Recycling of XLPE cable insulations

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Abstract
During the production of cables and at their “end of life”, plastic scrap and waste cables are produced which somehow have to be taken care of. The value of the conductor metal in the cables has since long been the main driving force for recycling and not much effort has been made concerning the recycling of the polymer fraction. For recycling the polymers in the cables need to be separated. Cross-linked polyethylene, XLPE, is used as insulation material in modern energy cables. As XLPE cannot be re-melted it has been considered difficult to recycle. Within the R&D-Programme Wire and Cable at Swerea IVF the recycling possibilities of XLPE have been investigated. As a result, a new promising method has emerged. XLPE is pulverized and mixed with high density polyethylene or linear low density polyethylene. Such blends can be processed by injection moulding and extrusion respectively. The injection moulding process ability and material properties are satisfying for blends with up to 70 % XLPE. It is also possible to use XLPE blends with lower XLPE content, for cable extrusion in applications like cable jacketing. The recycling cost is quite reasonable since existing grinding facilities for rotational moulding materials can be used.

1. Introduction
This paper describes a method to recycle XLPE from cable waste. The work has been carried out within the Swerea IVF R&D-Program Wire and Cable, which focus on recycling of the different polymers in cable waste. The participating companies in the program is Borealis AB, Ineos ChlorVinyl AB, VCC AB, Volvo 3P AB, Nexans IKO AB, Draka Kabel AB, ABB Power Systems AB and Stena Recycling AB. The objectives with the XLPE recycling project is to develop a method to separate and to recycle XLPE from cable waste and to investigate suitable applications for the recycled compounds.

2. Materials and processing
XLPE/HDPE blends
Recovered XLPE blended with HDPE has been processed by injection moulding, see reports by J.R. Powell [1] and M. Wennerbäck [2].

XLPE of silane cross-linked type has been recovered from insulated cables [2]. The cables insulations were cut and partially ground into flakes with a size of a few mm. The flakes were then ground further, into a particle size of approximately 500 µm. The XLPE powder was weighed and mixed with HDPE, MG9601 supplied by Borealis, according to the desired weight contents. The following blends were tested:

- 50/50 XLPE/HDPE
- 60/40 XLPE/HDPE
- 70/30 XLPE/HDPE

Batches of the XLPE and HDPE blends were fed directly to the injection moulding machine without pre-compounding. Dumbbell specimens were moulded. Tensile testing was performed in accordance to ISO 527, notched impact strength in accordance to ISO 179 and melt flow index measurements were carried out on the PE-based materials in accordance to ISO 1133.

XLPE/LLDPE blends
Recovered XLPE blended with LLDPE has been processed by injection moulding and extrusion respectively [3]. XLPE waste lumps from production of silane cross-linked type were collected by cable manufactures. The XLPE lumps were first granulated into flakes of a few mm size. The flakes were then ground further into two fractions, one with particle size ≤ 600 µm and one size ≤ 400 µm. The XLPE powder was weighed and mixed with LLDPE according to the desired weight contents.
The LLDPE used for injection moulding was LL 6201 from Exxon Mobile, called the a-type and the LLDPE used for extrusion was LL1004YB Film from Exxon Mobile, called the b-type.

The following blends were tested for injection moulding:

- 0/100 XLPE/LLDPE
- 40/60 XLPE/LLDPE
- 50/50 XLPE/LLDPE
- 60/40 XLPE/LLDPE
- 70/30 XLPE/LLDPE

The particle size of XLPE was $\leq 600\,\mu m$ in all the blends. Batches of the blends were feeded directly in to the injection moulding machine without pre-compounding. Dumbbell specimens were moulded. The injection moulded samples were evaluated by tensile testing, performed in accordance to ISO 527 and notched impact strength tests in accordance to ISO 179. Melt flow index measurements were carried out in accordance to ISO 1133.

The following blends were tested for tape extrusion:

- 0/100 XLPE/LLDPE
- 30/70 XLPE/LLDPE
- 50/50 XLPE/LLDPE
- 70/30 XLPE/LLDPE

The particle size of XLPE was $\leq 600\,\mu m$ in all the blends. Tape extrusion was performed with and without pre-compounding to evaluate the necessity of pre-compounding. The extruded samples were evaluated by tensile testing in accordance to the cable standard IEC 60811, tensile modulus according to ISO 527, MFI in accordance to ISO 1133 and stress cracking resistance according to IEC 60811.

A wire extrusion trial was performed at Draka Cable to evaluate the wire extrusion processability of the compounds. Wires insulated with XLPE/LLDPE compounds were extruded. In this trial the influence of particle size of XLPE was also investigated. Compounds were prepared of XLPE powder with particle size $\leq 600\,\mu m$ and with particle size $\leq 400\,\mu m$ respectively.

The following blends were pre-compounded and extruded as wire insulation:

- 30/70 XLPE/LLDPE, size $\leq 400\,\mu m$
- 30/70 XLPE/LLDPE, size $\leq 600\,\mu m$
- 50/50 XLPE/LLDPE, size $\leq 400\,\mu m$
- 50/50 XLPE/LLDPE, size $\leq 400\,\mu m$

The compounds with 30 % and 50 % XLPE respectively were also mixed with the pure LLDPE to obtain the following blends, which also were extruded as wire insulation:

- 5/95 XLPE/LLDPE, size $\leq 400\,\mu m$
- 5/95 XLPE/LLDPE, size $\leq 600\,\mu m$
- 15/85 XLPE/LLDPE, size $\leq 400\,\mu m$
- 15/85 XLPE/LLDPE, size $\leq 600\,\mu m$

The evaluation of the wires is proceeding with tensile testing, ageing, stress cracking test and surface roughness measurements.

The XLPE/LLDPE compounds have also been tested in a cable application at Nexans IKO Sweden. The particular cable has two jackets, one inner jacket of a polyolefin copolymer and one outer jacket of polyvinylchloride, PVC, see Fig. 1. In the trial the polyolefin copolymer in the inner jacket was substituted with XLPE/LLDPE compound mixed with pure LLDPE. The following blends were extruded as inner jacket:

- 10/90 XLPE/LLDPE
- 15/85 XLPE/LLDPE
- 20/80 XLPE/LLDPE

The particle size of XLPE was $\leq 600\,\mu m$ in all the blends. The evaluation of the cables is proceeding with tensile testing and ageing.

Fig. 1 - Cable with an inner jacket containing 20 % recycled XLPE in LLDPE.
3. Results and Discussion

**XLPE/HDPE Blends**

It was found that blends with up to 70 % XLPE could be injection moulded with retained process-ability as a common thermoplastic. Melt flow index (MFI) vs. XLPE content is shown in Fig. 2. Although MFI decreased below 1 g/10 min at 70 % XLPE, injection moulding was easy. The moulded specimens are homogeneous with smooth surface. There was no need of pre-compounding, XLPE powder and HDPE pellets could be simply mixed into the injection moulding machine. Injection moulding machines with two feeders makes the feeding easier and more effective.

![Fig. 2 - Melt Flow Index vs. XLPE by % weight in HDPE](image)

Of the materials produced it is believed that the 60/40 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. 3.

![Fig. 3 - E-modulus, Notched Impact vs. XLPE by % weight in HDPE](image)

It is reasonable to assume that the 60/40 blend of XLPE/HDPE can be used for applications similar to that of LDPE unless exceptionally high impact resistance is required. Such applications may include bowls, buckets, cold water tanks and road cones. Furthermore; it is possible to extrude the recycled material into pipe or sheet. It should also be possible for the material to be used by the cable industry as a filler material and, possibly as a jacketing material.

**XLPE/LLDPE Blends**

It was found that blends with up to 70 % XLPE could be injection moulded with retained process-ability. MFI vs. XLPE content is shown in Fig. 4. The LLDPE formed a thin layer next to the surface of the specimens which gave a smooth surface, see Fig 5. XLPE powder and LLDPE pellets could be simply mixed into the injection moulding machine without pre-compounding.

![Fig. 4 - Melt Flow Index vs. XLPE by % weight in LLDPE a-type (injection moulded samples)](image)

The E-modulus decreased slightly with increasing content of XLPE and the material become less stiff and less ductile see Fig. 6. The impact resistance is very good since all the specimens tested passed the test without break.

![Fig. 5 - SEM picture showing cross section of injection moulded specimen with 70 % XLPE by weight.](image)

The XLPE/LLDPE blends can replace LLDPE and flexible copolymers in injection moulded applications.
Extrusion of XLPE/LLDPE blends could be processed with up to 50% XLPE but the surface of the extruded bands with such high XLPE content were very rough.

MFI vs. XLPE content in LLDPE is shown in Fig. 7. Pre-compounding resulted in improved homogeneity of the extruded bands but the material properties were almost the same with or without pre-compounding, see Table 1. Compound is easier to handle but add costs for the pre-compounding. For extruders with 2 feeders there is no need for pre-compounding.

The wire extrusion trial showed also 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 a maximum of 20%. The use of XLPE powder with different particle sizes showed no visual difference for the wires. The jacket extrusion trial showed that XLPE/LLDPE blends can be used in cable jacketing. Possible cable application is also filler strings and bedding material. Other applications might be cable cover tubes and pipes.

4. Further work

The next step is to investigate the possibilities to recycle XLPE from granulated cable scrap, see process steps in Fig. 8. Cable scrap from cable manufacturers are collected and processed by cutting, granulation, metal and plastic separation. The method used for separation of XLPE and PVC is called Plastsep, a process that combines the sink/float method where XLPE is separated as the light fraction and the shaking wet table for separation of the heavy plastic, PVC, and residual metal. The XLPE fraction would be grounded and recycled in blends with LLDPE (HDPE). The blends will then be tested in cable jacketing.

If XLPE can be recycled from granulated cables, large amounts of cable scrap can be recycled. It might also be possible to recycle XLPE from field cables.

5. Conclusions

XLPE cable insulations and lumps from cable manufactures can be recycled quite easily by grinding and mixing XLPE with HDPE or LLDPE.

Injection moulding can be performed with up to 70% XLPE in HDPE and LLDPE respectively. Considering the material properties and costs in total it is believed that injection moulding of blends with 50-60% XLPE filler offers the best possibilities. The ease of processability together with reasonable material properties means the blends have a number of potential applications.

The XLPE can also be recycled back to cables in blends with LLDPE. Cable jacketing is a suitable application.

The recycling cost is quite reasonable since existing grinding facilities for rotational moulding materials can be used.

6. References

