SARDINIA2009

XII International Waste Management and Landfill Symposium

Proceedings

5-9 October 2009 S. Margherita di Pula (Cagliari), Sardinia, Italy

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iww
international waste working group

ISBN 978-88-6265-007-6

AN INNOVATIVE CONCEPT FOR FIBER RECOVERY FROM SHREDDER LIGHT FRACTION

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SUMMARY: The directive 53/2000/EC on end-of-life vehicles demands considerable high quotas for recycling and recovery. In order to fulfill these requirements, which will be further tightened in 2015, within the last years so-called post shredder technologies have been developed. By applying mechanical processes, the shredder light fraction (SLF) can be separated into plastics, fines and fluff. There is, however, a potential for the recycling of the fluff fraction which mainly consists of fibers, films and fine plastics. A more profitable solution for the fluff would increase the overall economic situation of SLF treatment. Vienna University of Technology has developed a new concept exclusively based on mechanical processes which can convert the fluff into a marketable recycling product. First results demonstrate that SLF-fluff derived fibers show quite similar characteristics in regard of fiber length and width to both tire derived fibers and ground cellulose and successful application in the field of construction materials is likely. Further tests on a larger scale and application experiments are necessary in order to gain sufficient data for an industrial realization.

1. INTRODUCTION

In the European Union the handling of waste significantly changed within the last decades.

Today in the EU numerous regulations for waste exist aiming to ensure environmental sound practices. Generally a so called waste hierarchy favors waste prevention and recycling and landfill is only designated as last option. For some types of waste special EU directives are mandatory such as the WEEE (Anonymous, 2002) or the end-of-life vehicles (ELV) directive (Anonymous, 2000). According to the ELV directive since 2006 a minimum quota of 85 % is required for reuse and recovery (includes thermal recovery). The rate for reuse and recycling (excludes thermal recovery) is 80 %. In 2015 these strict quotas will even more tightened demanding 95 % for reuse and recycling and 85 % for reuse and recovery. In order to comply with these regulations, further improvements are necessary to realize economically viable solutions.

Proceedings Sardinia 2009, Twelfth International Waste Management and Landfill Symposium
S. Margherita di Pula, Cagliari, Italy; 5 - 9 October 2009

2. TREAMENT OF END-OF-LIFE VEHICLES

Some years ago end-of-life vehicles have been disposed on scrap yards only dismantling some valuable parts. In the EU legislation is quite rigorous and it is well established today that end-of-life vehicles are collected and dismantled. One the one hand it is compulsory the remove environmental problematic substances such as lead accumulators, lubricants and fuel. On the other hand dismantling companies focus on removing valuable spare parts suitable for reuse, recycling, or sale. Economically viable dismantling is only possible to a certain extent. Although in the literature certain automations are described (Staake, 1998, Ahlmann, 1988, Hauesler, 1991, Oberlaender, 1991, Schaetzing, 1992, Salzmann, 1996, Sattler, 1993), labor work is still predominating resulting in high dismantling cost (Salzmann, 1996). In Germany dismantling companies state prices for depollution to range between € 50 to € 100 and for dismantling between € 250 and € 350 on the basis of 2002 (Leuning, 2002).

After the removal a limited number of parts, the vehicles undergo a series of mechanical and physical separation steps in order to recover the ferrous and non-ferrous metals. Typically an aggregate called shredder is used. The residual of the shredding process, shredder light fraction (SLF), represents about 20 – 25 % of the end-of-life vehicles weight.

In Germany from approximately 3 Million end-of-life passenger vehicles in 2006 only about 16 % were dismantled, while about 17 % were exported. The whereabouts of the major portion (⅔) is, however, unknown (Berninger, 2008) but a proper disposal is unlikely. Generally, the portion end-of-life vehicles that are either legally exported or properly disposed is rather low in many EU countries, the lowest value (13 %) is reported for Poland (Scherhaufer, 2008).

SLF is a highly heterogeneous material which is still landfilled to a large extent. On the one hand landfilling of SLF is increasingly becoming more expensive or even impossible (e.g. deposition ban in Austria and Germany) requiring high expenses for thermal disposal. On the other hand the compulsory recycling quotas according to the directive 53/2000/EC cannot be met without a recycling process of SLF. Thus, the development of proper recycling technologies is intensively investigated in the EU.

SLF exhibits a quite variable composition. Shredder companies do not exclusively process end-of-life vehicles but also white goods, mixed scrap and other types of waste. The portion of end-of-life vehicles ranges between 27 to 85 % (Reinhardt, 2004). Furthermore, the composition of passenger cars is changing. Vehicles constructed in the period 1960 to 1975 contained about 78 % steel and 2.3 % fibers. In contrast, in the period 1996 to 2000 the iron fraction was reduced to about 58 % while the fiber portion increased to 7.3 % (Reinhardt, 2004). In addition the processing conditions of the shredder aggregate can be altered, thus, influencing the composition of SLF, in particular the metal content. In conclusion SLF consists of the following compounds whereas the percentages can significantly vary. The values as shown in Table 1 can significantly vary, the iron content is also reported to range between 7 and 15 % (Drost, 2003).

- Plastics (thermoplastics, duroplasts, elastomeres); predominantly in form of bulk but also fibers, foils and foams;
- Other organic compounds (wood, paper, lacquer residues, etc.);
- Metals (iron, copper, aluminum); see Table 1;
- Minerals (glass, ceramics);
- Others (sand, dust, rust, lead, zinc, etc.); see Table 1.

Table 1. Metal content of SLF (Granata, 2009).

Metal	Fe	Al	Cu	Zn
Content [ppm]	93 ± 7	15 ± 2	15 ± 4	11 ± 2

Metal	Pb	Mn	Ni	Cr	Cd
Content [ppm]	3.1 ±0.9	0.9 ± 0.2	0.4 ± 0.1	0.31 ± 0.08	0.03 ± 0.01

There are two main categories processing SLF, so called post shredder technology (PST). On the one hand, mechanical processes are based on grinding and sorting of SLF into different fractions that can, at least partially, be recycled and sold. On the other hand, a thermal treatment of the waste generates a feedstock for energy generation and material recovery.

Pyrolysis, gasification and incineration are among the classical thermal processes. Several companies developed new industrial processes based on these classical methods optimized for SLF. These methods can be classified either as disposal or recovery (Anonymous, 1991) which is an important aspect in regard of the directive 2000/53/EC (Anonymous, 2000). Generally, thermal processes require a great effort (high temperatures, efficient gas cleaning, etc.) and, thus, disposal costs are rather high. In the following the most important industrial thermal processes are briefly introduced.

- Incineration

  SLF is fired either together with municipal waste in incineration plants or in industrial processes such as the cement industry in order to recover thermal energy. This praxis is rather costly and due to heavy metal problems the maximum portion is restricted (e.g. in Switzerland maximal 5 %). Based on judgments of the European Court of Justice incineration in an incinerator constitutes disposal, even if energy is recovered (Anonymous, 2003a), while co-incineration in a cement kiln does constitute recovery (Anonymous, 2003b). Disposal cost range between 150 and 240 €/t.
- TwinRec process

  The so called TwinRec process was developed by Japanese company EBARA and is based on fluidized bed gasification with ash vitrification (Hirayama 1995, Fujimura, 1997, Selinger, 2003). The remaining metals and large inert particles are separated from the combustibles and fine ash. Currently approximately 20 lines are in operation worldwide. The cost for the process are estimated to be in the range of 120 to 200 €/t.
- RESHMENT process

  The Reshment process was developed by CTC Umwelttechnik of Switzerland. It uses a combination of mechanical and thermal treatment to recover a metal fraction and to produce a vitrified material which can be recycled in the road construction industry (Schaub, 2002, Aldo, 2004a, Aldo, 2004b). Currently, there is not even a pilot plant in operation and thus no reliable data about costs are available.
- Thermoselect process

  The process of the company Thermoselect is based on pyrolysis followed by a gasification process (Kiss, 1992, Yamada, 2004, Drost, 2004, Drost, 2003, Kaiser, 2004). The output fractions are synthesis gas, sulfur, water, metals and minerals. In Japan there are seven lines in operation while the only plant in Europe (Karsruhe, Germany) was shut down due to a series of problems. The cost are estimated to range at approximately 140 €/t.
- "Schwarze Pumpe" process

  The term "Schwarze Pumpe" is related to the name of its location which is a district of Spremberg (Germany). Since 1995 the SVZ (Sekundaerrohstoff-Verwertungszentrum Schwarze Pumpe) operated a plant which is based on a slagging-bed-gasifier (Rabe, 1997, Anonymous, 2001, Hauptmann, 2004, Buttker, 2005). Solid and liquid wastes were treated mainly resulting in a synthesis gas and, subsequently, in methanol. In 2005 the plant was overtaken by Sustec Industries AG, but finally closed in 2007.

- Oxyreducer process
  The oxyreducer process was developed by the Swiss company Citron Holding AG (Brueggler, 2008). Organic compounds are pyrolized and used as agents to reduce some of the metal oxides. The output of the plant consists of metals and minerals which can be used for further recycling. The costs are considered to range at approximately 120 €/t.
- PyroArc process
  The PyroArc process was developed by the Swedish company ScanArc Plasma Technologies AB. The technology comprises a pyrolysis step followed by a vitrification of inorganic materials and a plasma decomposition of gases. The products comprise fuel gas, leach resistant slag, molten metals and small amounts of dust. A pilot plant is operated since 1986. The costs range between 50 and 230 €/t.

In the case of mechanical separation, the main products are plastic granulates, sand and a so called fluff fraction, which contains fibers, foils and foams. Compared to thermal processes the effort is lower and the disposal costs are more economic. However, the technology still generates wastes that require incinerators or landfill sites. In the following the most important PST are briefly introduced.

- SRTL process
  The SRTL (Shredder Residues Treatment Line) process has been developed by he Belgian company Galloo (Vandeputte, 1999, De Feraudy, 2000, De Feraudy, 2007). It comprises at least four steps: mechanical separation (by shape factor), cleaning and at least two further steps of mechanical separation (by density). The resulting fractions (Anonymous, 2006) are plastics (9 %), metals (30 %), waste derived fuel (13 %) and waste (48 %). The overall costs (including subsequent landfill) range at approximately 65 €/t (Reinhardt, 2004), but the method does not meet the requirements of the 53/2000/EC.
- SiCon / TBS /UEG
  The German companies SiCon and VW developed a mechanical process schedule to separate SLF into the main fractions of plastics (subdivided into PVC rich and poor), sand (fine mineral material) and fluff (Goldmann, 2007a, 2007b, 2007c, 2007d). The sand fraction can be landfilled while the fluff fraction is used as filtration aid for sewage sludge dewatering and the plastics can be used as reduction agent in the blast furnace process (Buergler, 2004, 2008). SiCon has developed the technology and erects plants for operators such as Auto Recycling Nederland (ARN) in Tiel. The Austrian companies TBS and UEG operate PST plants using a similar technology again producing plastics, fluff and sand.
- SALYP process
  The Belgian company Salyp developed a separation process which is based on a special method to separate plastics from waste (Stricker, 2001, Gisquiere, 2004a, 2004b, 2005). Apart a fluff and a sand fraction, plastics sorted into mono-fractions are available.
- Other process
  It can be assumed that other companies, especially outside the EU, will operate plants to process SLF. The following processes / companies are mentioned in the literature (Reinhardt, 2004, Anonymous, 2006, Jody, 2006):
  - Scholz (Scholz AG, DE)
  - WESA process (R-plus Recycling GmbH, DE)
  - Cometsambre (COMETSAMBRE S.A., BE)
  - SULT process (Hachinohe, JP)

3. A NEW CONCEPT FOR SLF RECYCLING

3.1 Fluff as potential source for fibers

It is evident that PST's are already far developed and that, in particular, mechanical processes seem to be quite economic. However, the overall benefit of a recycling process is significantly influenced by the possible applications of the generated fractions. It is also clear that end-of-life vehicles contain a considerable portion of fibers and foils and that this portion will even increase within the next years. The manufacture of fibers is more complex than compared to bulk materials and demands a considerable portion of energy and resources. It seems, thus, to be worth to recover and reuse fibers from different types of wastes, also SLF (Bartl, 2008).

It has been reported that tire derived fibers (TDF) can be used as additive in the bitumen industry (Bartl, 2005, Bahardoust, 2006). Test results on bitumen modified with TDF showed that the addition of fibers to bitumen, used for asphalt road pavements, changed the properties tremendously. The addition of TDF slightly worsened the low temperature properties of bitumen, but at the same time significantly improved the high temperature properties. Since the improvement at high temperatures was more pronounced, the temperature range of application for the TDF-modified bitumen increased (Bartl, 2005).

It has also been reported that TDF and fibers recovered from nonwovens can be used as viscosity modifiers (Bartl, 2006a, 2006b). The investigations revealed a predominant effect of the fiber length (aspect ratio), independent of the origin of the fibers. Ground cellulose (Arbocel®) was used as technical and commercial reference. In terms of influence on viscosity, reclaimed fibers show a quite similar behavior than compared to commercially available ground cellulose. It seems possible to substitute expensive state-of-the-art solutions by fibers derived from waste.

It is just obvious SLF is a possible source for deriving fibers. This is in particular valid for the fluff fraction which is significantly enriched with fibers. The processing of fluff originating from SLF to an aggregate to be used in the construction industry is already state-of-the-art (Bartl, 2008) but is not yet realized in an industrial scale.

3.2 Deriving fibers from SLF fluff

In a first test series, fluff fraction originating from the PST plant of UEG was processed at Vienna University of Technology. The fluff was dried and extricated from residual contraries such as small metals and minerals. Subsequently the fluff was ground with a cutting mill. The resulting product was quite homogenous and entangling was largely prevented.

In order to get estimation on the fiber content a sieving analysis was carried out. The material was sieved with mesh sizes of 200 and 800 μm. The coarse fraction (> 800 μm) predominately consists of fibers but also residues of films and small adhering particles. The fine fraction (< 200 μm) is largely fiber free. Figure 1 shows the respective percentages of the obtained portions. The fraction of intermediate which contains both fibers and non-fibrous individuals is relatively high and ranges at about 40 %. It will, however, be necessary to define a single mesh size to result in only two, a fiber rich and a fiber poor, fraction. The respective size will depend on the subsequent application.

The reclaimed fibers have also been analyzed by an automated image analysis system (MorFi) which was originally developed for pulp characterization (Tourtollet, 2001, Passas, 2001) but which is also a useful tool for characterizing recycled fibers (Bartl, 2005). The results obtained from SLF fluff are compared with fibers reclaimed from nonwovens ("nonwovens") and end-of-life tires ("tires") as well as with Arbocel®, which is ground cellulose and represents a common additive for bituminous road pavements (Rettenmaier, 1991). Table 2 compares the mean values,

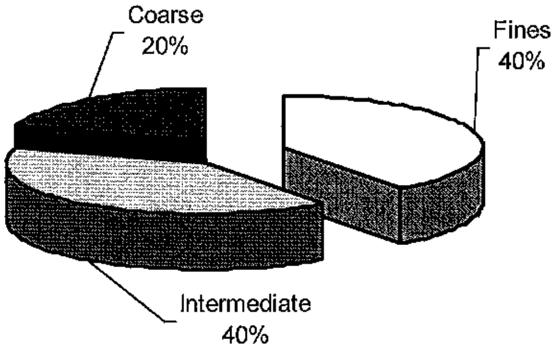

Figure 1. Sieving analysis of processed SLF fluff; coarse: > 800 µm; fine: < 200 µm.

Figures 2 and 3 show a plot for both fiber length and fiber width distribution.

Considering the mean values for length and width there are no distinct differences between the individual samples. Fiber length is within the range of 0.5 and 0.6 mm. Fiber width was determined at about 25 µm except for the "nonwovens" sample (19 µm).

More specific information is given by fiber width distribution as plotted in Figure 2. There is a distinct difference between Arbocel® and SLF fluff, on the one hand and, tire and nonwovens derived fibers, on the other hand. The latter ones show a distribution with a maximum at about 0.5 mm. Both, Arbocel® and SLF fluff contain the highest portion in the smallest size class, most probably containing a significant portion below the detection limit of the MorFi (0.1 mm). For the Arbocel® sample this effect can be explained by its native origin. In the case of SLF fluff it seems very likely that a considerable portion is dirt originating from foils and foams is present.

Table 2. Average fiber length and width obtained with the MorFi analyzer.

	SLF fluff	Arbocel®	"Nonwovens"	"Tire"
Mean width [µm]	24.5	25.6	19.3	25.8
Mean length [mm]	0.56	0.55	0.48	0.60

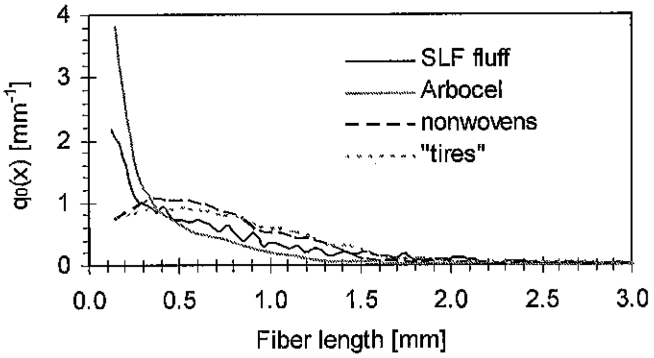

Figure 2. Fiber length distribution determined with the MorFi analyzer.

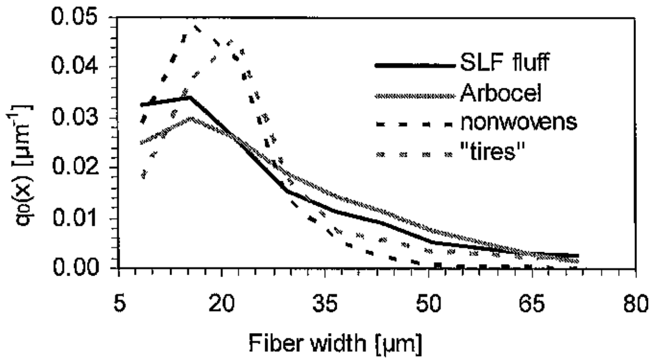

Figure 3. Fiber width distribution determined with the MorFi analyzer.

For all reclaimed fibers the specific length can, of course, by influenced by the grinding conditions. In particular, all samples (SLF, tire, nonwovens) have been finally ground with a mesh size of 0.50 mm. It is, thus, not amazing, that the fiber length is within the same range (0.5 to 0.6 mm). Depending on the final application of the recycling product fiber length can be adjusted to the respective requirement.

Figure 3 compares the width of fibers derived from SLF, nonwovens and tires to ground cellulose (Arbocel®). It is clear that fiber width is not affected by the grinding process but is a fact of the fiber origin. The Arbocel® sample shows a quite broad distribution due to its native origin (ground cellulose). The SLF fluff sample is quite similar probably caused by a variety of man-made fibers exhibiting different titers. In contrast, fibers derived from nonwovens and tires show a distribution which is significantly less broad. On the one hand, tire manufacturer use a quite small spectrum of fiber denier. On the other hand, the results of the nonwovens sample origin from a concept test using new material containing a single titer. However, it is demonstrated that FDF fibers show a quite similar width (range 24 to 26 µm) than other reclaimed fibers (except nonwovens: 19.3 µm) as well as the commercial product Arbocel® (26 µm).

4. SUMMARY AND OUTLOOK

Even today it is common praxis to landfill shredder light fraction (SLF). However, in the EU more severe regulations for waste shift the streams towards incineration and recycling. In order to meet the requirements of the ELV directive and to reduce disposal costs, within the last years post shredder technologies have been successively developed. It seems that methods based on mechanical separation are quite economic if adequate applications for the resulting fractions can be found. Although several marketable recycling products can be generated, there is still a considerable potential for further increase in the economic benefit of SLF processing.

It has been shown that fibers can be derived from SLF fluff even though a certain amount of non-fibrous particles cannot be avoided. In terms of fiber length and width the reclaimed fibers are comparable to well established products used in construction industry. However, further test on a larger scale as well as application experiments are necessary in order to gain sufficient data for an industrial realization.

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