NEW TECHNOLOGY FOR RECYCLING OF PLASTICS FROM CABLE WASTE

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ABSTRACT

The driving force of cable recycling has since decades been the high value of copper and aluminum. Also for environmental reasons it is very important to recycle these metals. For a sustainable future the recycling of cables not in use need to increase and improved methods for recycling of both metals and polymers in cable waste need to be implemented. This paper focuses on the recycling of cable polymer waste.

KEYWORDS

Recycling, Cable, Waste, Plastic, Polymer

INTRODUCTION

Swerea IVF, a Swedish research institute, coordinates a long-term cable recycling program with partners from the cable business. An important objective of the project is to develop technology and sustainable methods for sorting and recycling of the various plastics in cable waste.

This paper describes a new method for sorting of cable plastic waste, recycling methods developed for cable plastic, environmental and economical advantages of increased sorting and recycling.

Every year large amounts of wires and cables become waste, only in Sweden approximately 40.000 tonnes per year [1]. The amounts of cables installed in the community increases every year, but only a small part, 1/6, of the cables built into the network, are being recycled in Sweden. The largest potential of recycling applies to the cables in the communication and power distribution network. These cables have a high value of copper weight per meter. Most of the cables not in use are hidden underground. According to a Swedish master thesis report [2]; the total amount of copper in the energy and communication network cables in Sweden (2005) was calculated to about 2 million tons and aluminium in the energy network to about 0,8 million tons. The amount of copper in cables not in use was calculated to about 620 000 tons and aluminium to about 180 000 tons. The value today of these metals hidden in the ground is more than 4,5 billion euro. Today, in 2011, the amounts of cables not in use have increased even more and by that the total value of the metals. The potential to increase the recycling of cables not in use is huge and could produce significant environmental savings.

Fig. 1: Cable waste at a cable recycling plant

The prices of metals and polymers used in cables rises, especially the copper price which should be a strong driving force to increase the cable recycling, see Fig. 2. The polymer price depends on the oil price and increases, which most probably will become an economic driving force to recycle the cable plastic. Landfill of polymer waste is not an option in the future and is in principle not allowed in the EU countries since 2008 but continue still. The landfill cost in Sweden today is 119 EUR/ton and will rise. Sustainable methods for sorting and mechanical recycling of cable plastics are needed. Energy recovery is an alternative for mixed polymer waste, free from chlorine (PVC free), in case sorting and mechanical recycling is not feasible.

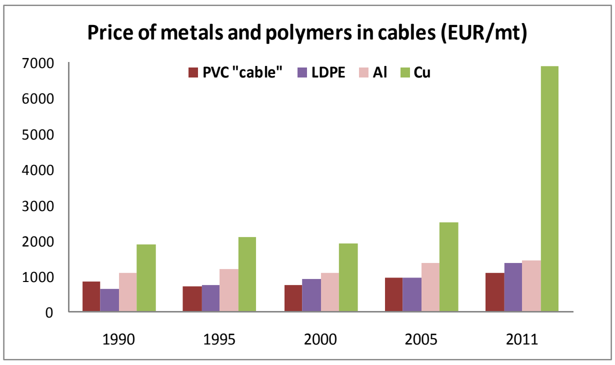

Fig. 2: Material prices increases

SORTING OF CABLE PLASTIC

Cable waste can be classified into different categories; production scrap from the cable manufacturing, installation scrap and end-of-use cable waste. The most common way to recover metals from cable waste in the developed countries is by the cable granulation process. Pre-sorting of cable waste is important to obtain maximum value for the recovered metal scrap. The cable waste is pre-sorted into different fractions before it is sent through the granulation and separation process, this to obtain as pure material fractions as possible. Usually pre-sorting includes sorting of thin and heavy conductors, plated or non plated conductor and most importantly sorting of copper and aluminum cable. The first step in reducing the size of the cables is the chopping. Then the granulators reduce the size of the material further and the insulation material can be separated from the metal. The plastic and metal granulates are then fed to a fluid bed that is slanted in two directions. The material enters from the rear of the fluid bed, and the mix is fluidised by air, lighter particles are lifted higher than heavier ones. Consequently, the heavier metal particles move up the fluid bed, while the lighter particles of plastic float down slope. The fluidised bed separator produces two fractions: a clean metal product and a plastic fraction. However the plastic fraction is contaminated with metal particles, 3 - 6 % by weight.
Pre-sorting with consideration of the plastics in the cables can make separation and mechanical recycling of the plastics possible as well. When it comes to plastic recycling, the potential for high quality mechanical (closed loop) recycling of cable plastic is high for cable scrap from manufacturing and installation scrap compared to end-of-use cable waste. Cables can contain several different polymers and compounds: polyethylene (PE) and polyethylene-co-polymers, cross-linked polyethylene (XLPE), Halogen-Free Flame Retardant compound (HFFR), polyvinylchloride (PVC) and rubber. The cable compounds contain additives like stabilizers, antioxidants and inorganic fillers. PVC contains plasticizer.

The various techniques available for separation of plastics are based on material properties like differences in density, magnetic, electric, chemical or optic properties. The most common technique used by the cable recycling industry is gravimetric separation in water. The separation follows a sink/float procedure, were materials with low density, like polyolefins, can be separated from material with higher density, like PVC.

PlastSep process

The PlastSep process originally developed at Watech, a company in the NKT group in Denmark, has been installed at two cable recycling plants at Stena Recycling AB in Sweden, see Fig. 3. By combining cable granulation and the PlastSep process for multi step wet density separation of the granulated cable plastic waste it has been demonstrated that the recycling of metals (copper and aluminum) can be increased to more than 99,5 %. The plastic waste can be separated into a light plastic polyolefin fraction, a heavier PVC rich fraction and simultaneously metal residues are separated from the mixed plastic waste.

Fig. 3: PlastSep plants at Stena Recycling AB

The process scheme is shown in Fig. 4. The plastic fraction is sent to a sink/float separator; a barrel containing water and small amounts of wetting agent. The density of the water solution (1.0 g/cm3) is higher than the density of PE and XLPE (0.9 g/cm3), but lower than the density of PVC (1.4 g/cm3). A paddle wheel moves the material down and forward and the lighter polyolefin fraction floats to the surface while the heavy fraction, containing PVC sinks. The polyolefin fraction is sorted out while the heavy fraction is sent to a vibrating wet separation table. Here the remaining metal is separated from the PVC and sent away to be melted and recycled. It is possible to separate more than one heavy plastic fraction on the wet separation table if the density difference is large enough.

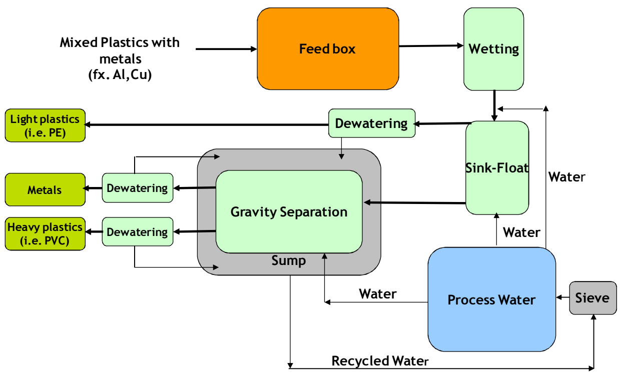

Fig. 4: PlastSep process

The light plastic fraction consisting of XLPE and/or PE, depending of cable input and mix, can be recycled into new polymer compounds to be used in new products alternatively, be used for energy recovery. The heavy fraction consisting of PVC alternatively HFFR, depending of cable input and mix, can be recycled into new compounds to be used in new quality products or if the plastic fraction is mixed be used for products with lower quality requirements. Benefits with the PlastSep process are increased metal recycling, which makes the process economically feasible, and the possibility to separate the different plastics into quite pure plastic fractions, depending on the in-put, that enables mechanical recycling or energy recovery of the plastics.

Electrostatic separation

Cable jackets with aluminum or copper attached to the plastic is a problem for the cable recyclers. If the plastic and metal can't be separated in the granulation process, both metal and plastic fractions will be contaminated. A method applicable to separate plastic with metal attached from the plastic fractions is electrostatic separation. An electrostatic separator (Hamos KWS) has been tested, installed in line with the PlastSep process. For electrostatic separation it is important that the material is dry, therefore a dewatering and drying unit has been installed between the PlastSep and the electrostatic separator. Promising results have been obtained. The electrostatic separator is also evaluated for separation of fine metal particles in the plastic fractions.

Extrusion screening (melt-filtration)

The purity of recycled polymer compounds for reuse in cable applications need to be very high, almost 100 %. Therefore the recycled material needs to be screened. Extrusion screening, i.e. melt-filtration, appears to be a very useful technique to remove small fractions of non-melting impurities from thermoplastics. However, to be practically feasible the starting material has to be pretty clean from the beginning (about 1 % of non-melting impurities is acceptable). The screens need to be changed regularly due to accumulation of impurities and it is a great advantage if the system has automatic hydraulic rotating screens so that the process can work continuously at constant flow and pressure. Fig. 5: shows extrusion screening, performed at Gneuss GmbH, with PVC compound recycled from cable manufacturing scrap. In line with the extruder the recyclate is cooled and pelletized in order to deliver PVC compound ready to use in new cables. If needed, additives like carbon black, stabilizers and antioxidants can be added during the process.

Fig. 5: Extrusion screening PVC compound

RECYCLING OF CABLE PLASTIC

High-quality mechanical recycling of cable plastics is defined as recycling of treated plastic into new cable applications or other high quality products replacing virgin material.

Low-quality mechanical recycling of cable plastic is defined as the recycling performed when mixed plastic fractions are recycled into products with low quality demands, like traffic safety markers, bumpers, traffic cones etc., were recycled plastic normally is used.

For high-quality mechanical recycling sorting of the cable scrap is most important. Plastics impossible to separate in the separation process need to be sorted separately at the cable factories. For example HFFR and PVC cable scrap need to be sorted separately since these plastics are difficult to separate by density in wet processes or by electrostatic methods.

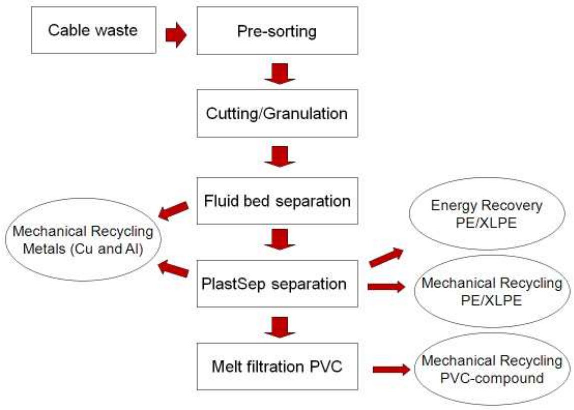

Fig. 6: Steps of cable recycling

Energy recovery of PE cable plastic mix

Incineration with energy recovery

Incineration is an alternative form of recycling suitable for mixed polyolefin plastic waste (light plastic) which would require such costly preparation for other recycling processes that it would not be economically worthwhile. Since polymer materials are mainly composed of hydrocarbon molecules, they have a high calorific value, about 30 MJ/kg. It is important that the incineration process is efficient and carried out at high temperatures in plants with effective flue gas-cleaning systems, to prevent hazardous or unpleasant emissions.

For incineration of polymer waste from cables it is important that the chlorine and metal contents are low. The metals are evaporating during the combustion process, which results in coating of the furnace, and the presence of chlorides causes corrosion. The chloride content can be neutralised with additives such as talc. More corrosion resistant materials can also be used in the furnace, which is a matter of costs. In most incineration plants the chlorine content need to be less than 1 %. PVC can therefore not be accepted. Regarding the metal content, it is also important to separate out the metals to avoid formation of toxic substances. Copper catalyses formation of dioxins in presence of chlorine.

Incineration in cement kiln

A cement kiln can handle quite a lot of different materials such as mixed plastic waste but licenses limits the PVC and chlorine input to about 1 % chlorine in waste, since chlorine has a negative impact on the quality of the clinker.

The high temperature (1 000 - 1 800 ℃) ensure that the input material are effectively destroyed, no dioxins or other toxic substances can be formed. The alkali raw material (lime) also neutralises acidic substances. The cement kiln can take care of metals like aluminium, which are limited in waste incinerators.

Mechanical recycling XLPE/PE compounds

XLPE is commonly used as insulation material in modern energy cables. The XLPE cannot be re-melted as other thermoplastics and has therefore been considered difficult to recycle. Within the cable recycling program at Swerea IVF the recycling possibilities of XLPE have been investigated. As a result, new promising methods have emerged. XLPE is pulverized (size 0,4 - 0,6 mm) and mixed with high density polyethylene (HDPE) or linear low density polyethylene (LLDPE). Such blends can be processed by injection moulding and extrusion. The injection moulding processability and material properties are satisfying for blends with up to 70 % recycled XLPE. It is also possible to use XLPE recyclate compounds with lower XLPE content, for cable extrusion in applications like cable jacketing. The recycling cost is quite reasonable if existing grinding facilities for rotational moulding can be used.

Injection moulding XLPE/PE compounds

Blends with up to 70 % XLPE have been injection moulded with retained processability as a common thermoplastic. Injection moulding gave homogeneous materials with smooth surface. If the XLPE powder can be feed directly into the injection moulding machine there is no need of pre-compounding. Melt flow index (MFI) decreased with increasing XLPE content, although when MFI decreased below 1 g/10 min at 70 % XLPE the injection moulding worked easily. Of the materials produced it is believed that the 50/50 blend of XLPE/HDPE offers the best set of material properties. This material maintains quite high stiffness and exhibits a high degree of ductility and impact resistance, see Fig. 7. The XLPE/HDPE compounds can be used for applications similar to that of LDPE. Such applications may include bowls, buckets, cold water tanks and road cones.

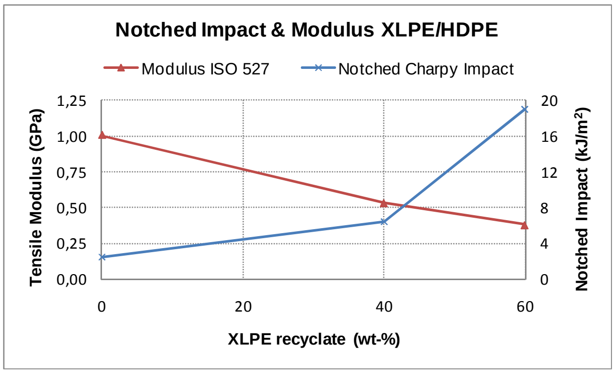

Fig. 7: Properties of XLPE/HDPE compounds (injection moulded dumbbells)

Cable extrusion recycled XLPE/PE compounds

Wire extrusion trials showed that XLPE/LLDPE blends with up to 50 % XLPE could be extruded with retained processability but due to surface roughness the content of XLPE should be limited to approximately 20 %. An appropriate application is cable inner jacket, see Fig. 8.

Use of XLPE powder with different particle sizes showed no visual difference in mechanical properties or in surface roughness. Cables with inner jacket of XLPE/LLDPE compound were produced, see Fig. 8. Possible cable application might also be filler strings and bedding material which can allow higher content of recycled XLPE. Other applications for extrusion might be cable cover tubes and pipes.

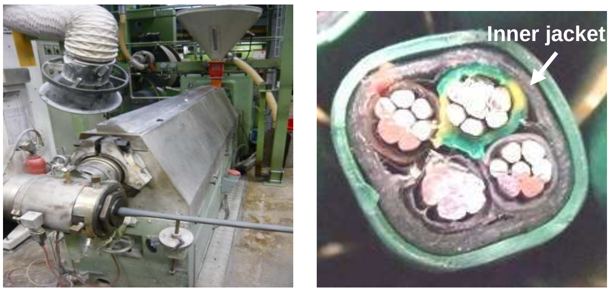

Fig. 8: Extrusion of cable with inner jacket of recyclate compound XLPE/LLDPE (20/80)

Tensile testing according to IEC 60811-1-1 (speed: 50 mm/min) was performed, see Table 1. The mechanical requirements for a standard cable jackets were fulfilled; tensile strength > 10 MPa and strain at break > 300 %.

XLPE/LLDPE recyclate compound			
XLPE (lumps)	Ageing 100℃	Strain at break	Stress at break
(%)	(days)	(%) median	(MPa) median
10	0	532	16,1
10	10	751	13,3
15	0	510	14,2
15	10	655	11,7
20	0	476	15,6
20	10	585	12,0

Table 1: Mechanical properties inner jacket

Ageing of recycled XLPE compounds

Heat ageing has been performed on moulded sample of XLPE/LLDPE compound, containing 10 and 20 % XLPE (silane crosslinked PE) respectively. The XLPE was recycled from cable manufacturing scrap and lumps from the cable extrusion lines. No additives were added. The mechanical requirements of a standard cable jacket with tensile strength >10 MPa and strain at break > 300 % was fulfilled for the recycle compounds, see Table 2. Compound containing 20 % XLPE recycled from lumps had reached the limit after 15 weeks of ageing and started to degrade. Lumps are not stabilized like the cables are therefore stabilizers/antioxidants should be added if lumps are used for recycling.

XLPE/LLDPE recyclate		Ageing 100℃	Strain at break	Stress at break
XLPE scrap	(%)	(weeks)	(%) median	(MPa) median
lumps	10	0	526	13,3
lumps	10	15	516	11,3
lumps	20	0	654	18,5
lumps	20	15	295	10,4
cable scrap	10	0	476	13,1
cable scrap	10	15	581	12,2
cable scrap	20	0	478	12,7
cable scrap	20	15	427	12,0

Table 2: Mechanical properties of XLPE/LLDPE compounds

Mechanical recycling of PVC compound

Trials have been performed within the Swerea IVF recycling program to sort PVC cable scrap at the cable factories with purpose to recycle PVC compound back into cables. A difficulty has been to avoid mixing of PVC and HFFR cable scrap. A mixture of these compounds cannot be separated with the PlastSep process due to similar density. Electrostatic separation trials of mixed PVC and HFFR compounds have been performed with the Hamos EKS system but the compounds were difficult to separate. For electrostatic separation the materials need to charge differently. Moisture content, polymer and filler properties influence all on the charging of the material.

A successful sorting and recycling trial has been performed with PVC cable manufacturing scrap. The cable scrap was processed in the cable granulation plant followed by PlastSep. Extrusion screening was performed to remove impurities.

Recycling in power cable jacket

The recyclate PVC compound will be re-used in a power cable jacket, 20 % recyclate PVC compound will be feed together with virgin jacket compound.

Ageing of recycled PVC compounds

Ageing stability at 100℃ of recyclate PVC compound mixed with a virgin standard jacket compound has been tested. The recyclate levels were 10, 20 and 30 %. The mechanical requirements of a standard cable jacket with tensile strength >10 MPa and strain at break > 200 % are still fulfilled after 10 weeks of ageing, see Table 3.

PVC recyclate compound			
PVC rec.	Ageing 100℃	Strain at break	Stress at break
(%)	(weeks)	(%) median	(MPa) median
0	0	267	14,8
0	10	247	15,6
10	0	274	16,7
10	10	267	16,9
20	0	277	16,9
20	10	273	17,9
30	0	268	17,5
30	10	246	17,8

Table 3: Properties of recyclate PVC compounds

Environmental and economic benefits of sorting and recycling

Environmental impact of different recycling alternatives is quantified through environmental system analysis. Also the economic impact is calculated. So far analysis has been performed for two specific plants, the Stena Recycling plants in Töva and Timrå (Sweden). This in order to compare cable granulation and fluid bed separation (Töva) with cable granulation and fluid bed separation added with the PlastSep process (Timrå), se recycling cases to compare in Table 4.

Recycling case	Data provider	Input	Output
1. Cable granulation with fluid bed sep.	Stena Recycling Töva	70% end-of-use cables, 30% manufacturing cable scrap	Metals to smelters Plastic mix to landfill
2. Cable granulation with fluid bed sep. and PlastSep	Stena Recycling Töva & Timrå	Same input as above Input PlastSep: Plastic mix	Metals to smelters Polyolefin fraction: Incineration cement kiln PVC rich fraction: Mechanical recycling

Table 4: Two cable recycling alternatives to compare

The avoided burdens, savings of CO_{2eq} emissions, for the cable recycling cases were calculated, see Fig. 9. The thickness of the arrows is proportional to the global warming impact measured in carbon dioxide equivalents from each process. The amount of CO_2 in gram is shown in the down left corner of each box. Green color and minus sign denotes avoided emissions. The elemental flow, e.g. 0.285 p of copper granulate, avoided burdens per kg = 0.285 kg, is shown at the top of each box.

The functional unit is defined as “end-of-life management (ELM) of 1 kg granuable cable waste”. The granuable cable waste is defined to include cable waste with plastic insulation.

Assumptions for calculations Fig. 9:

- The calculations are based on the conditions during the first quarter 2011.
- 100 % polyolefins were assumed to replace coal in cement production. The avoided burdens were calculated in relation to the heat values.
- 100 % recycled PVC compound is assumed to replace virgin PVC. The avoided burdens were calculated in relation to weight; i.e. 1 kg of recycled PVC is assumed to avoid the production of 1 kg of PVC consisting of 42 % virgin PVC polymer, 23 % plasticizer, 2 % stabilizer and 33 % filler [3].
- For metals, avoided environmental burdens are assumed to be proportional to the price paid for the recycled material compared to London Metal Exchange prices.

The calculation in Fig. 7 shows that using PlastSep saves more CO_2 equivalents than not using PlasSep. Thus from a climate change perspective it seems environmentally preferable to separate the PVC from the polyolefins with the PlastSep process. Also for photochemical smog, eutrophication and acidification, adding the PlastSep step gives less impact with the above assumptions. To verify the results, calculations were also performed with the assumption that the avoided burdens due to plastic recycling are proportional to the price paid for virgin plastics in relation to the price for recycled plastics. Even with this assumption the PlastSep saves more CO_2 equivalents. Thus, it can be concluded that it is most probably always preferable, from a climate change perspective, to use the PlastSep process. Economical analysis performed shows also that it is profitable to add the PlastSep process. The net gain raises about 10 %. The main reason is that the PlastSep process saves more in avoided landfill costs than it costs to run. This was calculated using 2009 metal prices. Capital costs were not included in the calculations.

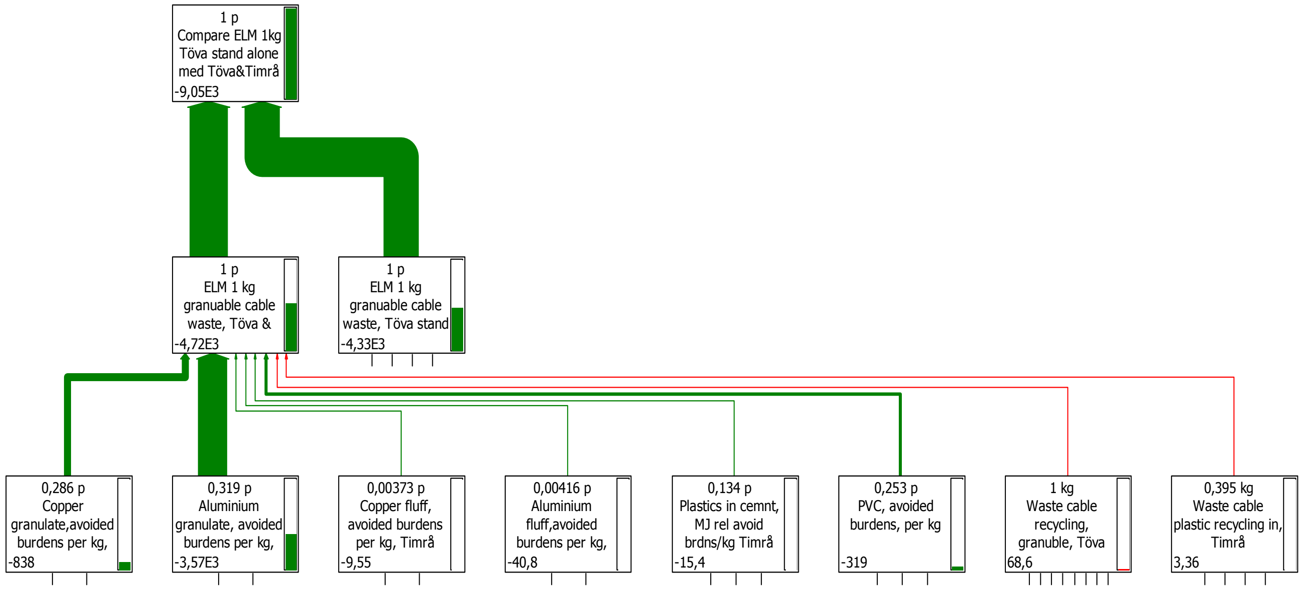

Fig. 9: Base case calculations for the recycling plants at Töva and Timrå, Sweden

CONCLUSIONS

- With the PlastSep process the plastic waste can be separated into a light plastic polyolefin fraction and a heavier PVC rich fraction. Simultaneously metal residues (copper and aluminium) can be separated from the plastic fractions and be recycled with increased yield compared to conventional cable waste recycling, approximately 99,5 %.
- PlastSep together with recovery of the produced polyolefin fraction as fuel and mechanical recycling of the PVC fraction is profitable and preferable from a climate change perspective according to life cycle assessments.
- XLPE can be recycled from cable waste by grinding and mixing the XLPE into compatible blends with HDPE or LLDPE. Considering the material properties and costs it is believed that injection moulding of blends with 50-60 % XLPE offers the best possibilities and can be used for applications similar to that of LDPE. Blends with up to 20 % XLPE can be used for extruded cable applications like cable inner jacket.
- PVC cable waste is appropriate for mechanical recycling if not too contaminated with other polymers. Extrusion screening with automatically shifting screens is a preferable method to remove impurities and produce a pure recyclate PVC compound. PVC compound recycled from manufacturing scrap can be reused in new cable applications like cable jacketing.

FUTURE NEEDS

- Cables designed with consideration for recycling of metals and polymers after end-of- use
- Customers demanding recyclable cables
- Standards and specifications adapted for cables and cable harnesses containing recyclate compound
- Implementation of standards for excavation and recycling of cables not in use
- Implementation of sorting and recycling standards for cable scrap at the cable factories and at the original source of end-of-use cables

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