RECYCLING OF AUTOMOTIVE SHREDDER RESIDUE BY GRANULOMETRIC SEPARATION

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Recycling of end-of-life vehicles at shredder plants, among well-managed metal recycling, ends up with huge amounts of waste residue, for which the complex recycling route is still missing. Automotive shredder residue (ASR) is often called light fraction, because after the separation of all the metal particles (by magnetic drum, eddy-current, pneumatic separator and multiple unites of sieving) it contains mostly non-metallic materials like plastics, rubber, wood, paper, textile, leather or glass. There is a small content of metals (Fe, Cu, Zn, Cr, Ni), but is low and the value of other materials cannot cover the costs for multi-stage recycling of light fraction. However, the presence of heavy metals and their compounds (~ 5 wt %) is the reason why is the light fraction classified as a hazardous waste.

The possibility to separate the metal-bearing part of a light fraction based on the granulometric differences in contained materials has been investigated. The system of test sieves was used for the granulometric separation and sample was divided into following granulometric classes + 50 mm, - 50 + 25 mm, - 25 + 15 mm, - 15 + 10 mm, - 10 + 0 mm. Material of the grain size < 10 mm was grinded down on a mortar grinder and sieved further to + 0.5 mm, - 0.5 + 0.315 mm, - 0.315 + 0 mm. The obtained fractions were subjected to chemical analysis for the content of Fe, Zn, Cu, Ni and Cr and the material recycling has been proposed.

As for gaining both, metals and potential secondary fuel, method of sieving was compared with more complicated process consisting of sieves, magnetic separator, eddy-current separator and air separator.

KEYWORDS

end-of-life vehicle, light fraction, ASR, sieving, recycling, heavy metals

1 INTRODUCTION

Non-metallic components represent about quarter of the total weight of a passenger car, which is a considerable amount of material, proportionally growing with the increasing number of annually discarded vehicles.

Article 7 of Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of-life vehicles ("ELV Directive") declaims that the Member States shall take the necessary measures to ensure the target for all end-of-life vehicles 95% of reuse and recovery and 85% of reuse and recycling by 1 January 2015 [Law 79/2015 on waste 2015], Directive 2000/53/EC 2000].

To process 95% of the vehicle means the need to start recycling even the waste residue from the shredding process, a light fraction, because it represents one quarter of the car weight. Twelve years after Slovakia joined the European Union, so far processing of light fraction did not receive sufficient attention. Related to the huge amounts of produced light fraction (10,000 tons/year just in Slovakia), the processing becomes more and more acute and strategic task [Kanari 2003].

Due to its character, current efforts to process light fraction from shredding plants are moving in two directions. Figure 1 shows the average material composition of the light fraction, which indicates that this material has as energy potential as well as the potential to recover metals [Granata 2009], [Morselli 2010].

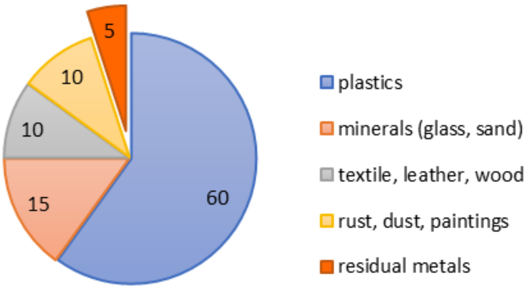

Figure 1. Material composition of light fraction [wt.%]

In automotive industry, there is number of feasible technologies applied for the separation of metallic and non-metallic components of end-of-life vehicles. There exist cost effective methods for the separation of the light fraction and its transformation into energy and mineralogical-rich fractions. Part of the material can be converted to useful products, part of it energetically evaluated. However, in practice the quantity of used separation technologies that could actually recycle light fraction, is not sufficient to cover the whole global increase of discarded vehicle. Processing of hazardous waste with a low metal content is inefficient, and much easier to deal with is disposal of light fraction. It is still true, that environmental taxes are more convenient than investment in new recycling technologies [Kanari 2003], [Granata 2009].

The competition between the car manufacturers and increasing fees are one of the reasons for the implementation of a variety of mechanical and thermal processes, which are used today for the treatment of light fraction. Collectively they are known worldwide as post-shredder technologies. Mechanical separation is commercially used in processes SiCon, SRTL, Suit, Scholz, R-Plus and Argonne. Examples of commercial processes using thermic treatment are Citron, TwinRec, Schwarze Pumpe or Reshmet. While the driving force in this respect remains for the major car manufacturers, who want to demonstrate an environmental policy, generally, processing of old vehicles is running on tracks established years ago and far insufficient attention is paid to this commodity [Zorpas 2012], [Intention 2016], [Cossu 2012], [SiCon 2016], [Toyota 2014], [Santini 2012], [Hwang 2008], [Galvagno 2001].

The aim of this work is to show a simple, flexible and economical solution for the separation of light fraction, which could be easily applicable beside the landfilling huge volumes of hazardous waste. In not ideal scenario, proposed sieving, as described in the paper, can at least lead to significantly reduced quantity of waste, which ends up at the landfills.

2 HYPOTHESIS

Light fraction from shredding of old vehicles is a heterogeneous mixture in terms of composition and particle size. It contains plastics, rubber, wood, paper, textile fibres, lather, glass, oil and a small amount of the metal-bearing material. There is, so far, no uniformed sampling method applicable for the light fraction. The composition of the light fraction is very variable as regards to both, particle size and chemical composition. Thus, it can be assumed, that the individual substances are not equally distributed within the volume of light fraction, necessitating to quantify the occurrence of the individual substances in the individual components. In this regard, attention is focused on the metal-bearing constituent as a potential material-recyclable residue (iron, copper, zinc, nickel, chromium, etc.), and the component of high energy potential (plastics, wood, paper, rubber, etc.).

The total amount of the metal-bearing materials is relatively low, which makes recycling of all the light fraction ineffective, and on the contrary, the heavy metals content complicates energy recovery of light fraction from the environmental point of view. By separating the metal bearing components from other material, it is possible to obtain a metal concentrate, and the remaining material can be energetically reused, increasing the chances for effective material recycling of light fraction.

3 EXPERIMENTAL PART

Sample of light fraction from the shredder plant in Kendice (Slovakia), which contained ~ 3% of non-ferrous metals, has been used for the experiments. The sample was subjected to sieving on the sieves with the mesh size of 50, 25, 15 and 10 mm. View of the fractions is shown on Fig. 2.

Figure 2. Granulometric classes a) + 50 mm; b) - 50 + 25 mm; c) - 25 + 15 mm; d) - 15 + 10 mm; e) - 10 + 0 mm.

Even the simple view shows that coarse particles were made up of mostly non-metallic materials, such as plastics, polyurethane foam, rubber, paper, wood, textile fibres and other combustible material. From each fraction, a small sample was taken for chemical analysis of Fe, Zn, Cu, Ni, Cr, Pb and Mn concentration. In the middle fractions appeared also pieces of cables, wires and stones (Fig. 2c, d).

Shredding of car bodies is not a gentle process, but metallic or metal coated particles are crashing to shredder or to each other and are breaking down to smaller particles. So it was assumed, that the fraction smaller than 10 mm should be metal-bearing, and in addition to the dust contaminants, should include metals and their compounds (Fig. 2e).

Granulometric class - 10 + 0 mm was grinded down further on a mortar grinder and sieved to the proportions of + 0.5 mm, - 0.5 + 0.315 mm and - 0.315 mm + 0 mm, and the units of the sample were subjected to chemical analysis of Fe, Zn, Cu, Ni, Cr, Pb and Mn. The chemical analysis was done by atomic absorption spectrophotometry on a Varian AA Spektr 20+. The finest fraction was subjected to qualitative X-ray diffraction phase analysis on the device PANalytical X'PERT Pro.

4 RESULTS AND DISCUSSION

Fig. 3 shows cumulative and distributive function of the weights for the given granulometric classes, indicating that most of the material is coarse-grained and only about 5% of the sample weight belongs to the class - 10 + 0 mm. The metal distribution into individual fractions is shown in Fig. 4.

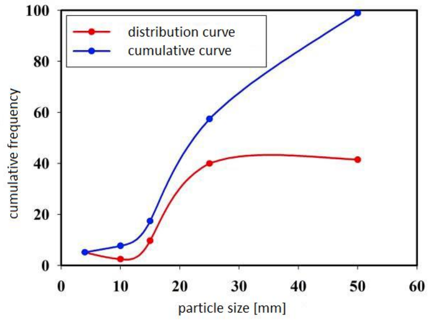

Figure 3. Cumulative and distribution curve.

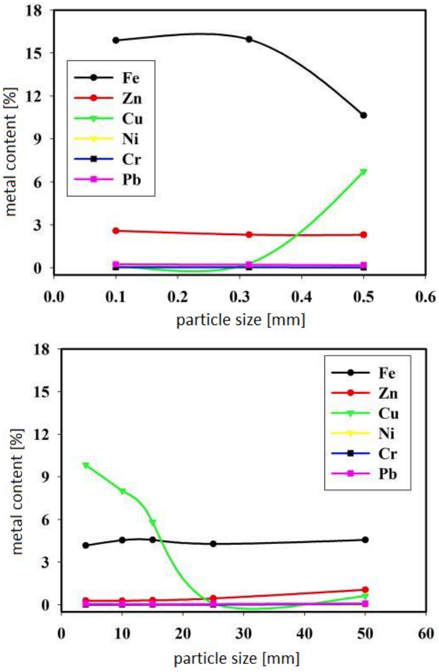

Figure 4. Metal distribution a) in coarse-grained material - 50 + 4 mm; b) in fine-grained material - 0.5 + 0 mm.

From the graphs of metal distribution is clear that metals pass into the fine-grained fractions. Detailed results are shown in Tab. 1. Significant metal concentration was found in the finest fraction < 0.5 mm, Tab. 2. Especially Zn content 2.4% should be considered.

	Fe	Zn	Cu	Ni	Cr	Pb
+ 50 mm	4.17	0.29	9.84	0.007	0.003	0.06
-50 + 25 mm	4.54	0.28	8.01	0.005	0.004	0.05
-25 + 15 mm	4.56	0.31	5.81	0.004	0.003	0.04
-15 + 10	4.28	0.44	0.071	0.007	0.003	0.05

mm						
-10 + 4 mm	4.56	1.05	0.62	0.006	0.05	0.09

Table 1. Chemical analysis of coarse-grained classes [%]

	Fe	Zn	Cu	Ni	Cr	Pb
-4 + 0.5 mm	10.64	2.30	6.73	0.017	0.02	0.18
-0.5 + 0.315 mm	15.96	2.31	0.29	0.04	0.02	0.21
-0.315 + 0 mm	15.89	2.58	0.11	0.06	0.03	0.24

Table 2. Chemical analysis of fine-grained classes [%]

The achieved results confirmed the hypothesis that it is possible to obtain the metal-bearing concentrate of the light fraction by very easy and cheap method of sieving. A little outside of expectations behaved copper, which was more concentrated in the middle-size fractions. The form of its presence is on Fig. 5, showing the copper is present in the form of wires. Of course, copper as a tough metal resists the grinding process and its fibrillar structure does not allow passing through the sieves.

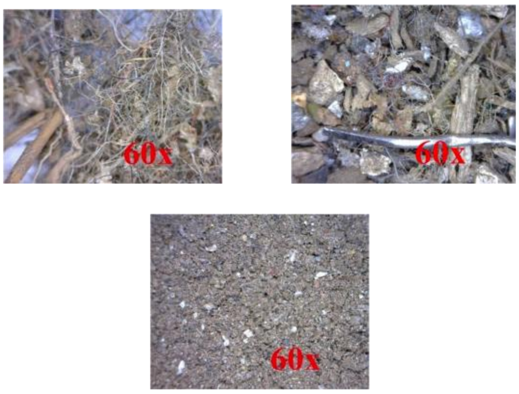

Figure 5. Microscope photography of fine fractions a), b) + 0.5 mm; c) - 0.315 mm.

The efficiency for enriching the fine fractions by metals is quantified in Tab. 3, which shows that even when samples tested in this work were already depleted of non-ferrous metals, still becomes possible to obtain the metal concentrate in this simple way. The enriching index varies for different metals.

	Fe	Zn	Cu	Ni	Cr	Pb
+ 0.5 mm	3.8%	0.5%	1.8%	0.01%	0.01%	0.06%
-0.5 + 0 mm	14.2%	2.4%	2.4%	0.04%	0.03%	0.21%
enriching index	4	5	0.3	4	3	3.5

Table 3. Chemical analysis of fine-grained classes [%]

To better understand the form of presence and composition of metals in the metal concentrate, the finest fraction (- 0.315 + 0 mm, Fig. 5c) was subjected to qualitative X-ray diffraction phase analysis (Fig. 6). The analysis showed that the powder sample contained glass (SiO_2), metallic zinc and zinc oxide originating from coating of metal particles and car body, iron in the form of oxides mainly from rust and PbO. X-ray diffraction pattern is shown in Fig. 6.

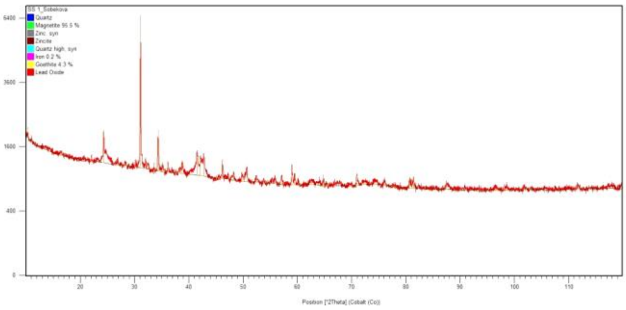

Figure 6. X-ray diffraction pattern of metal concentrate from light fraction (- 0.315 mm)

The following experiments were partially performed at the Institute of Processing and Recycling, RWTH Aachen University (Germany). The aim of the experiments was to define, if more sophisticated combination on the multiple devices can be effectively adapted to the separation of such heterogeneous material. The proposed process was composed of sieves with the mesh size 20 mm, 10 mm, 4 mm and 1 mm, magnetic separator with a rotating drum, eccentric eddy-current separator and pneumatic separator. The applied separation process was more complicated and the question was, if the multi-step process is really needed, if it can give comparatively better results in terms of richer powder concentrate or cleaner any other individual fraction separated out.

The sample of the light fraction was delivered from a shredding plant in Eschweiler (Germany) and it has been already rid of metals. The powder metal concentrate was considered < 1 mm and represented ~ 50% of the sample weight. The metal concentrate sieved out was subjected to the chemical analysis of major metals Fe, Cu and Zn by atomic absorption spectrophotometry on a Varian AA Spektr 20+. Even if the most of the metals were already removed at the shredder plan, the concentrations of Fe and Zn content were considerable (Tab. 4). The powder metal concentrate < 1 mm had a metal recovery potential of 16% Fe and 2% Zn.

	Fe	Zn	Cu	Ni	Cr	Pb
-1 + 0 mm	15.67	1.98	0.47	NA	NA	NA

Table 4. Chemical analysis of the powder metal concentrate from Eschweiler [%]

The method using multiple devices was effective in the magnetic and pneumatic separation steps. It was observed that a fibrillar structure of some present metals did not give sufficient separation purity for the middle-coarse fractions. Remaining process steps were only suitable choice to tune better the material separation of coarse particles. The whole process could be adapted better by incorporation of further separating techniques. But anyway, to obtain a metal concentrate the sieving step was crucial.

5 CONCLUSIONS

The method combining multiple devices was time-consuming and not fully effective. The whole process could be adapted better by incorporation of further separating techniques, but probably it would require much money and energy. Therefore, the possibility of obtaining the powder metal concentrate from light fraction via a simple method of sieving was determined and experimentally verified.

It was found that metals are concentrated in fine fraction < 0.5 mm. The concentration of metals in the metal concentrate was 4 – 5 times higher than in coarse-grained fractions, except of copper. Copper was present in the form of wires and fibrillar structures, not easily falling through the sieves. Even though, sieving is very simple and very cheap method for removing of hazardous heavy metals from the non-hazardous rest. It is mainly powder, what makes a light fraction hazardous waste category, the metals from the coarse fraction in the form of alloys, cables and small metallic plates do not have hazardous properties. Since they are fixed in the larger particles, their distribution into the environment is reduced. The heavy metals present just small amount ~ 5 wt.% of light fraction, but the double goal can be reached by sieving them out. The metal concentrate with notable amount of Zn 2.4% is obtained as economically interesting source of secondary metal very easily obtainable. But also the hazardous nature of the light fraction is reduced just to a small amount. On the other hand, since the metal concentration in the coarse-grained non-metallic material was already low and only within the limits allowed by law, coarse-grained material is not dangerous in terms of heavy metals anymore and can be also energy utilized. Sieving could also have wider application for large volumes of material.

Whatever large is the ratio between the powder mass volume and the volume of remaining material, the determining factor is well separation of the powder, because this is where the heavy metals are concentrated. For instance, if a light fraction contains just 30 wt.% of a metal-bearing powder, from 10,000 tons of light fraction landfilled in Slovakia, it makes 3,000 tons of a potential secondary source for hydrometallurgical recovery of Fe, Zn or Cu.

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