–1.9
Polyvinyl chloride	1.4
Polystyrene	1.0–1.1
Polypropylene	0.9
Rubber	0.8–0.9
Wood	0.4–0.8
Polymeric foam	0.01–0.6

Table 10 - Densities of aluminium and contaminant materials [4]

In the first floatation stage, in which pure water (SG = 1) is used as the separation media, most of the non-metallic materials, such as low-density plastics, foam, and wood, are floated out and removed. The sink portion of the first stage is then transferred to the second media slurry with a SG of 2.5. Here, high-density plastics, magnesium and hollow aluminum alloys are removed by floatation. Then, a third bath with a specific gravity of 3.5 is able to separate casting and wrought Al alloys, leaving behind heavier metals such as copper, zinc, and lead.

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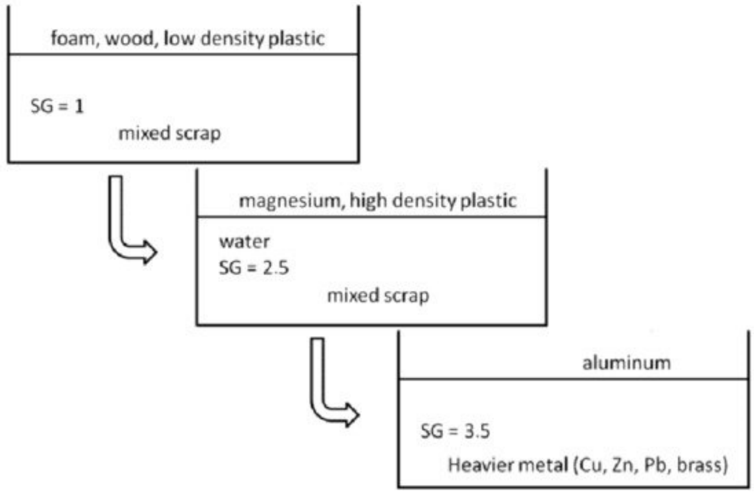

Figure 16 - The steps of sink float sorting technology with different specific gravities (GS)

3.1.2.8. X-ray Transmission Sorter (XRT)

The mass-absorption coefficient depends on the compositional elements. The X-ray transmission (XRT) sorter analyzes the difference of the mass-absorption coefficient and separates the target material from the others. The intensity of the incident X-ray, is attenuated while passing through a layer of sample with thickness *t* according to the Beer–Lambert law. This technology is sometimes coupled with other techniques, such as XRF and eddy current.

3.1.2.9. Other sorting system

Other sorting system [5] are available on the market but their use are not so widely used by the industries, or are still on a development stage, such as:

- hot crush;
- PGNAA - Prompt gamma ray neutron activation analysis;
- Color sorting.

3.1.3. Heat treatment-decoating

Pre-consumer aluminum scraps, but especially end-of-life scraps, such as beverage cans, food containers, building materials, and car parts are usually covered or lined with organic materials.

We can find scrap with cutting fluids (emulsions), paints, lacquers and inks used to improve corrosion resistance and appearance up to organic materials that are very difficult to remove, such as foams, plastics and rubber

In order to obtain the best possible metal yield and therefore a reduced production of dross during the melting of the scrap, it is necessary to remove all the organic component present before it comes into contact with the aluminium in the liquid state.

The process has not only important economic and environmental advantages, but also safety-related advantages; in fact, by heating the scrap to remove the organic component, any water content present in the scrap is suppressed, avoiding the risk of explosion and oxidation of the metal itself

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There are different methods and specific solutions to remove the organic component in aluminium scrap. The choice of the most suitable system depends on the quantity and type of organic material present in the scrap

The main industrial processes used to remove organic coatings applied to aluminium scrap are listed below.

3.1.3.1. Decoating

Decoating is a process by which the coatings applied to aluminium products are removed from the scrap material. Aluminium can be found in an array of products, from beverage cans and food containers to construction materials and car parts in a wide variety of forms and they possess a wide range of coatings. These can be related to the manufacturing process, such as cutting fluids, and to the final use, such as paints, lacquers and inks used to improve corrosion resistance and appearance. De-coating is the process by which paint, ink, paper, plastic, and oil are removed from the surface of a material to enhance recyclability. The scope of this thermal process is to combust the carbonaceous materials without oxidizing the metal. For this purpose, it is usually used a rotary kiln that utilize high temperatures and a controlled atmosphere to remove volatile organic compounds from the aluminium by converting them to a gaseous state. In the kiln the scrap comes in contact (countercurrent) with a pyrolytic gas at a temperature of 500-550°C. At this temperature the coatings on the surface are removed. The pyrolytic gas, fresh out of the oven enters an afterburner and the residual carbon content reacts with the oxygen during the combustion phase, generating CO, CO2 and heat, that is used to preheat the air used in the kiln, obtaining a saving of the energy.

The decoating process can eliminate all types of organic materials and is strongly recommended when the aluminium scrap contains a high level of organic, greater than 5%.

The decoated scraps outs from the kiln at a temperature of 350-400°C and it is usually loaded directly in a static oven by means a conveyor belt, optimizing the energy saving of the melting.

3.1.3.2. Dryer

The dryer is a process for removing cutting fluids, containing oil or solvents, from small aluminium scrap such as chips.

It works like decoating process, the chips containing the emulsion are introduced into a rotary kiln where it meets a counter-current air flow at a high temperature (about 500 °C) and with a very low oxygen level (about 10%) to avoid burning the oil present in the scrap and therefore to oxidize it.

This process is only suitable for removing cutting fluid from small aluminium scrap such as chips.

In order to obtain a high energy and production efficiency of the drying process, the chips with emulsion values higher than 15% are previously centrifuged to reduce the amount of water and oil present.

3.1.3.3. Multi chamber melting furnace

Multi chamber Melting Furnaces are generally based on integrated scrap preheating/de lacquering process.

They are designed for remelting of scrap with impurities like oil, paint and plastic. Total non-metallic, organic substances may reach 5% of charge weight, subject to calorific value.

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Scrap is charged with a charging machine onto the dry hearth ramp for preheating and gasification of organics. Thereafter the scrap heap is pushed into the melt bath by the charging machine or an integrated scrap pusher.

The time to fully preheat the entire scrap heap to about 500°C depends on the type of scrap and the density.

For an adequate preheating of the loaded scrap and for the gasification of the organic component, the multi-chamber furnace blows hot air from the main chamber towards the scrap which, when heated, releases the organic substances. the hot fumes containing the gasified organic substances are then introduced into the hot chamber for their destruction, generating heat.

This process of combustion of the organic component leads to obtaining a saving of the energy necessary for melting the scrap.

4. General Procedure for scrap processing

The different types of scrap proposed by COMET can be considered different in:

- initial metal content;
- type and content of impurities;
- geometry.

For that reason different way of pre treatment have to be considered to maximize the metal yield of each kind of material.

4.1. Procedure for zorba stream scrap

End-of-life smelting scrap from the Zorba fraction will be evaluated for use in producing AlSi10MnMg alloy for the SALEMA project.

Currently, based on the numerous tests carried out by COMET and Raffmetal, these difficulties of use are highlighted

Chemical composition

Chemical analyses carried out on the materials selected by Zorba show a high content of Copper, Iron and Zinc since the scrap present consists mainly of internal combustion engine castings (typical composition: AlSi9Cu3).

The values found are considerably higher than those needed to produce AlSi10MnMg alloy, thus not suitable for such low impurity alloy productions.

Foreign material

Smelting waste from the Zorba stream normally contains a high amount of foreign material, mainly:

- organic material (paint, oil and plastic);

- surface oxide (due to the high copper content in the alloy).

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Therefore, all Zorba waste must be heat-treated before casting and, in order to remove the oxide present in high amounts on the casting surface, it must be melted in salt.

4.2. Procedure for alternative material

About the alternative material it is necessary to consider in a different way the end of life material (PVP, frames of electric scoots and bike, rims/wheels) from the scrap coming from the production (stamping process).

4.2.1. End of life material: PVP and bikes frame

End of life material, as frames of bikes, scoots or photovoltaic panels, have to be shredded to reduce and homogenize the dimensions of the scrap. Range 20-100 mm proposed by COMET could be quite large, and could be reduced by a 25% using an hammer mill with a grid of 80x80 or 70x70 mm dimension. The crushed material at the exit of this process will be in a range of 20-80/70 mm. COMET provided a manual selection of the scrap, so it could be reasonable think that no other unwanted material will be present, while we have to consider the presence of iron (bolts screws rivets), copper (wire, collectors), plastics, rubber and others if this manual selection was not done. So the next steps will be to pass the scrap through a drum magnetic separator, that will provide to separate ferrous from non-ferrous material. After the scrap has been deferred, it is necessary to carry out a separation according to the size of the material, by using of a drum with 3 section with holes of different sizes on its surface: at the end the material will be separate in 3 different range of dimensions: fine (0-15 mm), medium (15-30 mm), oversize (>30mm). This separation is applied to ensure that the downstream machines, in particular the X-ray sorters, work as much as possible with material of very similar dimensions. Medium and Oversize material have to be processed by an ECS (Eddy current Separator) machine and a X-ray machine. The eddy current separator will remove non-ferrous metals from inert material while X-ray will remove copper and zinc.

The smallest material (Fine) with dimensions below 15 mm is usually a processing waste, this is because pieces of scrap with small dimensions have usually high percentages in the chemical analysis of silicon and zinc.

The final product is a very homogenous scrap but it still contains organic material mainly due to the paint presents on the surface of the frames, so the scrap have to be heat treated before melting.

At the time of writing, it was not possible to measure the yield of metal from the scrap provided by COMET, but similar material, usually available on the market and commonly pre-treated and used by Profilglass, have this mass loosing (% in weight) through the pre-treatment and melting process:

- magnetic separator: 1-3%
- size sorter: 4-6%
- ECS + Xray: 7-11%
- decoating: 0.5-2%
- melting: 3-5%

So the final yield is about 75-85%. About the heat-treatment a decoating process is preferable due to the unknown organic content in the scrap.

It is understood that if the scrap from COMET is already sorted and selected, Profiglass can evaluate only the lost mass in the decoating and melting process, and in this case the estimable yield increased up to 93-96%.

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4.2.2. End of life material: rims/wheels

The aluminum alloy rims, divided into whole and crushed, are processing differently according to their shape and dimension.

4.2.2.1. Entire Rims

For each single rim the chemical composition (with a mobile spectrometer) and the level of inclusions such as free iron, weight balance (lead or zinc) and valves (brass) and paint thickness must be checked.

4.2.2.2. Crushed rims

A representative sample of approximately 300 kg of the load will need to be melted to determine the chemical analysis and yield of the metal and the amount of organic material. At the end of the selection process the scrap is homogeneous but it still contain organic material mainly paint presents on the rims surface, so they have to be heat treated before melting.

In Raffmetals experience, the process of sorting, heat treatment, and melting of whole and crushed rims results in a loss of metal yield, so at the end of the scrap processing, we estimate a metal yield of 90-96%.

4.2.3. Alloys from production scraps

The scraps coming from the production, as the result of stamping or cutting operation, are not painted, not passivated nor anodized, and seem to be not corroded nor particularly oxidized. For that reason this material does not require special pre-treatments. At the time of writing it was not possible to check directly the material proposed by COMET but scrap available on the market of this type is usually in range of thickness 0,5-5 mm, and the lubricant/oil in case present is negligible. So this material could be used directly in the melting furnaces. A cutting operation before melting could be useful to better manage the materials. In the case of presence of a PVC layer and/or paint, the material have to be shredded and melted in a multi chamber furnace.

The yield of the scrap is usually of 95-97%. If the presence of PVC or paint request the use of a multi chamber furnace the yield decrease between 93-95%.

5. Conclusions and Outlook

Innovative sorting systems such as LIBS, used in the SALEMA project, allow us to identify and separate scrap based on its chemical composition.

Normally scrap is separated to recover material with low levels of impurities (iron, copper, etc.), but the SALEMA project has also taught us how to separate scrap to enhance the critical elements such as silicon and magnesium contained in the scrap.

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This scrap valorization, based on the presence of the alloying elements (critical and non-critical), will allow us in the future to use the right scrap to produce the right alloy, with obvious savings in natural energy resources and a significant reduction in the extraction of raw materials from the ore.

The scrap supplied by COMET should not need further processing and sorting, as it should already meet the quality requirements for producing alloys for application to electric car chassis.

The level of cleanliness and organics of COMET-supplied scrap appears to be limited to a layer of paint that prevents direct use of such material in melting furnaces.

Such scrap requires treatment to remove the paint present by heating the scrap to high temperatures before it comes into contact with the liquid aluminum contained in the melting furnace.

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