COMETa 2018
4th INTERNATIONAL SCIENTIFIC CONFERENCE
27th - 30th November 2018
Jahorina, Republic of Srpska, B&H
University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

IMPROVING THE QUALITY OF INNOVATIVE PROCESSES IN THE CONSTRUCTION OF ELV RECYCLING EQUIPMENT

Lozica Ivanović[1], Andreja Ilić[2], Aleksandar Aleksić[3], Miroslav Vulić[4]

Abstract: Considering the increasingly stringent regulations in the field of environmental protection, one of the main goals of the car manufacturers is to improve the design of the vehicle through the use of light metal materials. A light vehicle plays an important role in increasing fuel economy, supporting the increased usage of aluminium in the production of cars. The benefits of using aluminium are not only in a significant reduction in weight compared to other materials, but also in the fact that it can be recycled without loss of quality. Because of numerous ecological and economic benefits by recycling aluminium it is necessary to improve collecting technics and aluminium recovering from ELV. A literature survey shows that a newly developed technique, such as Laser-induced breakdown spectroscopy (LIBS), provides a good alternative to conventional sorting techniques, as it can lead to significant energy savings and efficient classification of non-ferrous metallic automotive scraps. This paper shows an overview of the available results of improving the recycling technique of aluminium, with the aim of promoting a continuous enhancement of the recycling process as a key component of sustainability.

Key words: Aluminium scrap, Laser-induced breakdown spectroscopy, Recycling, Sorting

1 INTRODUCTION

Development of the modern recycling centres for the End of life vehicle (ELV) treatment imply reducing of the costs of mechanical treatment of auto-residual recycling residues. In the same time, it enables the introduction of innovative technologies that should provide bigger separation level of different materials after crushing.

The aim of sorting the crushed waste is to obtain pure metal fractions from a very complex and different flow input. The input material contains magnetic metals such as steel and iron, and non-magnetic metal fractions such as aluminium, magnesium, copper, zinc and brass, as well as plastics, glass and other composite materials.

[1] PhD, Lozica Ivanović, University of Kragujevac, Faculty of Engineering, Serbia, lozica@kg.ac.rs (CA)
[2] PhD, Andreja Ilić, University of Kragujevac, Faculty of Engineering, Serbia, andreja.coka@gmail.com
[3] PhD, Aleksandar Aleksić, University of Kragujevac, Faculty of Engineering, Serbia, aaleksic@kg.ac.rs
[4] MSc, Miroslav Vulić, University Business Academy in Novi Sad, Serbia, miroslavvulic@live.com

Progressive usage of electronic products and new design concepts of “light“ vehicles have brought huge demand for high-quality secondary raw materials of non-ferrous metals, especially copper and aluminium. Traditional methods of separation such as magnetic separation, indicates a good results for magnetic materials but new technologies for sorting non-ferrous metals are necessary. One of the research challenges is the development of a sorting technology that would generate clean non-ferrous metals from automotive waste.

The development and usage of technologies for sorting based on the sensors and automated sorting systems could overcome weaknesses of conventional methods and could contribute significantly to the development of the recycling process ELV [1, 2]. Some of the research results in this field will be presented and discussed about hereinafter.

2 RECYCLING OF NON-FERROUS METALS

Nowadays, huge part of the total resources which are using in automotive production is obtained by using recycled metal components. The use of waste metal has become an integral part of the modern industry which improves economic industry sustainability and reducing the impact on the environment [3]. Compared to extraction of ore, the use of secondary metals significantly reduces CO_2 emissions, energy and water consumption and air pollution. At the same time, recycling of metals makes more efficient use of natural resources of the country. Because of that, the metal industry strives to replace primary resources with secondary raw materials as much as possible. Figure 1. shows a comparative overview of the amount of new metals obtained using recycled material, as well as the energy savings that are materializing in this process [4, 5].

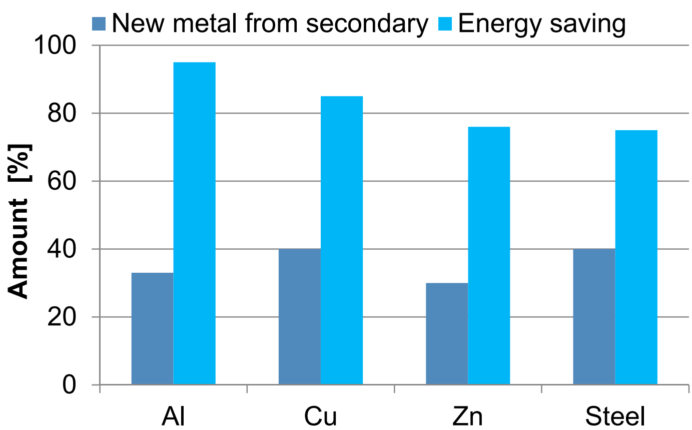

Figure 1. *Effects of production of the different metals using recycled material*

In comparison with other materials such as copper, zinc and steel, aluminium production creates the biggest difference in energy between primary and secondary ways but it is not case with share of secondary production with regard to the total (Figure 1). The recycled aluminium fraction is about 33%, which is close to the value of recycled zinc (> 30%), while copper and steel materials with the highest impact in terms of recycled amounts (> 40%). Beside of that, in comparison with production of primary aluminium, by recycling of aluminium products it is emitting only 5% of gases to the greenhouse effect, by recycling cooper 35% and steel 42% [5].

Metal recycling industry has a big potential because of great demand for the secondary raw materials. However, without using the contemporary sorting equipment, valuable materials can be lost in the residual waste stream and the quality of the recovered fractions could not generate the actual value [6]. Because of economic reasons it is important to assort the mixtures of waste metals in the different fraction. Separation of copper and brass is technically solved and adequate devices for industrial use are available. Separation of the other metals and alloys is much more difficult because that their characteristics are very similar, like colour and electrical conductivity. For the non-ferrous metal industry, the separation of aluminium and various cast and forged alloys of aluminium is of particular importance.

Production of passenger cars in Germany is increasing from 4.7 in 1997 to predicted 6.9 million units per year in 2040. Besides that, application of advanced concepts in car design implicate much higher demand of aluminium products from 460 thousand tonnes in 1997 to predicted between 2,160 and 3,450 thousand tonnes in 2040. Furthermore, increasing of passenger cars production with simultaneous increasing share of aluminium-intensive vehicles must be followed by improvement in sorting technology. Necessity of improvement in sorting technology of wrought and casting alloys comes from the fact that the absolute amount of old scrap is higher than the casting demand [7].

Usage of high-strength, low weight aluminium for making of elements of car and truck construction will continually increase during the next decade with higher level of increase more than any time till nowadays. It is expected that total aluminium content will grow from around 180 kg per vehicle (397 PPV) in 2015 to around 256 kg (565 PPV) in 2028, that represent about 16 percent of total vehicle abridge weight [8]. Uninterrupted growth of aluminium content in light vehicles during next decade is basic assumption of all present mass reduction scenarios. Strategy for the 7% mass reduction by 2028 involves an average addition of around 6 kg (12-15 pounds) of aluminium content per year starting from 2015 onward as it is presented in Fig. 2 [8].

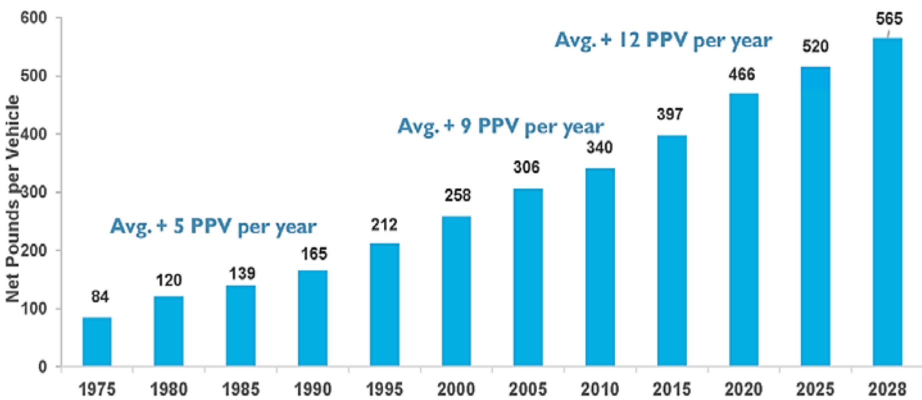

Figure 2. *Accelerating aluminium used in automotive [8]*

Aluminium is material that is the most recycling, after steel and paper. As indicated, recycling of aluminium is not only economically sustainable, but also energy and environmentally efficient. By recycling, aluminium does not lose original physical characteristics and with the help of that it can be recycled unlimitedly into new products. In order to obtain useful aluminium, pure aluminium must be added to the secondary resource until the concentration meets the specifications. This secondary resource still contains small amounts of other metals that are not sorted and one of the aims is to get small as possible amounts of inclusions in aluminium waste.

Compared to aluminium, aluminium alloys can provide improved performance and because of that they are suitable for engineering applications in various industrial sectors. In the automotive industry, bigger use of cast and forged aluminium alloys is noticeable in the bodywork construction and engine parts, and thanks to the development of new technologies, advanced alloys are becoming more and more used [8].

In the recycling process, aluminium and zorba, which is a waste that containing a mixture of non-ferrous metals (predominantly aluminium and aluminium alloys) from the ELV process [9], are usually sent directly to the foundry after crushing and sorting.

Recycled aluminium alloy ingot is the output of scrap melting. Recycled aluminium alloy ingot can be used interchangeably with ingots made of primary aluminium, means that recycled aluminium alloy substitute primary aluminium. Presented facts implicate that aluminium economy have cyclic character. It can be stated that aluminium is not consumed but rather used in present. Cyclic character means that life cycle of an aluminium product is "cradle-to-cradle" in practise, not “cradle-to-grave" as it is characteristic for linear life cycle. The life cycle of usual aluminium product typically ends when the recycled aluminium is extracted in a form that is usable for making of completely new aluminium product that means that an ingot is used to fabricate and manufacture new products. Characteristic cycle of aluminium product life is presented in Fig. 3 [10].

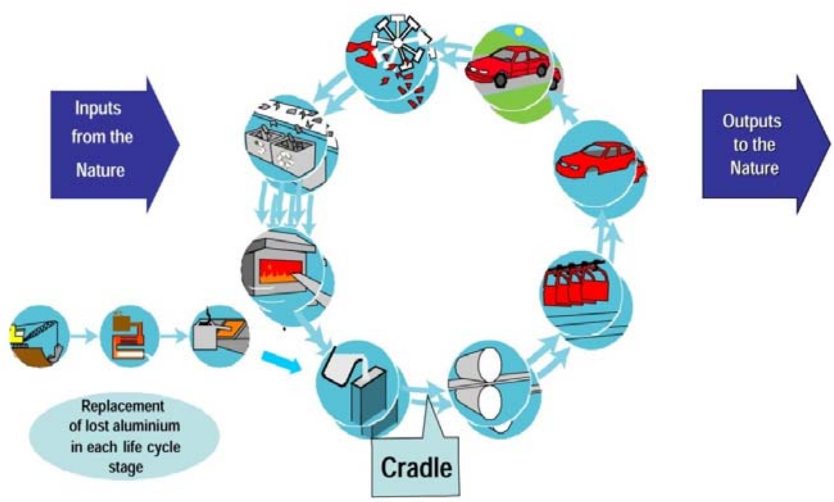

Figure 3. *Closed-loop aluminium material flow [10]*

Compared to many other metals, the challenge is to remove unwanted elements from aluminium and its alloys. There are different solutions dealing with the separation of unwanted elements and each represents a compromise between the cost and the separation efficiency [11]. Depending on the waste composition, several traditional physical separation and sorting technologies can be applied to obtain high-quality fractions of non-ferrous metals.

Method of separation of the non-ferrous and ferrous scrap components by using of magnetic forces is known as magnetic separation. Usually two conveyor belt near each another with the scrap materials are used. One conveyor belt equipped with NdFeB magnets. When scrap is near to magnet, the ferromagnetic portion of scrap (steel and some iron) is attracted to the magnet and pulled onto the conveyor belt while the non-ferrous portion falls into a collection bin. This sorting method is widely used in the recycled aluminium industry [11].

Using of Eddy currents soon became standard industry practice for further separation of non-ferrous automotive shredder residue. Eddy current separation method is based on advantage of the large range in conductivities of many of the mixed metals present in scraps. Concept of Eddy current separation is a similar to concept of magnetic separation. A rotor is lined with NdFeB magnets with alternating north and south poles Nonmagnetic electrically conductive metals are pulled by external magnetic field produced by rotor. This provokes their removal from the scrap stream, leaving the non-metallic particles. Rotor speed controls the magnetic field [11].

The manual sorting method is still significantly widespread in present sorting. High purity level is characteristic for this sorting method. High labour cost for this process implicate that this sorting method is used only as a final check for quality control purposes. Manual sorting method can differentiate aluminium from other materials such as copper and zinc. It is still a challenge for this separation method differentiation of specific Al alloys. However, the possibility of identifying castings against wrought Al alloys on the basis of their different appearance is not possible [4].

Separation of Al scrap from undesired materials can be based on the difference in density. Sorting method based on the density variation is known as sink float (Dense Media) separation. Separation of non-ferrous materials with a different density is done by using of water-based slurries with known specific gravity [4].

For the sorting of alloys contained in automotive waste of non-ferrous metals, other technologies based on sensors and laser-induced spectroscopy are being developed, which is a present significant contribution to increasing the recycling rate of valuable metal fractions [12,13].

3 INNOVATIVE SORTING METHODS IN ALUMINIUM RECYCLING

In the past few years, researchers are focused on the development of innovative technology for separating high quality fractions from ELV, and some of the most important existing technologies and systems are presented below.

Sorting metals which is based on the atomic density at high capacity without regard to surfaces and material thickness is using with X-Ray Transmission (XRT). After the non-ferrous scrap stream moves through ECS, a conveyor belt system carries the scrap to the XRT equipment's feed mechanism. The x-ray source and ejection method of the individual scrap piece's belt location is alerting by laser, 3D camera and weighing scale. Below and above the conveyor belt are positioned an x-ray source tube and an x-ray detection system. Once the belt location and density are known, the ejection system is alerted to either fire the compressed air or pneumatic hammer system to induce separation or to allow the scrap piece to fall if the material's density does not meet the pre-programmed criteria. Zorba could be converted into furnace ready aluminium by utilizing an XRT based system [14].

Beside the analysis of the elemental composition of metals, X-Ray fluorescence (XRF) has more possibilities than XRT. XRF identify alloying elements and their respective weight percentages by technology of x-ray fluorescence detection from an unknown scrap. Otherwise low energy x-ray radiation is fired at the scrap streams which leads to the excitation of low-energy electrons causing them to eject from orbit. The material is excited by low-energy x-ray radiation and element specific fluorescence is released. With an energy dispersive x-ray sensor this fluorescence can be measured. Result is processed data and information about the presence of elements and their concentration. For basic stainless sorting and some non-ferrous alloy grade separations, XRF has traditionally been used but determining the difference between types of aluminium has always been a challenge [4].

The overview of upgrading technologies available at both the industrial and lab-scale for improving purity of aluminium scrap and facilitate recycling is known to researchers and practitioners [13]. The wide range in technologies already available highlights the fact that models are necessary in order for producers to properly choose which upgrading technology will have the most benefit.

Three high-value metals that make up most of the non-ferrous fraction - copper, aluminium and brass are sorting by MIS (magnetic induction spectroscopy) which is a new classification method [15]. Metal recycling uses induction sensors that are distinctly applicable: They are low-cost, reliable, practical, and robust. They are resistant to harsh environments and they are unaffected by variable lighting or dirty samples. However, their performance is dependent on a degree of homogeneity in the geometry of the metal fragments; something difficult to achieve in practice [6]. Multi-frequency induction sensors and a simple, straightforward classification algorithm are using for projection of an effective non-ferrous metal sorting system which present main conclusion. Magnetic induction spectra and the selection of frequency components as features, based on the physics of how induced eddy-currents circulate in metal objects are newest aspects. Frequency components that are chosen as features: (1) A high frequency component, where magnetic field penetration is negligible, to model the geometry of the metal fragments, and (2) a low frequency component, where skin-depth is significant, which is a function of both geometry and conductivity of the fragments. If these key criteria are satisfied, good performance rates could be achieved and well-suited to industry needs [15].

Recent advances in physical processes, sensors, and actuators used as well as control and autonomy related issues in automated sorting and recycling of source-separated municipal solid waste are presented in [16].

Laser Induced Breakdown Spectroscopy (LIBS) utilizes a high-power laser pulse [1]. A LIBS system is composed of a solid state (Nd:YAG) Neodymium-doped yttrium aluminium garnet laser, a CCD spectral range spectrometer and a processing unit for fast data analysis (Figure 4). First step is collecting of waste into the inspection area, which is a further task of the laser. This leads to ablation of waste material, which generates plasma plumes. CCD spectrometer capture the radiation from emitted the ablated portion. Optical spectroscopy reads and distinguishes the characteristic atomic emission lines and enables a quick analysis of the bulk waste followed by the detection of constituent materials. Next step is sorting of the detected constituent materials into their respective bins [16].

Comparing LIBS with the eddy current technique shows that the segregation of waste takes place at a relatively higher volume and speed with LIBS. A limitation of LIBS is that the waste sample must be free from lubricants, paints, or oxide layers, which is difficult to achieve in practice [16].

Separating both cast and wrought aluminium into their individual alloys is currently possible only with LIBS. Using the LIBS 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, with possibility that the chemical information about the material could be obtained by a spectral detector.

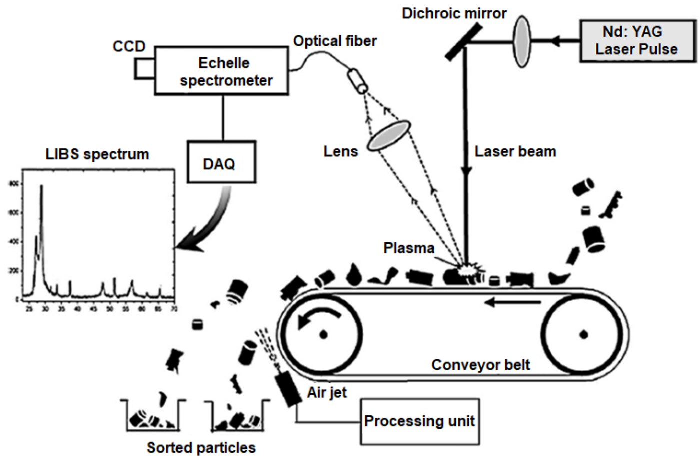

Figure 4. *Components of a LIBS sorting system [16]*

The resulting emission could be transferred to a sorting signal by using of an optical fiber, a polychromator and a photodiode detector which are all connected to a computer system. After that the sorting signal activates a mechanical device which forces the identified piece to be placed in a sorting bin. Separation of the scrap particles into specific alloys is completed by that [13]. Even if the scrap is free from these, the oxide formation on the surface could cause erroneous reading. The new generation of LIBS sensor, like this one, seems to have overcome this problem and has found a good application for special alloys [10].

Because of that, overview about LIBS studies published in the last four years focusing on industrial applications or perspectives therefore is given in [2]. LIBS is the best analytical method which offering such a wide range of measuring distances for chemical analyses [2].

4 CONCLUSION

This research shows currently difficulties of ELV recycling industry and innovative recycling approaches, in the first place using aluminium in cars. Also, paper presents potential of new recycling technology for aluminium and different aluminium alloys.

With concept of „light weight“ in the automobile applications and with the climate changes provides higher aluminium using in the cars. Usage of recycling aluminium instead of primary aluminium metal results with the reducing of the greenhouse effect and energy savings. High value of aluminium waste is the crucial economic effect for the recycling. In practice, recycled aluminium alloys replace primary aluminium alloys for new aluminium products. Also, in practice, ELV process includes selective dismantling with the accent on the dangerous and reusable components. New developed technologies, as LIBS, provide possibilities of using different applications for recycling automobile industry.

Development of new sorting technologies is crucial for recycling aluminium promotion in the high purity alloys which provide better environmental protection and economy and resource savings. Electromagnetic and spectroscopic characteristics of new sorting technology would provide higher contribution to recycling aluminium.

ACKNOWLEDGMENT

This paper is a result of the research activities conducted under the projects "Sustainable development of technology and equipment for motor vehicles recycling" TR 35033, which is financed by the Ministry of Education, Science and Technological Development of Republic of Serbia.

REFERENCES

[1] Anabitarte, F., Cobo, A., Lopez-Higuera, J.M. (2012) Laser-Induced Breakdown Spectroscopy: Fundamentals, Applications, and Challenges, International Scholarly Research Network, *ISRN Spectroscopy*, Article ID 285240, 12 pages

[2] Stojanović, B., Bukvić, M., Milojević, I., Ivanović, L., (2018) Influence of recycling of electric vehicles on energy consumption and greenhouse gas emissions, *ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering,* vol.11, no.1, p.p. 127-132.

[3] Noll, R., Fricke-Begemann, C., Connemann, S., Meinhardt, C., Sturm, V. (2018) LIBS analyses for industrial applications – an overview of developments from 2014 to 2018, *J. Anal. At. Spectrom,* JAAS, The Royal Society of Chemistry 2018.

[4] Capuzzi, S., Timelli, G. (2018) Preparation and Melting of Scrap in Aluminum Recycling: A Review, *Metals*, vol. 8, no. 4, 249.

[5] http://www.bir.org, accessed 15.07.2018.

[6] https://www.tomra.com/en/sorting/recycling/your-application/metal-sorting/end-of-life-vehicles-scrap, accessed 22.06.2018.

[7] Zapp, P., Rombach, G., Kuckshinrichs, W. (2002) The future of automotive aluminium, *Light Metals* 2002, Seattle, USA

[8] Ducker Worldwide, (2017), Aluminum content in North American light vehicles 2016 to 2028, Summary Report.

[9] Report on Recycling of Automobiles with ALIVE Technologies, 2015.

[10] Aluminium Recycling in LCA, (2013), European Aluminium Association, LCA study version: September.

[11] Gaustada, G., Olivetti, E., Kirchain, R. (2012) Improving aluminum recycling: A survey of sorting and impurity removal technologies, *Resources, Conservation and Recycling*, 58, p.p. 79– 87.

[12] Margarido, F., Novais Santos, R., Durão, F., Guimarães, C., (2014), Separation of Non -ferrous Fractions of Shredded End-of-life Vehicles for Valorising its Alloys, Proceedings of the International Conference on Mining, Material and Metallurgical Engineering, Paper No. 77, Prague, Czech Republic, August 11-12.

[13] Cui, J., Roven, H. J. (2010) Recycling of automotive aluminum, *Trans. Nonferrous Met. Soc. China*, vol. 20, no. 11, p.p. 2057-2063.

[14] Kelly, S., Apelian, D., (2016), Automotive aluminum recycling at end of life: a grave-to-gate analysis, *Final Report*, Center for Resource Recovery and Recycling (CR3), Metal Processing Institute, Worcester Polytechnic Institute.

[15] O'Toole, M., Karimian, N., Peyton, A. J. (2017) Classification of Non-ferrous Metals Using Magnetic Induction Spectroscopy, *IEEE Transactions on industrial informatics*

[16] Gundupalli, S. P., Hait, S., Atul Thakur, A. (2017) A review on automated sorting of source-separated municipal solid waste for recycling, *Waste Management*, vol. 60, p.p. 56–74.