Project Report
P102768

Recycling and Circularity in Power Distribution Cables: A fact-based study comparing market sourced MV XLPE and PP-TPE insulated cables

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Preface

Initiated by Borealis, the Swedish research institute, RISE IVF, has conducted a study to analyse the recyclability of different types of plastics in medium voltage 20kV power distribution cables.

Contents

Summary

RISE IVF was assigned by Borealis to perform a study on the recyclability of two medium voltage (MV) 12/20 kV 1x185 mm^2 power distribution cables with same design but different plastic set-up. One cable is the “XLPE cable” with crosslinked polyethylene (XLPE) in the cable core (insulation material) and thermoplastic polyethylene (PE) in the jacket. The other cable is the “PP-TPE cable” with thermoplastic polypropylene (PP) in the core and thermoplastic polyethylene (PE) in the jacket. The recyclability to recycle the cable plastic core material alone compared to recycle the cable plastics, core and jacket, together has been studied. The cable core and jacket plastics had been dismantled from the real cables and were received in grinded form at RISE IVF. Blends with the cable plastics were prepared to perform injection moulding and extrusion experiments. Injection moulding and extrusion grades of PP and high-density PE (HDPE) respectively were used for blends. The processability performance and properties of the blends were evaluated, as well as the impact of heat ageing and repeated reprocessing to simulate repeated recycling. The recycling value from a technical, environmental and economic perspective have been estimated.

Findings from the study are that the cable plastics in the XLPE cable, core plastics alone or core together with jacket, are recyclable and the plastics have a high re-use value. Injection moulding offered the best opportunities for recycling of the XLPE cable plastic blends. The processability performance and material properties obtained were good, especially the impact resistance which was improved significantly by the addition of XLPE. The extrusion performance was good in case of the blend with XLPE cable plastic and HDPE, but the sheets were rough. After ageing and repeated processing, the blends with XLPE cable plastic obtained improved mechanical properties. The XLPE cable plastics, core alone or with jacket are suitable for recycling. The core and the jacket can be recycled together and used in robust products like cable drums and cable channels.

The processability performance, injection moulding and extrusion, of blends with PP-TPE cable plastic were also good. The PP-TPE cable core blends offered higher toughness (strain and stress at break) compared to the other blends. However, the results of blends with PP-TPE cable plastics (core and jacket together) were mixed and after ageing and reprocessing the mechanical properties were reduced. Since the jacket material is polyethylene and the core material is PP, the miscibility of the polymers is limited. The core and jacket should be recycled separately to obtain high quality recyclates. The blends with PP-TPE cable core can most probably be used for extruded pipes, profiles and injection moulded products.

The environmental saving is substantial when recycling cable plastics and replace virgin plastic. Between 1.4 and 1.6 kg CO_2 can be avoided for each kg of cable plastic recycled. The economic gain can be 0,6 and 1,3 €/kg, depending on the application and methods used.

Introduction

On the market, there are some cable solutions that are claimed to be more recyclable than others, while there is a lack of fact-based information to help judge the recyclability. Therefore, Borealis assigned RISE IVF to perform an independent study on the recyclability of the plastics in two cables.

The work carried out in this study should help to evaluate the recyclability and circularity performance at end-of-life of the two cables with different insulation systems and cable plastic composition. The two studied medium voltage (MV) 12/20 kV 1x185 mm^2 power distribution cables have similar design but different plastics: The “XLPE cable”, with product code ARE4H5E 12/20 kV, and the “PP-TPE cable”, with product code ARP1H5EX.

The designations “XLPE cable” and “PP-TPE cable” will be used in this study.

Pictures of the cables are shown below in Figure 1 and Figure 2. The plastic covering the metal conductor consists of the insulation layer and two semiconductive layers and is called the core. The plastic used in the layer contains carbon black and is thus black in colour. The outer protective plastic layer on the cable is the plastic jacket.

Figure 1 Cross-section of the PP-TPE Cable

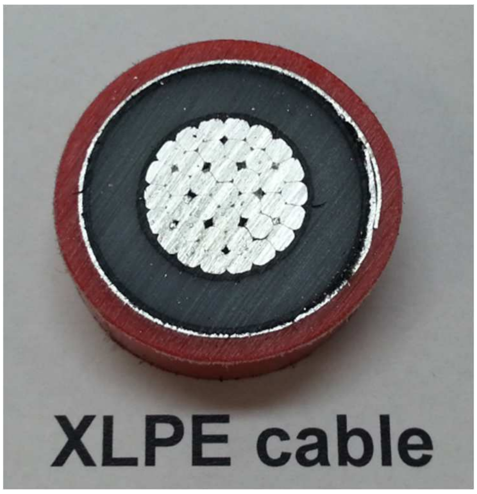

Figure 2 Cross-section of the XLPE Cable

This is the first study of its kind performing an equal evaluation of the recyclability, aiming to simulate recycling and the re-use value of the plastics in these two different kinds of cables at the end-of-life. Technical, environmental and economic aspects have been considered. At RISE IVF (former Swerea), we have long experience of cable plastics recycling from several projects performed within the R&D-Programme Wire and Cable and Vinnova funded projects. The present recyclability study was set up based on the collected experience.

Background

The recycling processes of cables are described here as background to give an understanding of the cable recycling processes.

The cable metals (copper and aluminium) have since long been recycled due to the high economical value of the metals. The state-of-art method, in most countries, to recycle cables and metals in cables is the cable shredding process, see the process steps in Figure 3.

Unfortunately, the plastics in the cables most often ends up at the incineration plants.

Cable recycling – Cable shredding process

The cables are sorted into different fractions according to the metal conductor type and size. The cables are chopped and fed through the cable shredding process. After further size reduction to approximately 5-8 mm, the metal and plastics are separated gravimetrically on a slanted shaking table. The shaking table generates two fractions – a clean metal product and a plastic fraction. The plastic fraction contains all the plastics in the cables (insulation, semiconductors, jacket and bedding materials) and is often contaminated with fine metal particles, usually 4 - 5 wt-%.

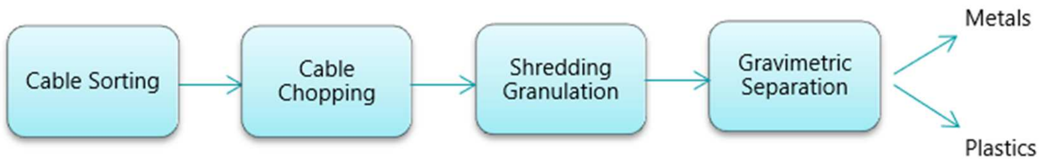

Figure 3 Cable shredding process

The plastic fraction can be a mix of different plastics (polyolefins with or without mineral fillers and polyvinylchloride (PVC) compounds). The mix of plastics and high content of metal residues makes it difficult to recycle the plastics without further material separation. Most recyclers do not carry out further separation of the plastics and the smaller pieces of metal from the plastic, hence the plastic fraction is not considered suitable for general re-use.

Some recyclers use an electrostatic separator to recover more metal from the plastic fraction. The plastic fraction contains less metal residues after the electrostatic separation. The semiconductive plastics have also been separated but it is still in a mix of plastics.

Plastic separation – PlastSep process

Another common method is gravimetric separation of the plastic fraction in water to separate and recover the remaining metals and at the same time the plastics are separated into a light and a heavy plastic fraction, respectively. Sink-float barrels or shaking tables with water are used.

Stena Recycling AB has a method combining sink-float at shaking wet-tables to separate remaining metals from the plastic and divide the plastic fraction into a light and a heavy fraction. The process is called PlastSep[1].

The process has a sink/float separator, i.e. a barrel containing water and wetting agent. The density of the water solution (1.0 g/cm^3) is higher than the density of PE and XLPE (0.9 g/cm^3), but lower than the density of PVC (1.4 g/cm^3). A paddle wheel moves the material down and forward and the lighter polyolefin fraction (with XLPE, PE and PP) floats to the surface while the heavy fraction, containing plastics with mineral fillers and 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 heavy plastic and sent away to be recycled. It is possible to separate more than one heavy plastic fraction on the wet separation table if the density difference is large enough. The process scheme is shown in Figure 4.

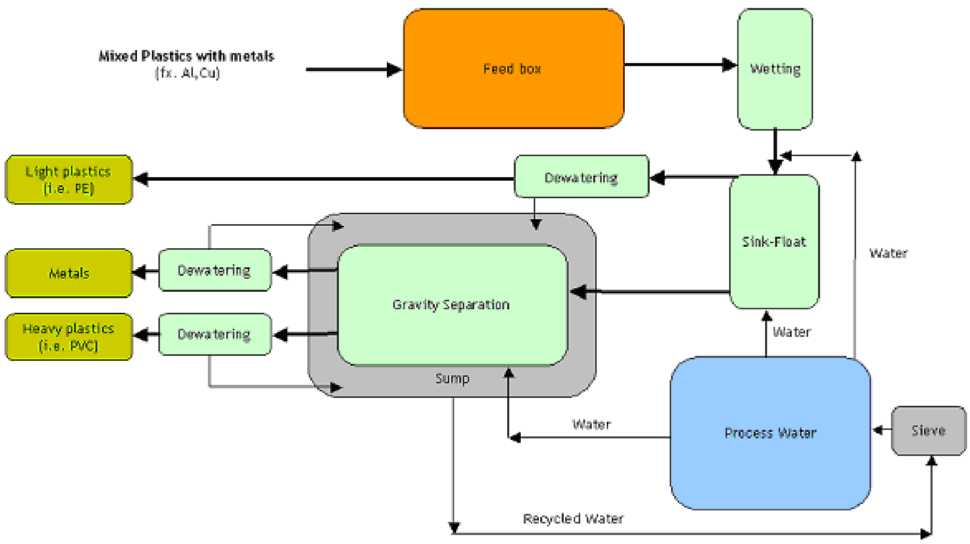

Figure 4 PlastSep process scheme

With this method, the plastic output usually contains less than 1 wt-% metal, but it depends on the input material. Sometimes an aluminium foil that sticks to the plastic is difficult to separate.

If the plastic is pure enough from metals and other plastic contamination it can be recycled. A big obstacle to recycle cable plastics are metal residues in the plastics. These metal contaminants can damage processing equipment and could also result in a negative impact on the produced product.

Cable recycling – Cable stripping process

Another method that can be used for cable recycling is stripping. The method is commonly used by cable producers to recover metal from the cables internally. There are automated machines that strips of the plastics from the metal conductor. These machines can be used for large size cables but are not common in cable recycling systems.

Stripping is a dismantling process where the materials are stripped off from the outside, layer by layer. Normally the insulation is dismantled together with the inner and outer semiconductive layers. With this method the metal conductor and the plastics in the cable (core materials and jacket), can become pure high quality recyclates. The plastics are shredded, milled and blends (compounds) are prepared to be used as raw material in new products. A big advantage with the stripping method is that pure plastic fractions can be obtained, without metal contamination. Additionally, the core and jacket materials can also be separated and recycled separately [2]. The method is not as efficient as the large-scale cable shredding process, but the method enables recycling of pure materials, both metals and plastics.

Cable plastics recycling

Depending on the manufacturing process when recycling the cable plastics and the final product requirements, the plastics need to undergo different recycling processes. To obtain the best material properties it is preferable if the cable core and jacket materials can be recycled separately. If the materials are compatible (i.e. can be blended) they can be recycled together.

The stripped plastic parts are fed into a shredder where the plastic is shredded to smaller parts and then is further ground to a size of approximately 5-8 mm. These steps are usually performed in-line. This recycled cable plastic fraction can then be blended directly into a manufacturing process with a suitable grade of similar plastic, or if needed first be compounded with a plastic having suitable properties to produce a recyclate that can be used, see the process steps below in Figure 5.

Cross-linked XLPE cannot be re-melted and is therefore often considered difficult to recycle compared to thermoplastics but XLPE is recyclable in blends with PE or PP. Finer grinding of the XLPE may be required for some applications.

Methods to recycle XLPE cable plastics in PE and PP blends have been developed within the RISE IVF R&D Programme Wire and Cable and have been tested in several applications [3].

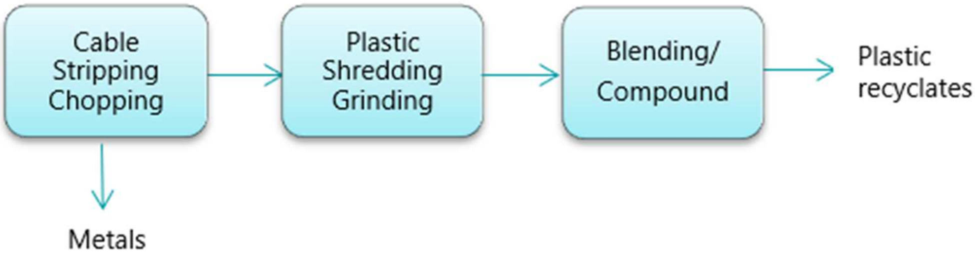

Figure 5 Cable recycling by stripping and production of plastic recyclates.

Materials

From market-sourced 3x1x185 mm^2 triplex formations of cables, two different types of cables were selected. These are –

a) "XLPE cable" with product code ARE4H5E and
b) "PP-TPE cable" with product code ARP1H5EX

Both of these cables are medium voltage (MV) single core 12/20 kV 1x185 mm^2 power distribution cables.
For detailed cables brands information get in contact with Borealis.

PP-TPE cable comprises of

PP-TPE core: PP based unknown grade
Jacket: Polyethylene polymer unknown grade

XLPE cable comprises of

XLPE core: Borlink™ LS4201R
Jacket: Borstar® ME6053

The jacket and the core materials were dismantled/stripped of the cables by Borealis. The PP-TPE core and jacket as well as the jacket used in the XLPE cable were ground to a size of 6-8 mm. The XLPE core was ground to a size of 1 mm. The grinded core and jacket materials were received at RISE IVF in September – October 2020. See pictures of the materials received in Figure 6-9.

For detailed cable brand information, a contact with Borealis is advised.

Figure 6 PP-TPE cable core. *Figure 7 PP-TPE cable Jacket.*

Figure 8 XLPE cable core (1 mm) *Figure 9 XLPE Cable Jacket.*

For the sake of clarity, *cable plastic* refers to a composition with both cable core and cable jacket materials.

Virgin polymers were used to blend with the cable plastics to make the plastics processable and useful in new products. Polymer grades for injection moulding and extrusion respectively with suitable properties were selected by Borealis. This was done to explore the best re-use value of the cable plastics. The virgin polymers were supplied by Borealis.

Polymers for injection moulding:
- Polypropylene, here named as $PP_{(IM)}$
- Polyethylene, here named as $HDPE_{(IM)}$

Polymers for extrusion:
- Polypropylene, here named as $PP_{(EXT)}$
- Polyethylene, here named as $HDPE_{(EXT)}$

Methods and performance

The recyclability and the reuse value of the plastics in the PP-TPE cable and the XLPE cable have been studied. The study includes comparison of the recycling value from recycling the cable plastic core material alone versus recycling all the cables plastics, i.e., core and jacket, together. The purpose was to simulate the different cable recycling options. The stripping recycling process enables recycling of core and jacket separate while the plastics are mixed when the shredding recycling process is used.

To simulate repeated recycling of the cable plastics, heat ageing and repeated processing were performed. Based on the processability and properties of the various blends possible potential applications have been proposed. The environmental and economic impact of the different recycling options were compared. The procedure is illustrated in Figure 10.

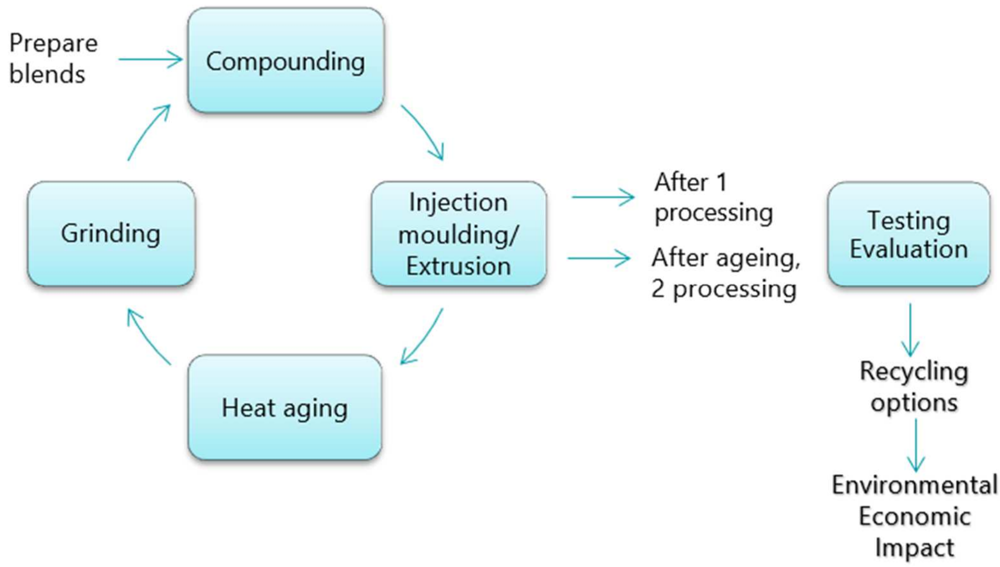

Figure 10 Performance Recyclability study.

Blends of the cable plastics and virgin polymers were prepared for injection moulding and extrusion experiments, respectively.

Blends prepared:

For injection moulding experiments –

A. Blend with 50% PP-TPE Core and 50% $PP_{(IM)}$
B. Blend with 50% XLPE Core and 50% $PP_{(IM)}$
C. Blend with 50% XLPE Core and 50% $HDPE_{(IM)}$
D. Blend with 50% PP-TPE cable plastics and 50% $PP_{(IM)}$
(33,5% PP-TPE cable core + 16,5% PP-TPE cable Jacket + 50% $PP_{(IM)}$)
E. Blend with 50% XLPE cable plastics and 50% $HDPE_{(IM)}$
(33,5% XLPE cable core + 16,5% XLPE cable Jacket + 50% $HDPE_{(IM)}$)

For extrusion experiments –

F. Blend with 40% PP-TPE cable plastics and 60% $PP_{(EXT)}$
(26,8 % PP-TPE cable core + 13,2% PP-TPE cable Jacket + 60% $PP_{(EXT)}$)
G. Blend with 40% XLPE cable plastics and 60% $HDPE_{(EXT)}$
(26,8 % XLPE cable core + 13,2% XLPE cable Jacket + 60% $HDPE_{(EXT)}$)

Since the plastics in the PP-TPE cable core is PP-based, the virgin plastic selected was a PP of injection moulding grade ($PP_{(IM)}$) and a PP of extrusion grade ($PP_{(EXT)}$) respectively. Same virgin PP grades were used for the PP-TPE cable blends with core and jacket, although the plastic in the PP-TPE cable jacket is a polyethylene.

In the XLPE cable the plastic core is XLPE and the jacket is thermoplastic PE. For blending with the XLPE cable plastics, a virgin HDPE injection moulding grade ($HDPE_{(IM)}$) and a virgin HDPE extrusion grade ($HDPE_{(EXT)}$) selected. In addition, a blend was prepared with XLPE cable core and $PP_{(IM)}$ as virgin material to create a blend of higher stiffness and dimensional stability than the blends based on HDPE.

In the blends D, E, F and G, the cable plastics (core and jacket materials) were added in the same weight-ratio as they are present in the cables selected for this study (67% core and 33% jacket) in order to simulate real-case recycling of the cable plastics together.

For injection moulding blends (A to E), 50% of virgin polymer was added and for extrusion blends (F and G), 60% of virgin polymer was added to recyclate blends to achieve good processability and material properties.

Compounding and pelletizing

For the compounding of the blends, a Coperion twin screw extruder (model ZSK 26 K 10.6) was used. The blends with PP virgin polymers, A, B, D and F, were compounded with the maximum temperature set to 230°C.

The blends with HDPE, C, E and G were compounded with the maximum temperature set to 200°C. The plastic compounds were cooled with water and pelletized.

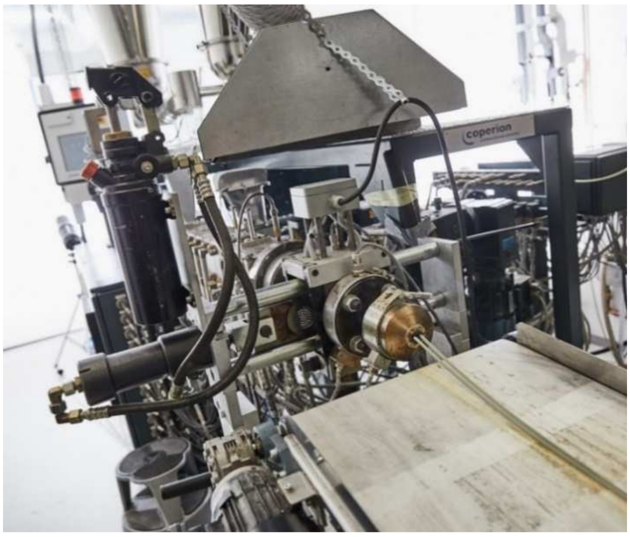

Figure 11 The Coperion extruder used for compounding.

Injection moulding

Test samples were injection moulded for tensile and impact testing according to ISO 527-2 1A. The machine was an Engel Injection moulding machine HL110 with a 30 mm screw. The injection moulding temperature setting was 230°C for the blends with virgin PP i.e. blends A, B, D and the $PP_{(IM)}$ material. The temperature was set to 220°C for the blends with virgin HDPE i.e. blends C and E and the $HDPE_{(IM)}$ material.

Figure 12 Injection moulding.

Extrusion sheets

Polymer sheets were extruded with an Axon Bx-35 film extruder. The materials were fed into the extruder and thereafter forced through the die. The plastic sheets which come out were drawn, with as low as possible drawing ratio (to ensure that the sheets were as thick as possible), by a rolling mill.

The extrusion maximum temperature was set to 230°C for the PP-TPE cable plastics blend F and the $PP_{(EXT)}$, and to 220°C for the XLPE cable plastics blend G and the $HDPE_{(EXT)}$.

Figure 13 Extrusion sheets.

Sample specimen extruded sheets

Samples of the extruded sheets were taken out in the extrusion direction. Test specimens were prepared with an automated milling cutter according to ISO 527-2 1A for tensile testing. For impact testing, the specimens were sawed out manually and notched in a Ceast 9050 notching machine.

Heat ageing

The injection moulded samples of the blends A-E were heat aged for 1000 h in 100°C while freely hanging in Binder cabinet ovens with fan. The air exchange was set to 15 changes per hour. Extruded sheets of the blends F and G, cut in pieces of approximately 150x300 mm, were heat aged free hanging in cabinet ovens with fan. The blends with PP-TPE cable plastics and XLPE cable plastics were heat aged in separated ovens.

Figure 14 Heat ageing injection moulded specimens.

Grinding and reprocessing

After ageing, the materials were ground to 5-7 mm size. The compounding, injection moulding and extrusion respectively were repeated. Test samples were injection moulded in standard dimensions for mechanical testing. From the extruded sheets the test samples were ground and prepared as described earlier on page 10.

Testing material properties

Tensile testing

Tensile strength (stress and strain) and E-modulus were measured in a tensile tester according to ISO 527. Injection moulded specimens and milled specimens from extruded sheets were tested. For each material, five samples for tested for tensile strength and E-modulus. Some extra specimens were tested on extruded blends due to high standard deviation. Injection moulded blends, A-E and extruded blends, F-G were tested before ageing, after ageing and second processing. Injection moulding grades - $PP_{(IM)}$ and $HDPE_{(IM)}$ and extrusion grades - $PP_{(EXT)}$ and $HDPE_{(EXT)}$ were tested only before ageing.

Figure 15 Tensile testing injection moulded sample.

The maximum elongation that could be measured was 570% due to limited workspace in the tensile testing machine.

Impact resistance

Impact testing (Charpy) was performed on notched samples according to the ISO 179-2 standard. The test was performed both in room temperature and in cold (-20°C for PP and -30°C for PE blends). The injection moulded blends (A-E) and extruded blends (F-G) were tested before ageing, after ageing and second processing. Injection moulding grades - $PP_{(IM)}$ and $HDPE_{(IM)}$ and extrusion grades - $PP_{(EXT)}$ and $HDPE_{(EXT)}$ were tested only before ageing.

Figure 16 Impact resistance (Charpy) testing.

Melt Flow Rate (MFR)

Melt flow rate (MFR) was measured according to ISO 1133 with an Instron Ceast 7024 MFR testing equipment. Sufficient material (approx. 10 g) was placed in the equipment and heated until it melted (190°C for PE and 230°C for PP blends). A piston with a weight (2,16 kg for PP and 5 kg for PE blends) pressuring upon the plastic melt, which is forced through a capillary. The material coming through the capillary is cut off in predetermined intervals and the strings were weighed and the weight was used to calculate the MFR value in g/10 minutes. MFR was measured on the blends before ageing, after ageing and second processing.

Density

Density measurements were performed according to ISO 1183-A on a Mettler Toledo AT200 scale. Rectangular specimens of approximately 60x10x4 mm were measured, two samples of each material. The samples were first measured in air and thereafter in ethanol. Based on the weights in these different "environments" and the density of air and ethanol the density for the materials were calculated. Density was measured on the blends before ageing, after ageing and second processing.

The measurements performed on the blends and materials are summarised in Table 1. The injection moulded and extruded blends were tested before and after the ageing and reprocessing. The injection moulded and extruded virgin polymers were tested once (since they were not aged and reprocessed). The cables core and jacket materials were used as received.

Table 1 Summary of the measurements performed

	A	B	C	D	E	F	G	PP (IM)	HDPE (IM)	PP (EXT)	HDPE (EXT)
Tested											
Tensile properties											
E-modulus	x	x	x	x	x	x	x	x	x	x	x
Stress @ yield	x	x	x	x	x	x	x	x	x	x	x
Strain @ yield	x	x	x	x	x	x	x	x	x	x	x
Stress @ break	x	x	x	x	x	x	x	x	x	x	x
Strain @ break	x	x	x	x	x	x	x	x	x	x	x
Impact resistance											
+23°C	x	x	x	x	x	x	x	x	x	x	x
-20°C - PP	x	x		x		x		x		x	
-30°C - HDPE			x		x		x		x		x
Melt Flow Rate											
MFR 230°C /2,16 kg	x	x		x		x					
MFR -190°C/2,16 kg			x		x		x				
MFR - 190°C/5 kg			x		x		x				
Density	x	x	x	x	x	x	x				

Results and Discussion

The results of the study are summarised and discussed in this report.

The virgin polymers used in preparing blends are named as below –

Polymers for injection moulding:
- Polypropylene, here named as $PP_{(IM)}$
- Polyethylene, here named as $HDPE_{(IM)}$

Polymers for extrusion:
- Polypropylene, here named as $PP_{(EXT)}$
- Polyethylene, here named as $HDPE_{(EXT)}$

Summarily, the blends prepared are listed here again.

For injection moulding experiments

A. Blend with 50% PP-TPE Core and 50% $PP_{(IM)}$
B. Blend with 50% XLPE Core and 50% $PP_{(IM)}$
C. Blend with 50% XLPE Core and 50% $HDPE_{(IM)}$
D. Blend with 50% PP-TPE cable plastics and 50% $PP_{(IM)}$
(33,5% PP-TPE cable core + 16,5% PP-TPE cable Jacket + 50% $PP_{(IM)}$)
E. Blend with 50% XLPE cable plastics and 50% $HDPE_{(IM)}$
(33,5% XLPE cable core + 16,5% XLPE cable Jacket + 50% $HDPE_{(IM)}$)

For extrusion experiments

F. Blend with 40% PP-TPE cable plastics and 60% $PP_{(EXT)}$
(26,8 % PP-TPE cable core + 13,2% PP-TPE cable Jacket + 60% $PP_{(EXT)}$)
G. Blend with 40% XLPE cable plastics and 60% $HDPE_{(EXT)}$
(26,8 % XLPE cable core + 13,2% XLPE cable Jacket + 60% $HDPE_{(EXT)}$)

To ease the reporting of the results, the analysis of the results for Injection moulded and Extrusion blends is described in separate sections below.

Injection moulded blends

The PP-TPE core and PP-TPE cable plastics blends (A and D) were easily processed and the test specimens were black with smooth surface finish. The black colour is due to the semiconductive material with carbon black in the cable core (see Figure 17).

The blends with XLPE cable core and XLPE cable plastics (B, C and E) were also easily processed and the specimens were dark-grey/black coloured, also due to the semi-conductive material in the cable core. The specimens were homogeneous with smooth surfaces (see Figure 18).

The specimens of blend B, the blend with $PP_{(IM)}$ had a better surface finish, were not warped and were dimensionally stable also after ageing. The surface finish was rougher for the specimens of the blends (C and E) containing $HDPE_{(IM)}$. Some of these specimens were slightly warped.

Figure 17 PP-TPE cable core blend A and plastic blend D.

Figure 18 XLPE cable core blends (B, C) and plastic blend E.

Tensile properties – E-Modulus, Stress and Strain

According to the tensile test results, the cable plastics were soft and flexible compared to the virgin polymers, $PP_{(IM)}$ and $HDPE_{(IM)}$. New materials with unique properties are obtained when blending the plastics from cables and virgin polymers.

E-modulus

The PP-TPE cable core blend A, had an E-modulus of 750 MPa, which is about 50% of the virgin $PP_{(IM)}$. Therefore, the blend is quite soft and flexible although the PP-TPE cable core material is PP based.

The blend D, with PP-TPE cable plastics, containing PP from the cable core and polyethylene in the jacket, had 12 % lower E-modulus compared to blend A. Thus, blend D, was slightly softer and more flexible. After ageing and reprocessing, the blend A was somewhat stiffer but for the blend D there was almost no difference (See Figure 19).

Blend B with XLPE cable core and $PP_{(IM)}$, had an E-modulus of 609 MPa and blend C with XLPE cable core and $HDPE_{(IM)}$ had an E-modulus of 501 MPa. Thus, the blend B showed a higher degree of stiffness. Blend E with XLPE cable plastics (core and jacket) and $HDPE_{(IM)}$ had an E-modulus of 565 MPa, somewhat higher compared to blend C. The E-modulus of the blends with XLPE cable plastics did not change with ageing and reprocessing (Figure 20).

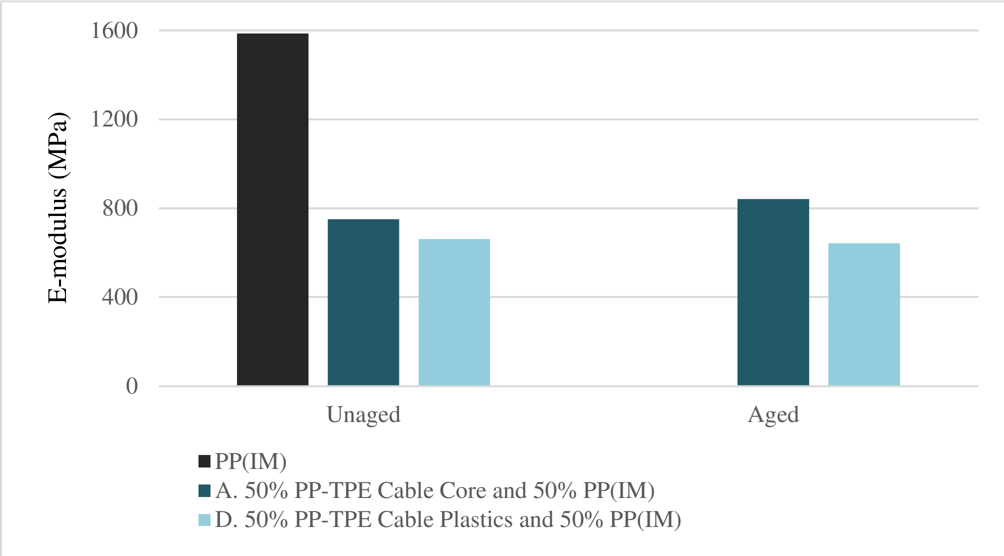

Figure 19 E-modulus (MPa) I.M. PP-TPE cable core and plastic blends A, D and PP$_{(IM)}$.

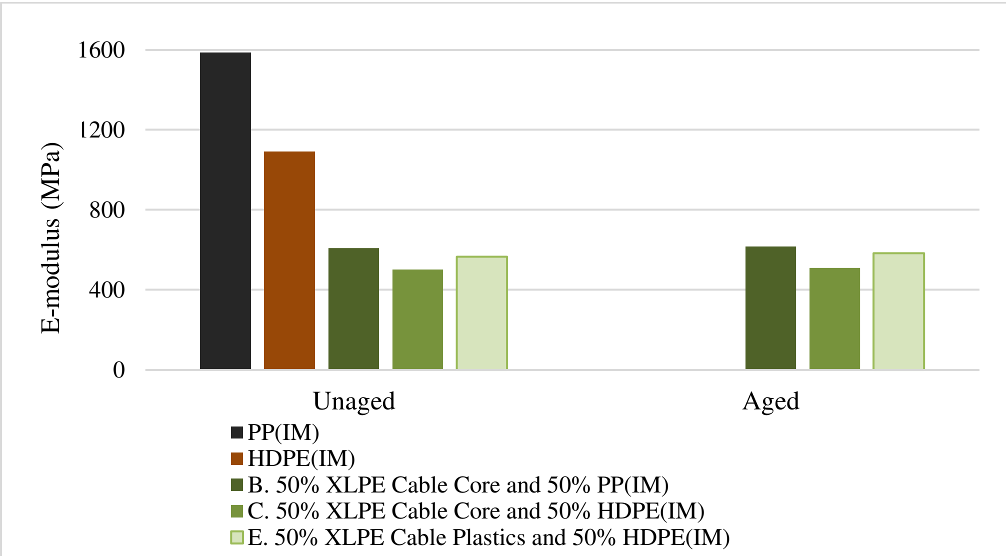

Figure 20 E-modulus (MPa) I.M. XLPE cable core and plastic blends B, C, E, PP$_{(IM)}$, and HDPE$_{(IM)}$.

Stress at Yield

The blends of PP-TPE cable core and plastics with PP$_{(IM)}$ obtained a higher stress at yield compared to the XLPE cable core and plastics blends with HDPE$_{(IM)}$ as seen in Figure 21 and Figure 22.

The difference between the blend A, with PP-TPE cable core and blend D, with PP-TPE cable plastics (core and jacket), was 15%. The PP-TPE Jacket of polyethylene (16,5% in blend D) decreased the stiffness. For the blends with XLPE cable core, the blend B with $PP_{(IM)}$ obtained the highest stress at yield value.

The blend E, with XLPE cable plastics (core and jacket) and $HDPE_{(IM)}$, had somewhat higher stress at yield compared to blend C with, XLPE cable core and $HDPE_{(IM)}$. After ageing and reprocessing the blends stress at yield had increased slightly for some of the blends.

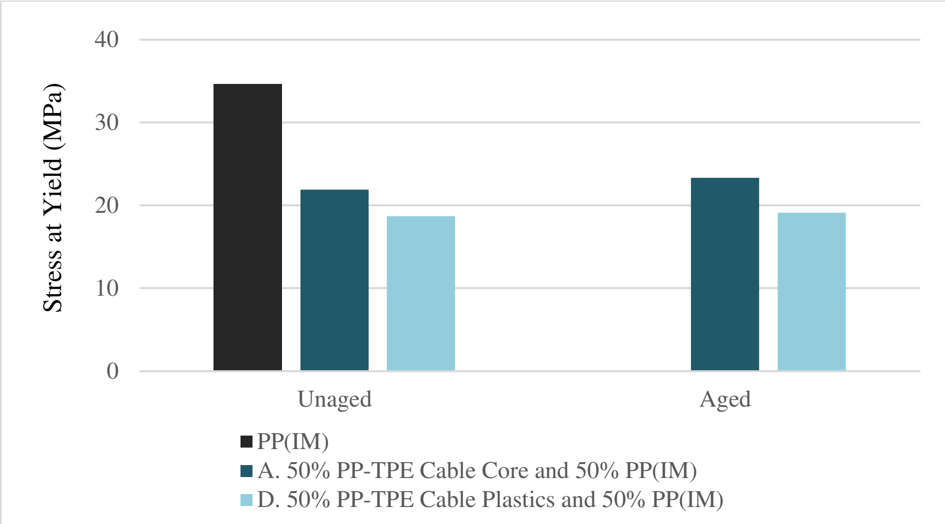

Figure 21 Stress at Yield (MPa) I.M. PP-TPE cable plastic blends A, D and $PP_{(IM)}$.

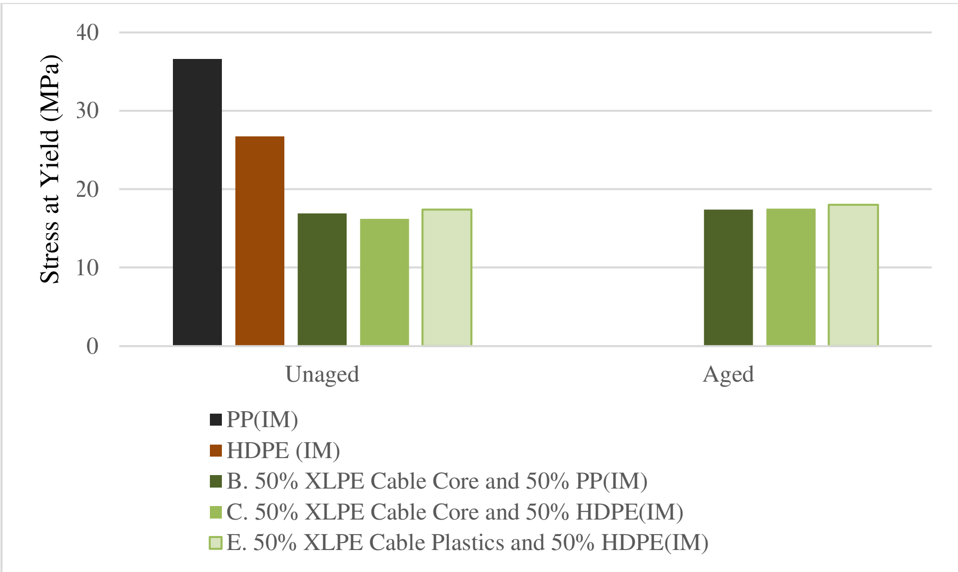

Figure 22 Stress at Yield (MPa) I.M. XLPE cable plastic blends B, C, E, $PP_{(IM)}$ and $HDPE_{(IM)}$.

Strain at Yield

Strain at yield was significantly higher for the blends containing $HDPE_{(IM)}$ compared to the blends with $PP_{(IM)}$, see Figure 23 and 24. The blend C, with XLPE cable core and $HDPE_{(IM)}$, had the highest strain at yield, 35,4%, compared to all the blends. After ageing and reprocessing strain at yield had decreased somewhat for the PP-TPE cable plastic blends, A and D, but had increased quite a lot for blend C, with XLPE cable core and $HDPE_{(IM)}$. The blends B and E had had similar strain at yield before and after the ageing and reprocessing.

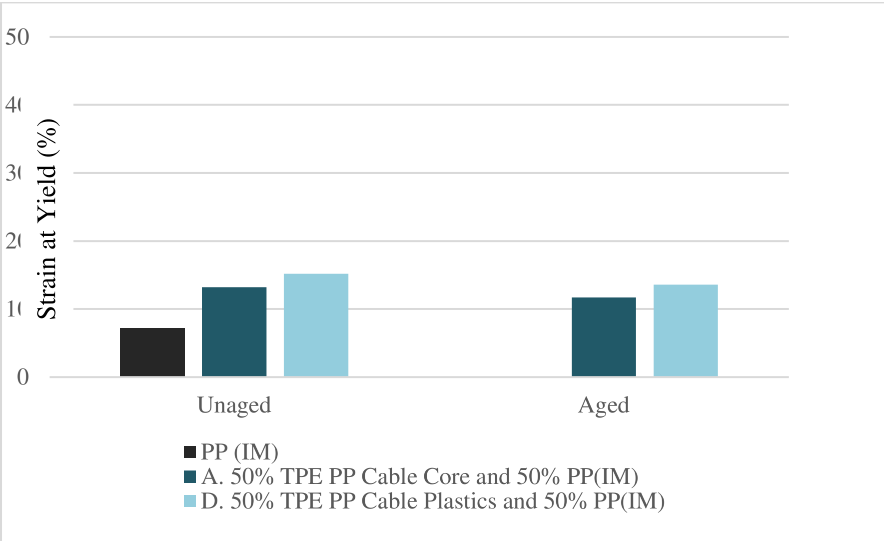

Figure 23 Strain at Yield (%) I.M. PP-TPE cable plastic blends A, D and PP(IM).

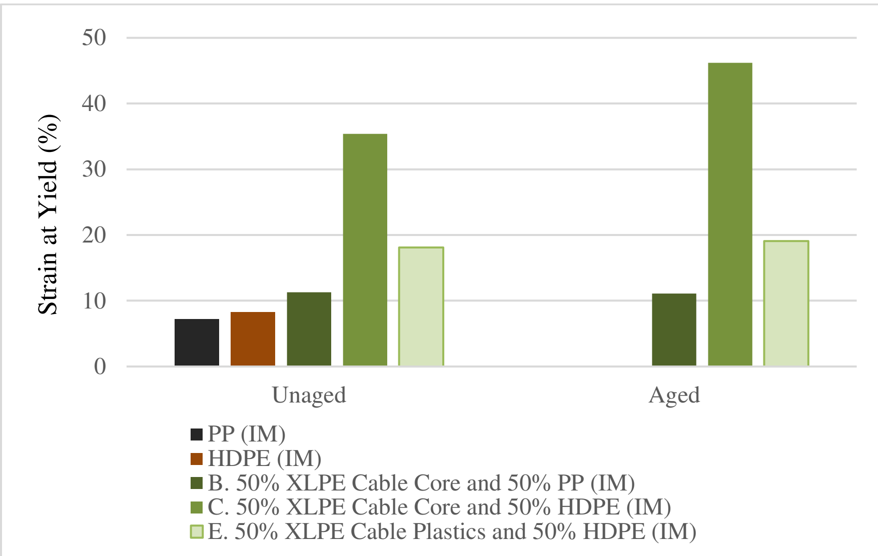

Figure 24 Strain at Yield (%) I.M. XLPE cable plastic blends B, C, E, PP(IM) and HDPE(IM).

Stress at Break

The blends of PP-TPE cable core and cable plastic, A and D, had no break at the maximum machine limit of 570% strain. Thus, stress at break could not be measured. After ageing and reprocessing, blend A had still no break, but blend D had a at break 12,1 MPa, a significant reduction, probably due to the polyethylene jacket. (Figure 25). The blend B, with XLPE cable core and PP(IM), had a break at 16,7 MPa and the blend C, with XLPE cable core and HDPE(IM), at 11,9 MPa. After ageing and reprocessing strain at break was almost the same for the blends with XLPE cable plastics as shown in *Figure 26*.

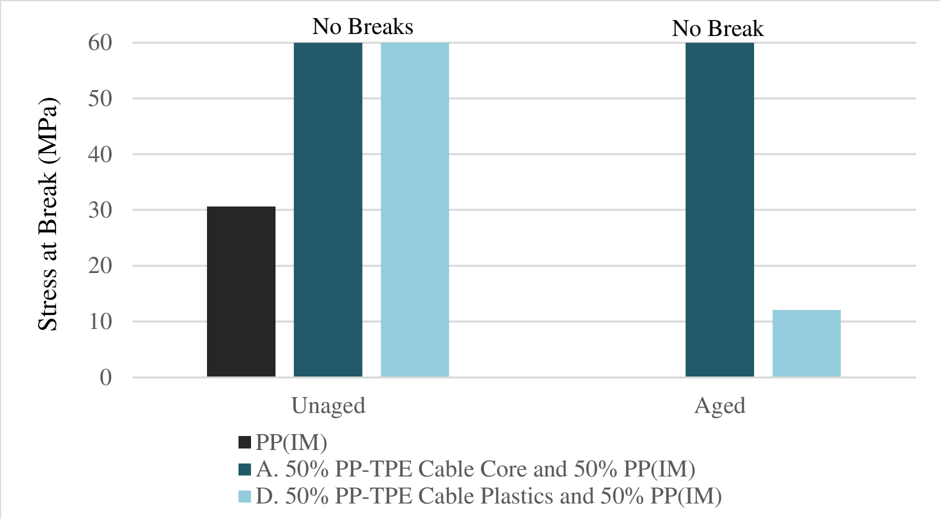

Figure 25 Stress at Break (MPa) I.M. PP-TPE cable blends A, D and PP(IM).

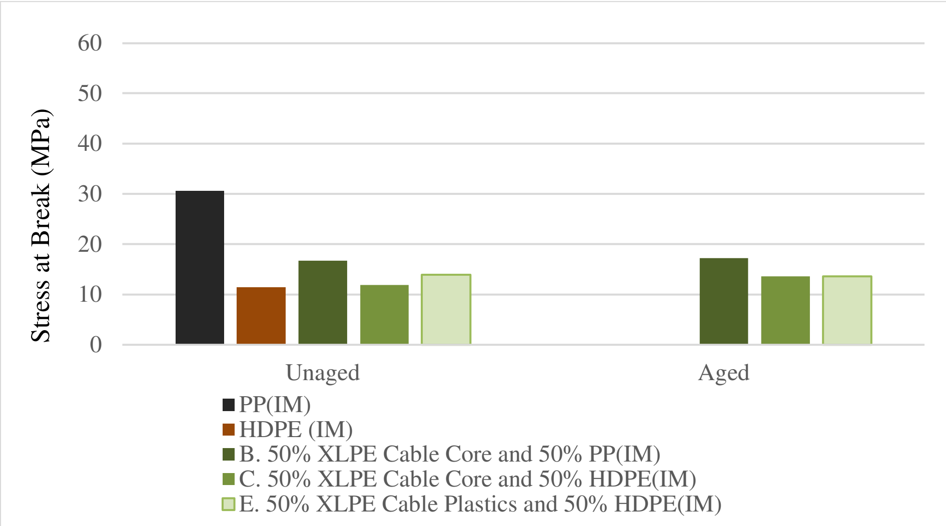

Figure 26 Stress at Break (MPa) I.M. XLPE cable plastics blends B, C, E and PP(IM) and HDPE(IM).

Strain at Break

The blends with PP-TPE cable core and cable plastic, A and D, had no break at the maximum machine limit of 570% strain. After ageing and reprocessing, blend A had no break but blend D, with PP-TPE cable plastics, had strain at break at 515%. (See Figure 27)

Blend B with XLPE cable core and PP(IM) break at 13,2% and blend C with XLPE cable core and HDPE(IM) at 74,6%. After ageing and reprocessing strain at break was almost the same for blends with XLPE cable plastics as seen in Figure 28.

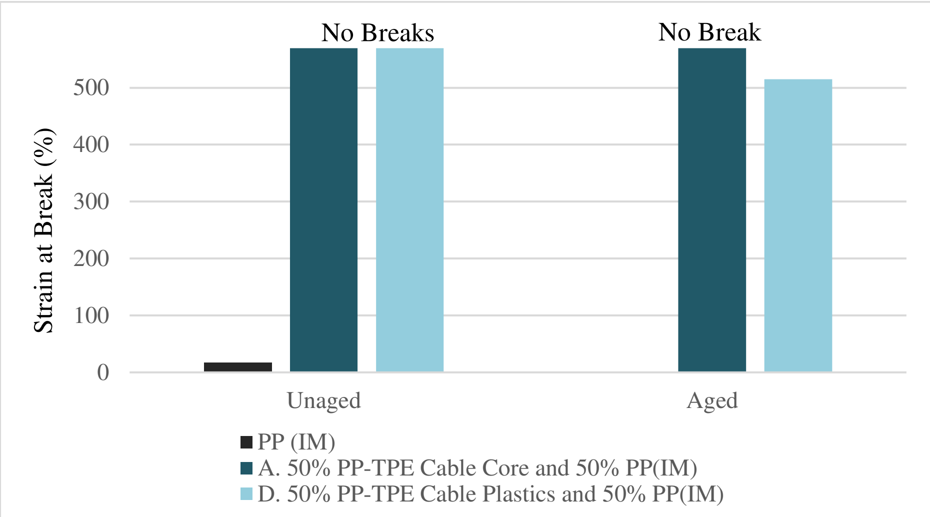

Figure 27 Strain at Break (%) I.M. PP-TPE cable plastic blends A, D and PP(IM).

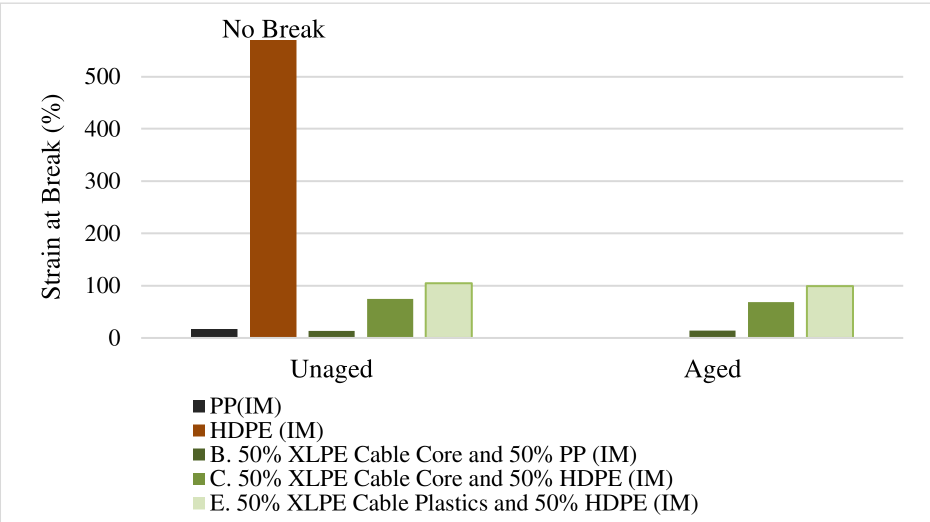

Figure 28 Strain at Break I.M. (%) XLPE cable plastic blends B, C, E and PP(IM) and HDPE(IM).

Impact resistance

The impact resistance tested at room temperature and at – 20°C was significantly higher for the PP-TPE cable plastic blends, A and D, compared to the impact resistance of the virgin PP(IM). The ageing and reprocessing had almost no influence on the impact resistance of the blends A and D, see Figure 29.

The XLPE core material has a great effect on the impact resistance of the blends C and E. The blend C with XLPE cable core and HDPE(IM) had 12 times higher impact resistance compared to the HDPE(IM) at room temperature. For the blend B, with XLPE cable core and PP(IM) the impact resistance at room temperature was 2,4 times higher than for the virgin PP(IM). The impact resistance was improved by the XLPE also at the low temperatures. The impact resistance of blend B at -20°C was double of the virgin PP(IM). After ageing and reprocessing, the impact resistance had significantly increased for blend C and E at room temperature, see Figure 30.

It was found also in studies performed within the Swerea R&D Programme Wire and Cable, that XLPE from recycled cables has a great effect on the impact resistance [3] and [4].

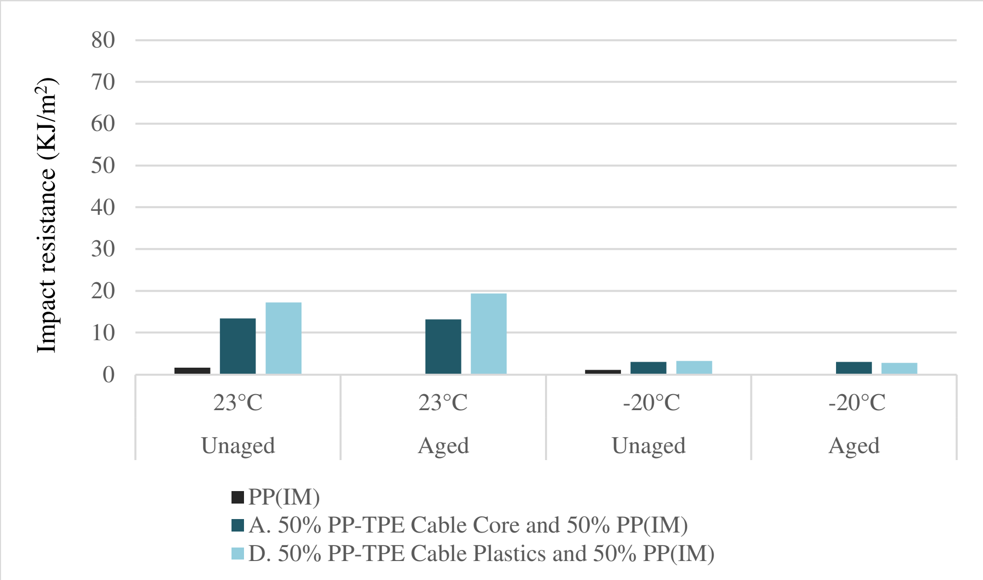

Figure 29 Impact resistance, Charpy notched samples (KJ/m²), I.M. PP-TPE cable core blend A and cable plastic blend D with PP(IM).

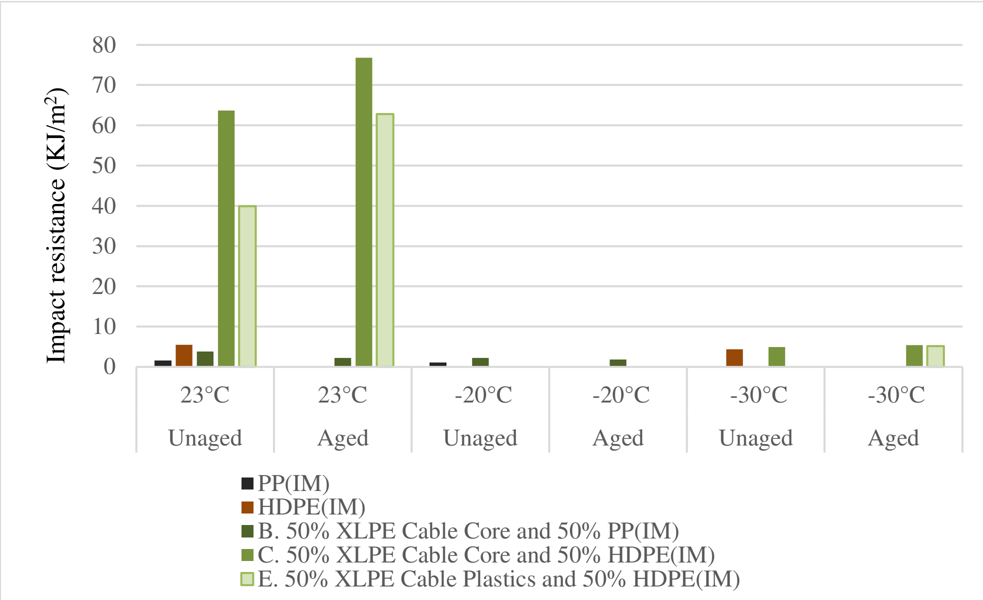

Figure 30 Impact resistance (KJ/m²) I.M. XLPE cable plastic blends B, C, E and PP(IM) and HDPE(IM).

Melt flow rate (MFR)

The MFR of blend A, with PP-TPE cable core, had increased 13% after heat ageing and reprocessing, see

Figure 31. MFR of blend D had not changed.

Blends with XLPE cable plastic had low MFR due to the crosslinked XLPE. The blend B, with XLPE cable core and PP(IM), had MFR of 8,4 g/10min and same after ageing and reprocessing. MFR was low for the blend C, with XLPE cable core and HDPE(IM) and had decreased after ageing and reprocessing. The MFR of blend E, with XLPE cable plastics and HDPE(IM), had decreased slightly after ageing and reprocessing as shown in the Figure 32 and Figure 33. MFR could not be measured for the blends C and E with the 2 kg weight after aging due to the low melt flow rate.

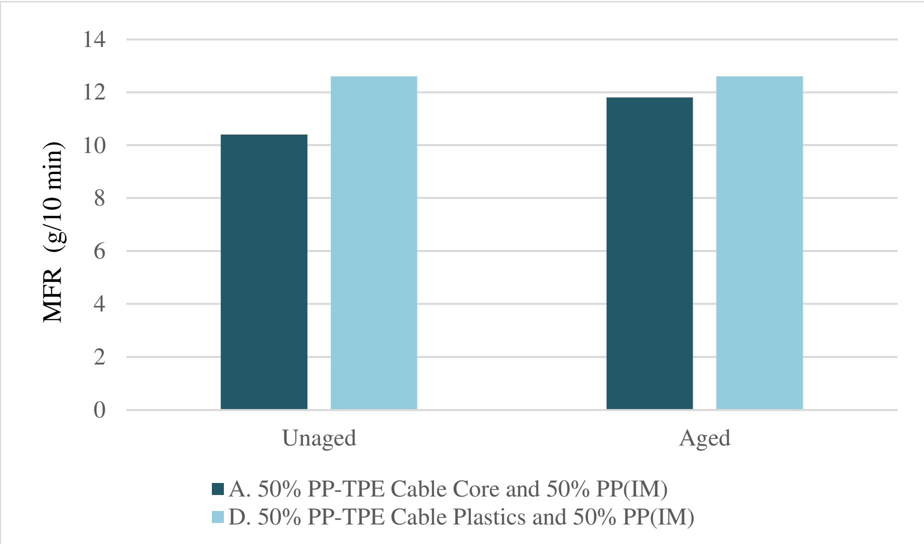

Figure 31 Melt flow rate 230°C/2,16 kg (g/10 min) I.M. PP-TPE cable plastics blends A and D.

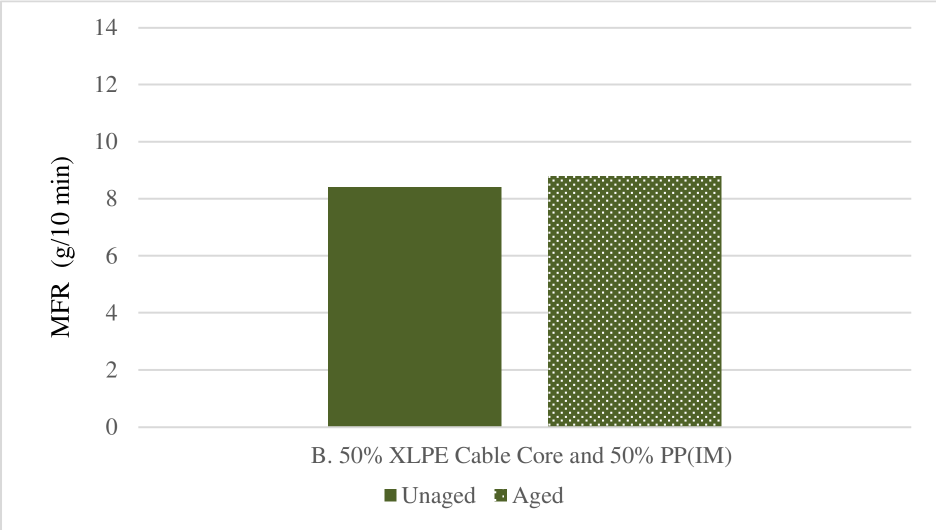

Figure 32 Melt flow rate 230°C/2,16 kg (g/10 min) I.M XLPE cable core blend B.

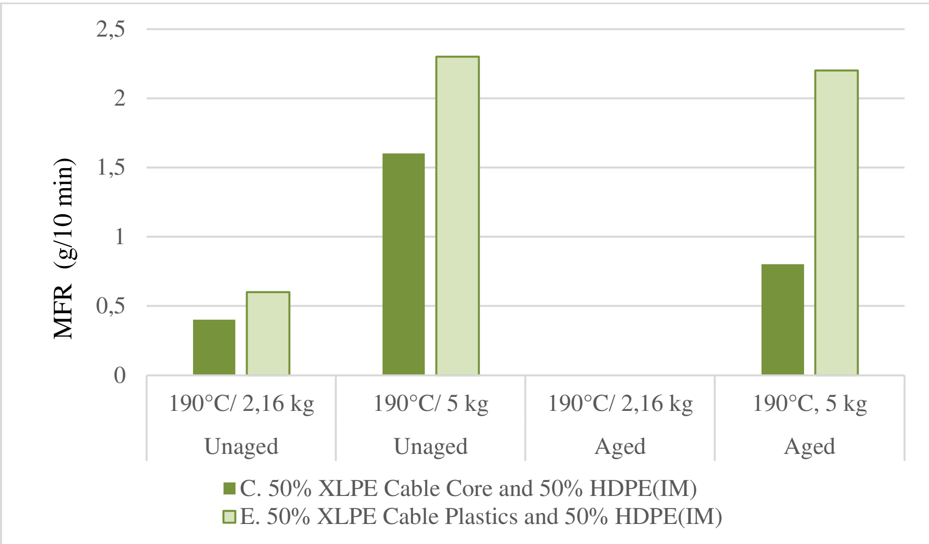

Figure 33 Melt flow rate 190°C/2,16 and 190°C/5 kg (g/10 min), I.M. XLPE cable plastic blends C and E.

Density

The density is somewhat higher for the blends with HDPE(IM) as a result of addition of the virgin material. The density of the injection moulded blends was not affected by ageing and reprocessing.

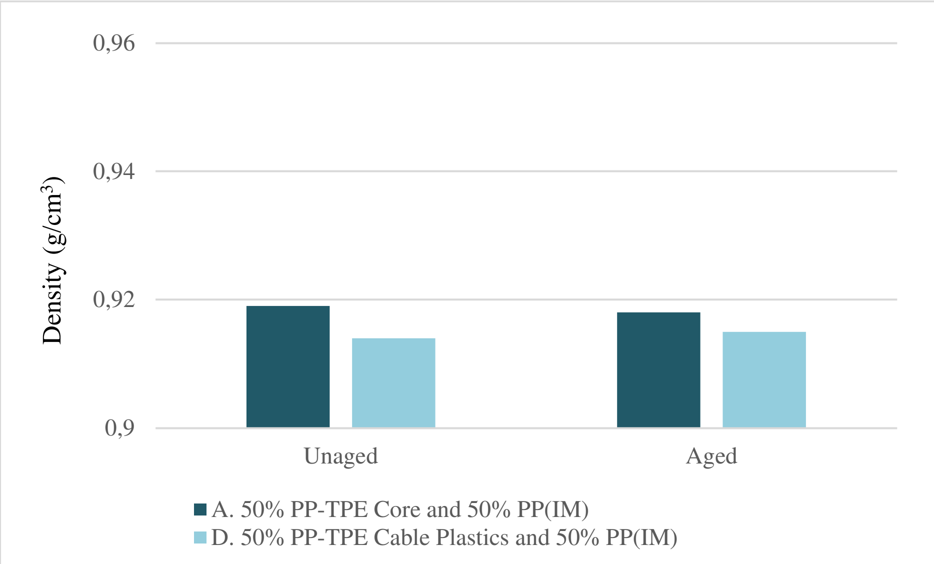

Figure 34 Density (g/cm³) I.M. PP-TPE cable plastic blends A and D.

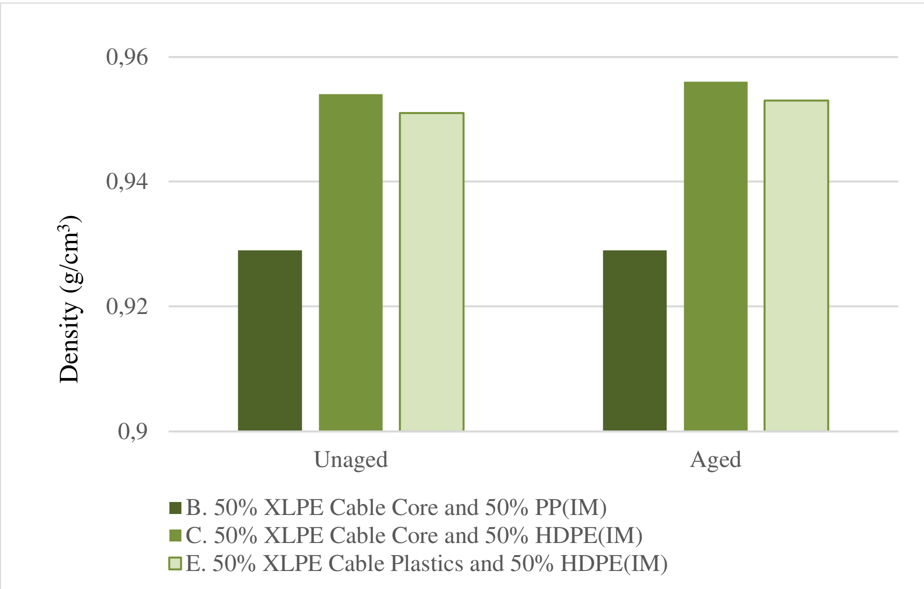

Figure 35 Density (g/cm³) I.M. XLPE cable plastic blends B, C and E.

Conclusions injection moulding experiments

- All blends produced were black. The carbon black in the semiconductive material in the cable core recyclates dominates the colour of resulting blend.

- All the blends of 50% plastic from the XLPE cable and PP-TPE cable respectively were injection moulded with good processability performance.

- When blending XLPE with HDPE or PP, a new polymer material with great impact resistance, even at low temperatures, was obtained.

- The PP-TPE cable core blend had some higher toughness compared to the XLPE cable core and plastics blends. The toughness of the PP-TPE cable plastics blend D was lower, most probably due to the polyethylene plastic in the jacket.

- Heat ageing and reprocessing had no negative impact on the mechanical properties of the XLPE cable plastic blends. The properties were in some cases improved after ageing and reprocessing.

- The blends C and E, with XLPE cable plastic had low melt flow rate.

- Heat ageing and reprocessing had mixed influence on the PP-TPE cable plastics blends (mix of PP core and polyethylene jacket), stress at break was significantly reduced, but the impact resistance had slightly increased.

Extrusion processability

The extrusion processability performance worked well, both for the blend F, with PP-TPE cable plastics and the blend G, with XLPE cable plastics. However, it was somewhat difficult to control the thickness of the extruded sheets with blend F. The surface of blend F was smooth. Pictures of the extruded sheets are shown in Figure 36 and Figure 37.

The extruded sheets of blend G were rough but compression of the sheets between cooled rollers made the sheets smoother. Thickness variations and the milling process to prepare test samples for the mechanical testing caused more deviation in the mechanical test results compared to the results of injection moulded samples. Therefore, some extra test samples were prepared for tensile testing and impact resistance testing.

Figure 36 Extruded sheet PP-TPE cable plastics blend F

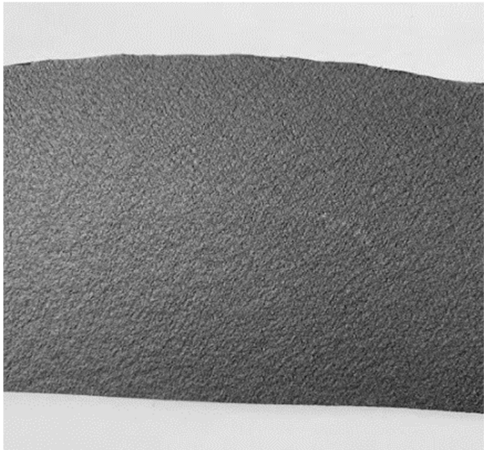

Figure 37 Extruded sheet XLPE cable plastics blend G

Tensile properties – E-modulus, Stress and Stain

E-modulus

The blend F, with PP-TPE cable plastics, obtained low E-modulus compared to $PP_{(EXT)}$ material, thus the material is soft and flexible. After ageing the E-modulus of blend F had increased with 44%, see Figure 38. The standard deviation of tensile tests was rather high for blend F after the ageing and reprocessing. It might to some extent depend on the sample preparation method. The E-modulus of blend G, with XLPE cable plastics and $HDPE_{(EXT)}$, had decreased with 37% after ageing and reprocessing, resulting in it becoming more flexible, see Figure 39.

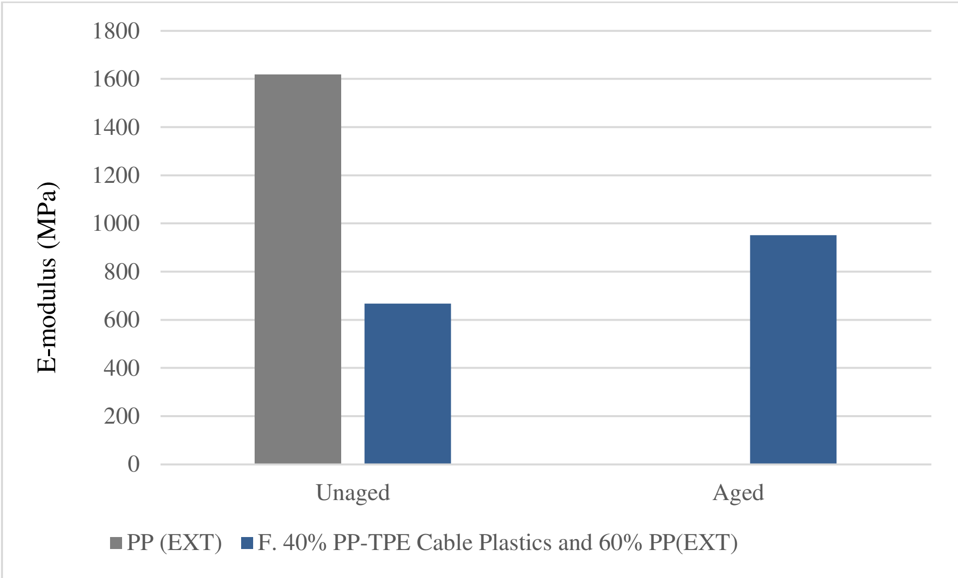

Figure 38 E-modulus (MPa) EXT. PP-TPE cable blend F and PP(EXT).

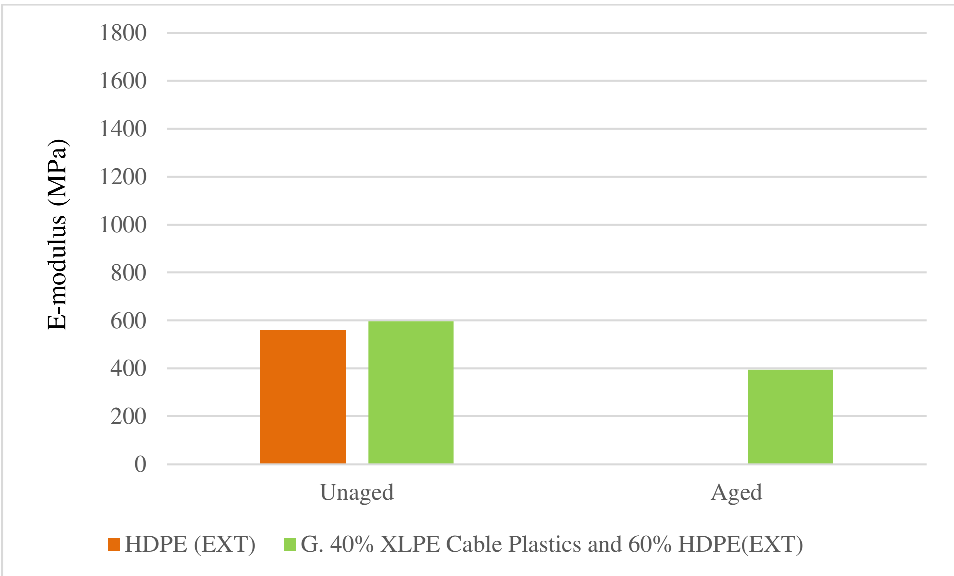

Figure 39 E-modulus (MPa) EXT. XLPE cable blends G and HDPE(EXT).

Stress at Yield

Stress at yield was 21 MPa for blend F, with PP-TPE cable plastics, low compared to the virgin PP(EXT) used for blending (see Figure 40). The blend is a soft and flexible material. After ageing and reprocessing stress at yield had increased a little. Blend G, with XLPE cable plastics, had stress at yield of 14,5 MPa and after ageing and reprocessing 13,3 MPa, a decrease of 8% as in Figure 41. Both blends, F and G, are soft and flexible materials.

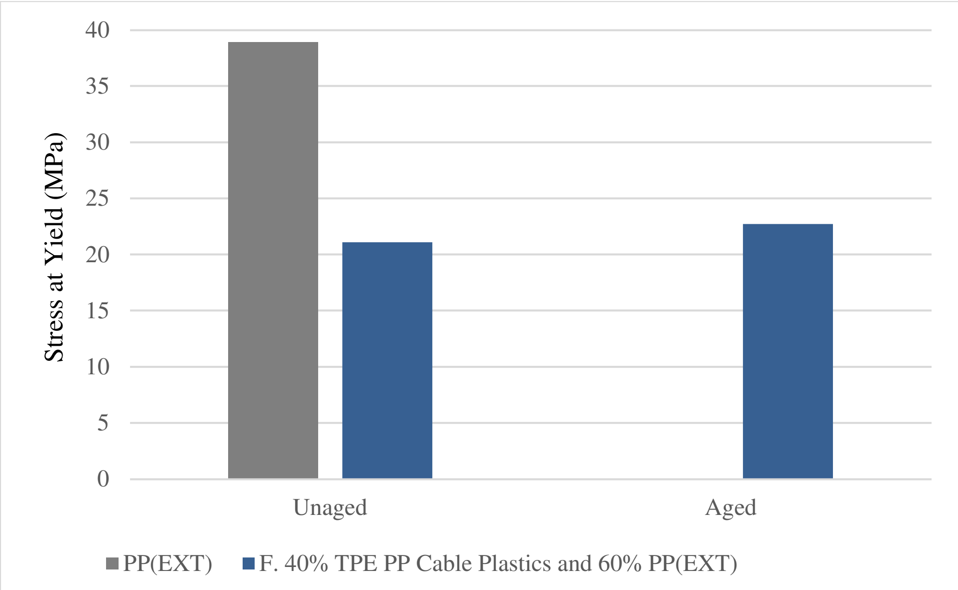

Figure 40 Stress at Yield (MPa) EXT. PP-TPE cable plastics blend F and PP(EXT).

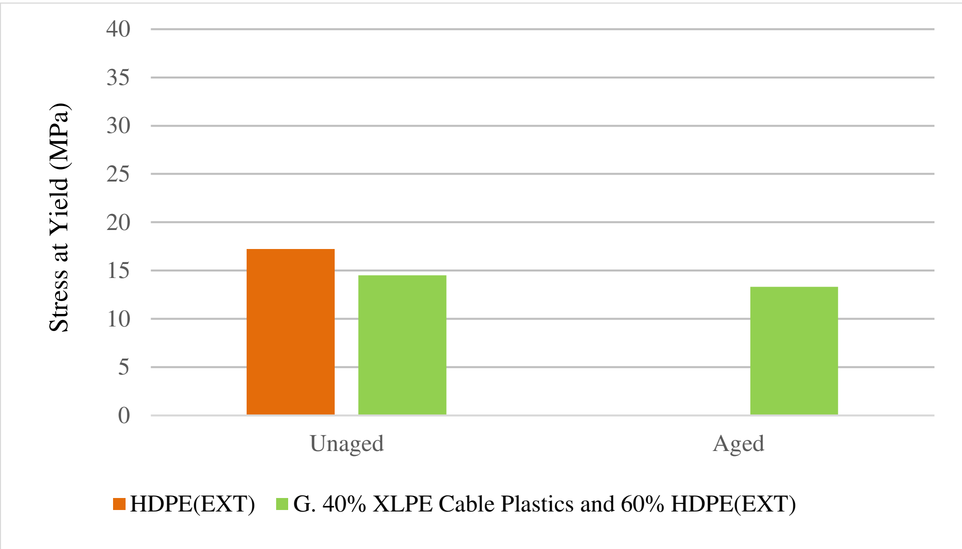

Figure 41 Stress at Yield (MPa) EXT. XLPE cable plastics blend G and HDPE(EXT).

Strain at Yield

Strain at yield had decreased significantly after ageing and reprocessing for blend F with PP-TPE cable plastics (Figure 42). Strain at yield was almost the same before and after ageing and reprocessing the blend G with XLPE cable plastics (Figure 43).

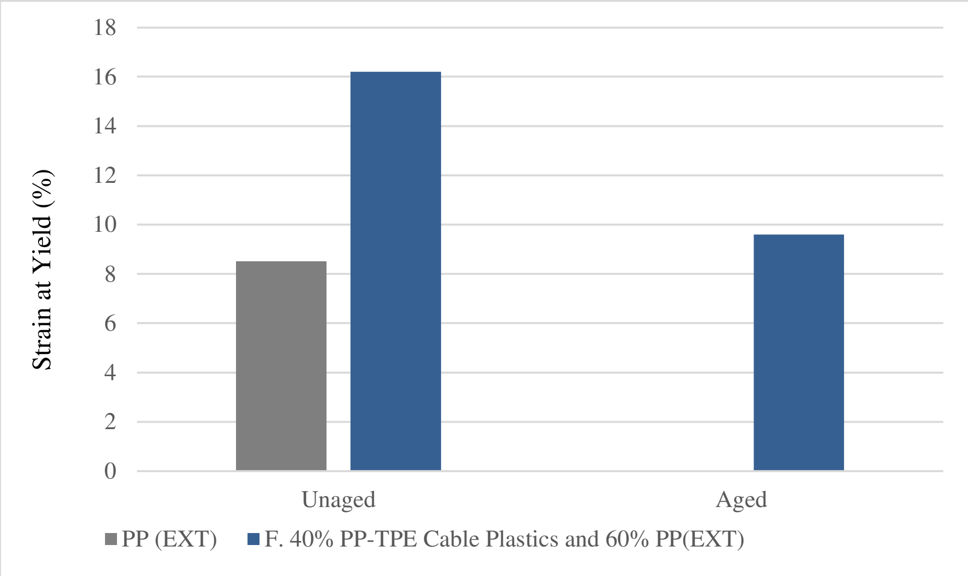

Figure 42 Strain at Yield (%) EXT. PP-TPE cable plastics blend F and PP(EXT).

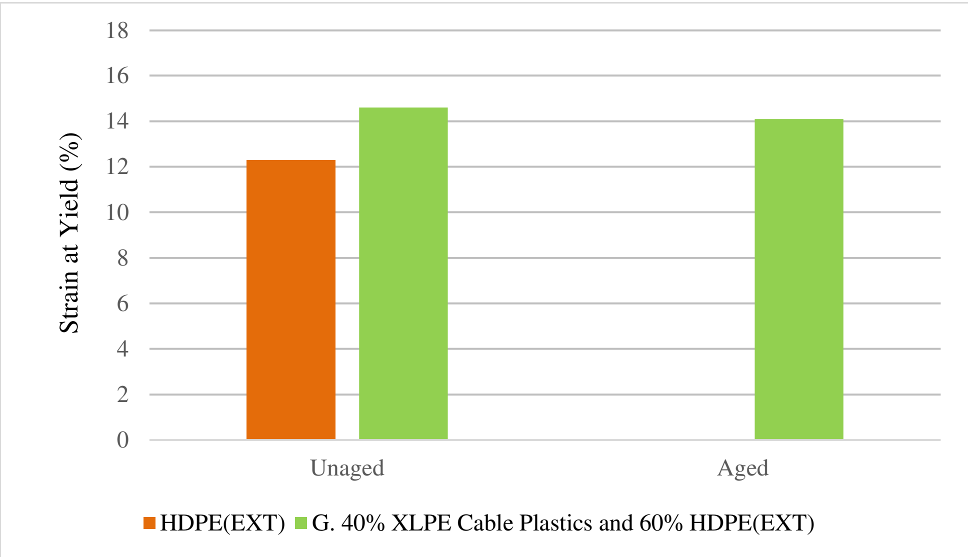

Figure 43 Strain at Yield (%) EXT. XLPE cable plastics blend G and HDPE(EXT).

Stress at Break

Blend F, with PP-TPE cable plastics had no break before ageing but after ageing and reprocessing the stress at break value was 19 MPa, see Figure 44. The polyethylene jacket is not compatible with the PP core and the PP(EXT), this is probably the reason for the loss in stress at break. Stress at break of blend G, with XLPE cable plastics, was low compared to blend F. There was only a small loss in stress at break after ageing and reprocessing, see Figure 45.

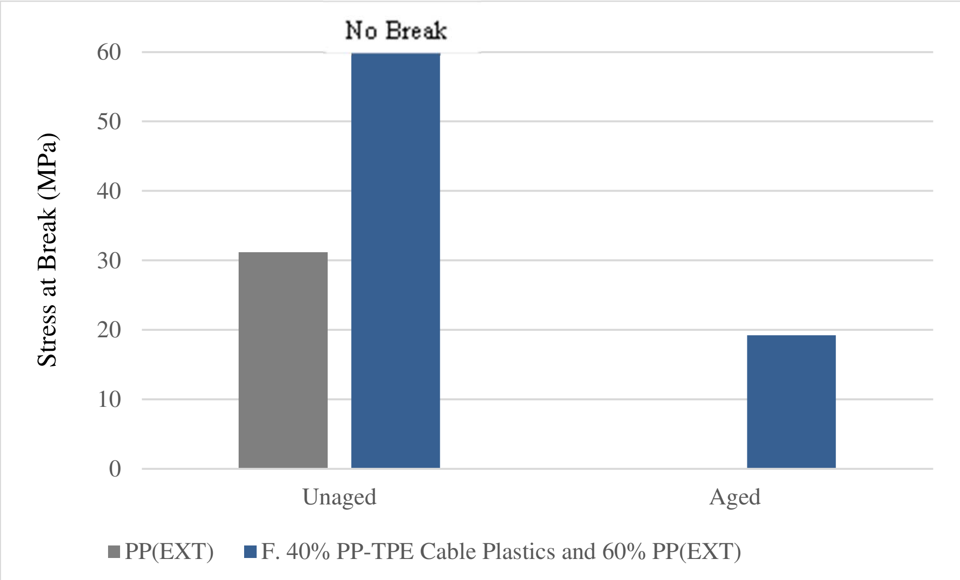

Figure 44 Stress at Break (MPa) EXT. PP-TPE cable plastics blend F and PP(EXT).

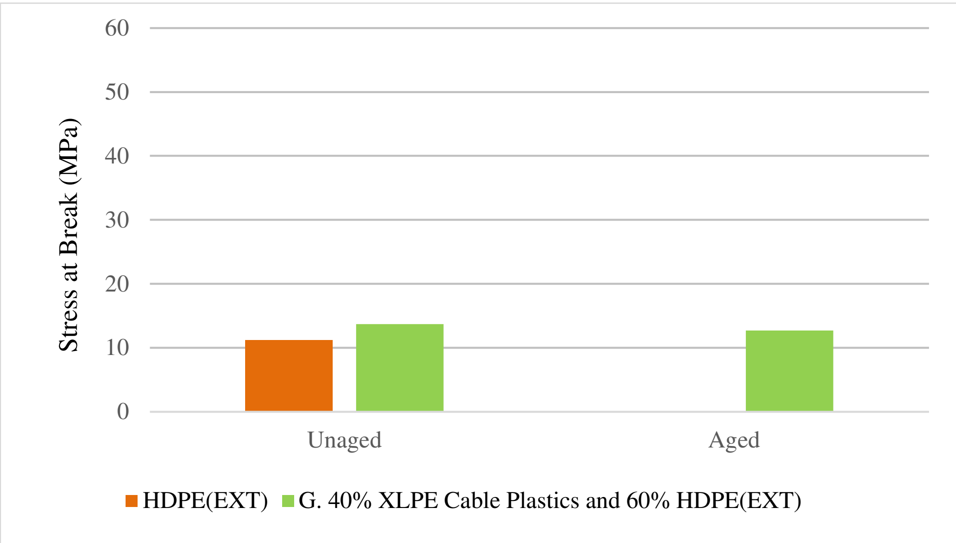

Figure 45 Stress at break (MPa) EXT. XLPE cable plastics blend G and HDPE(EXT).

Strain at Break
Strain at break was above the machine limit of 570 % for blend F, with PP-TPE cable plastics. After ageing and reprocessing strain at break was reduced to 328 %, see
Figure *46*. For blend G, with XLPE cable plastics, strain at break was 433 % and after ageing and reprocessing 403 %, see Figure 47.

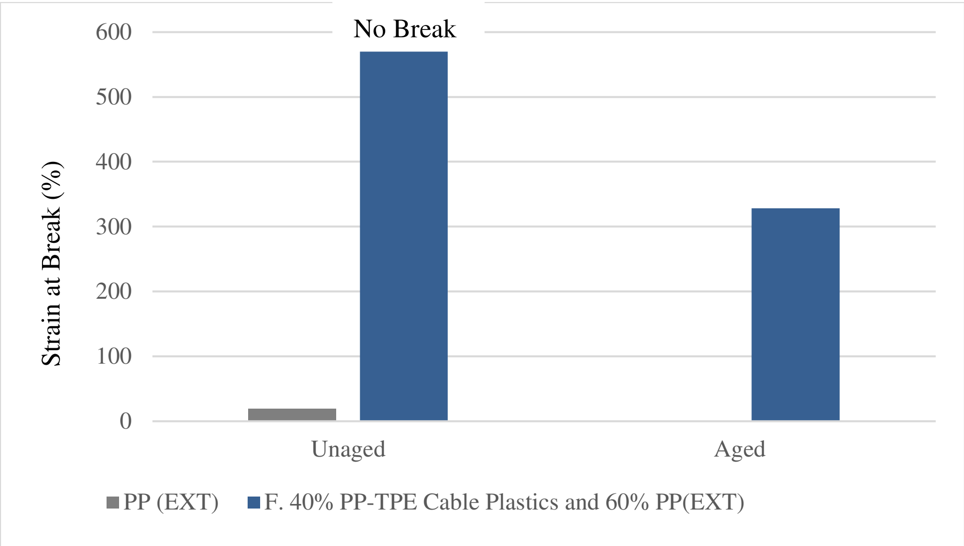

Figure 46 Strain at Break (%) EXT. PP-TPE cable plastics blend F and PP(EXT).

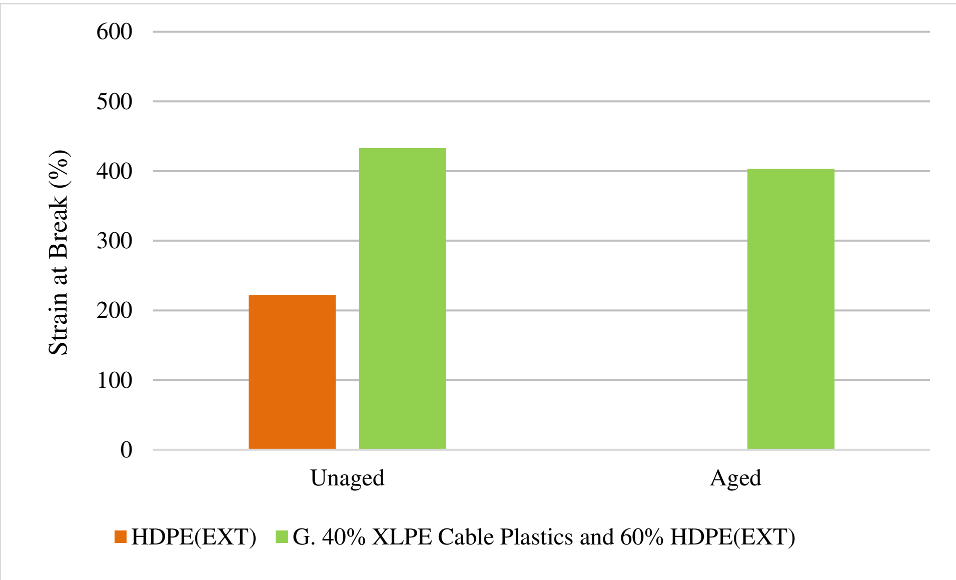

Figure 47 Strain at break (%) EXT. XLPE cable plastics blend G and HDPE(EXT).

Impact resistance

Blend F, with PP-TPE cable plastic, had no break before ageing, see Figure 48. After ageing the impact resistance had decreased to 51 KJ/m². At -20°C the impact resistance of blend F was only 3 KJ/m² after ageing and reprocessing, probably due to the mix of PP and polyethylene. The Impact resistance of blend G, with XLPE cable plastics, was 61 KJ/m² and had after ageing and reprocessing increased to 74 KJ/m² as seen in Figure 49. At – 30°C the impact resistance had increased slightly after ageing.

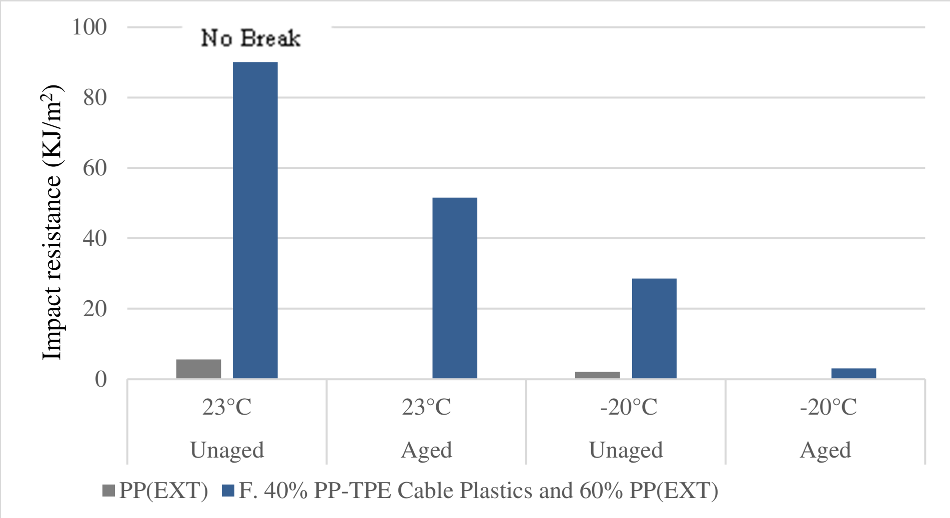

Figure 48 Impact resistance, Charpy notched samples (KJ/m²), EXT. PP-TPE cable plastics blend F and PP(EXT).

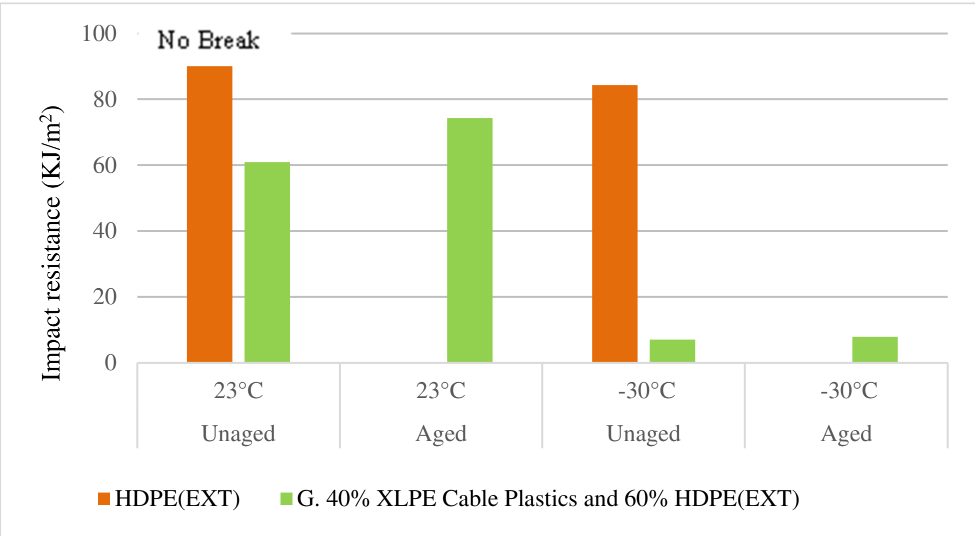

Figure 49 Impact resistance, Charpy notched samples (KJ/m²) EXT. XLPE cable plastics blend G and HDPE(EXT).

Melt flow rate (MFR)

The MFR of blend F, with PP-TPE cable plastics, had increased after ageing and reprocessing, see Figure 50. MFR of blend G, with XLPE cable plastics, was on a very low level but still easily processed. MFR was similar before and after ageing and reprocessing, see Figure 51.

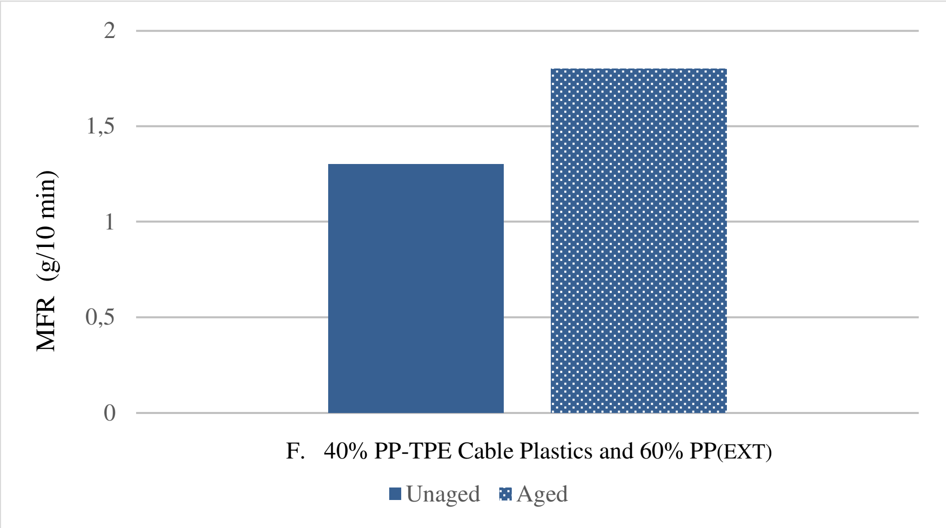

Figure 50 MFR 230°C/2,16 kg (g/10 min) EXT. PP-TPE cable plastics blend F.

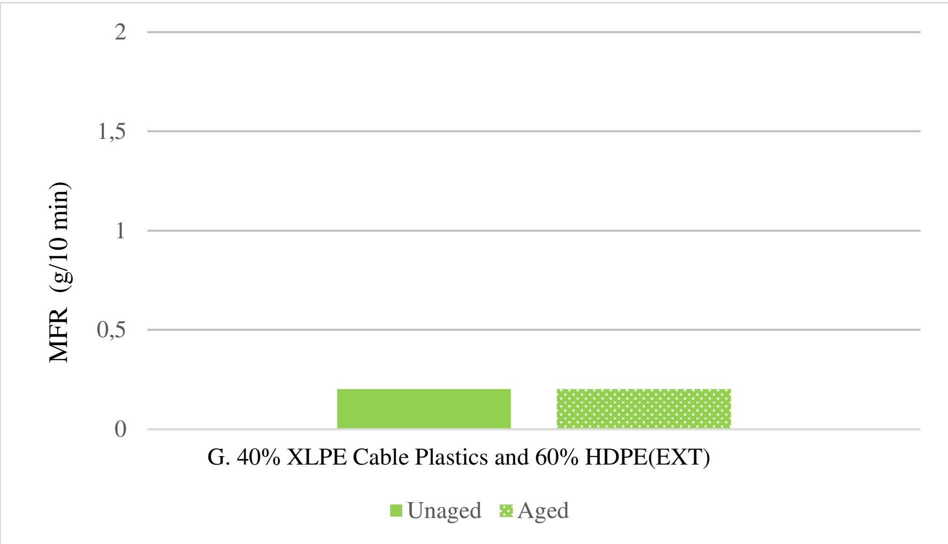

Figure 51 MFR 190°C/ 5 kg (g/10 min) EXT. XLPE cable plastics blend G.

Density

The density was about 0,91 g/cm^3 for blend F and 0,94 g/cm^3 for blend G. The density was not affected by the ageing and reprocessing of the blends as seen in the Figure 52 and Figure 53.

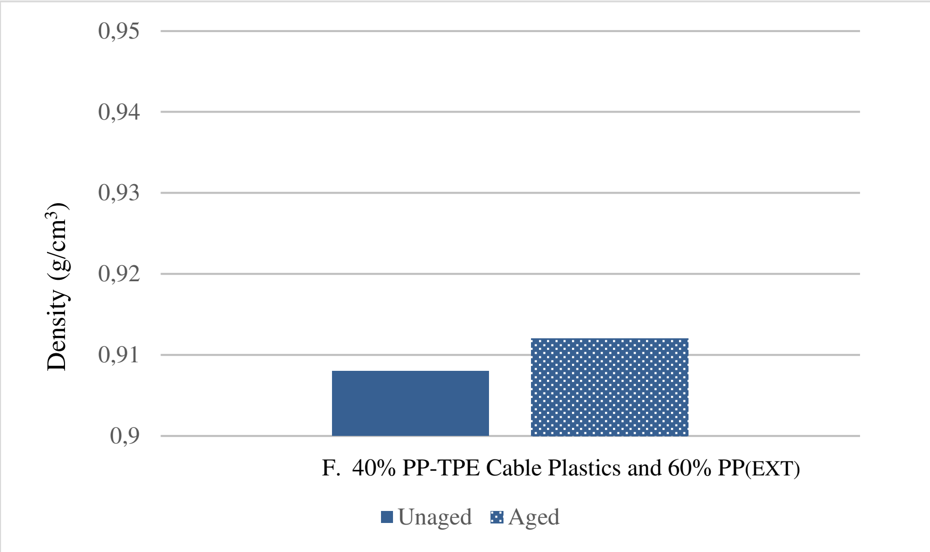

Figure 52 Density (g/cm^3) EXT. PP-TPE cable plastic blend F.

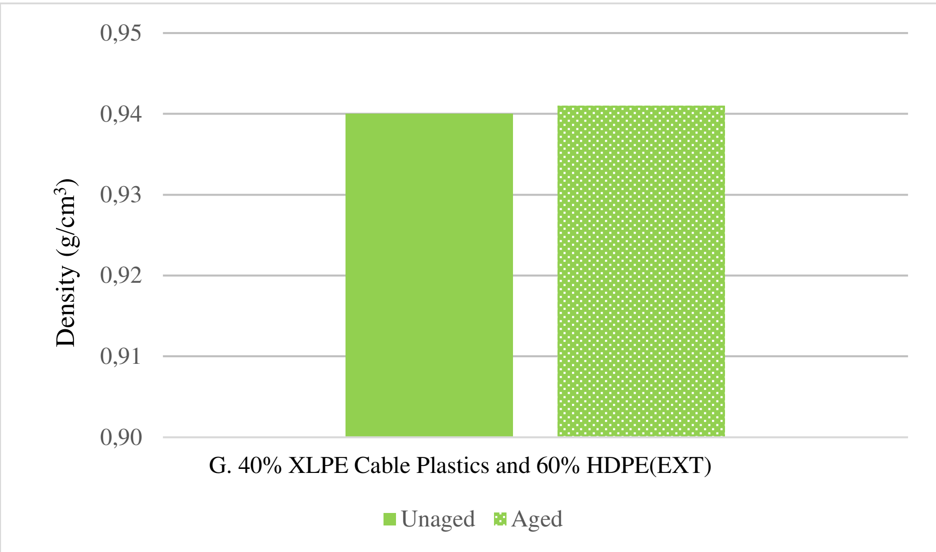

Figure 53 Density (g/cm^3) EXT. XLPE cable plastic blend G.

Conclusions extrusion experiments

- The sheets produced with the cable plastic blends were black. The carbon black in the semi-conductive material in the cable core recyclates dominates the colour of resulting blend.

- The blend F, with 40% PP-TPE cable plastics, was extruded into sheet with a nice appearance. It was somewhat difficult to control the thickness of the sheets.

- The blend G, with 40% XLPE cable plastics, was extruded with good processability performance, but the sheets produced were rough due the crosslinked XLPE particles. Compression of the hot sheets between cooled rollers after the extruder made the sheets smoother.

- Both blends with cable plastics, F and G, had a very good high impact resistance. The impact resistance had decreased significantly for blend F, with PP-TPE cable plastics, after ageing and reprocessing but for blend G, with XLPE cable plastics, the impact resistance had increased after ageing and reprocessing.

- Blend F, with PP-TPE cable plastics, had a higher degree of toughness (stress and strain at break) compared to blend G, with XLPE cable plastics.

- Heat ageing and reprocessing had no negative impact on the mechanical properties of the XLPE cable plastic blends. The properties were in some cases improved after ageing and reprocessing.

- The mechanical properties of blend F, with PP-TPE cable plastics, had been reduced after heat ageing and reprocessing. The reason is most probably the mix of PP core and polyethylene jacket materials with limited miscibility.

Applications for the recycled cable plastics

Several potential applications exist for plastics recycled from the PP-TPE cable and the XLPE cable, provided that the cable recycling is performed properly without contaminating the plastic. It facilitates the recycling quality a lot if the same type of polymer (i.e. PE or PP) is used in the cable core and jacket. Then, the plastics can be recycled together and high quality recyclate can be obtained.

The cable plastics can indeed then be used in products which are robust and durable. The plastics used in energy cables are highly engineered, high-performance materials which are stabilized for a long service life. The long-term properties of XLPE cable plastics have been investigated in a study performed at RISE IVF [6]. Thus, cable plastics are suitable for recycling in new durable product.

The cable plastics are quite soft and flexible materials. To obtain recyclates with good processing performance and more rigid properties the cable plastics can be blended with polymer grades of suitable properties.

The PP-TPE cable core blends obtained somewhat higher toughness (tensile strain and stress at break) than the XLPE blends. But the PP-TPE cable plastics blends, when the core and jacket materials were recycled together, was less tough, due to the polyethylene jacket material. The usefulness of the recyclates with PP-TPE cable plastics is uncertain since the mechanical properties in some cases were reduced after ageing and reprocessing. The best re-use value for the PP-TPE cable plastics is obtained if the core and the jacket materials are recycled separately.

The plastics in the XLPE cable core and jacket, can be recycled together and can be recycled more than once since the mechanical properties were found to be improved after ageing and reprocessing. The XLPE cable plastics can be injection moulded in blends with HDPE and PP if more stiffness is needed. For some applications, the XLPE needs to be fine grinded. A great advantage with the XLPE is the high impact resistance obtained. The XLPE works as an impact modifier, for HDPE as well as for PP. The best effect is when blending with HDPE, which is compatible with XLPE. Thus, a blend with XLPE can replace impact modified HDPE and PP compounds.

A limitation with recycled XLPE cable plastic blends is that the surface finish is not so good. When extruding blends with XLPE, the sheets become rough. Compressing the hot sheets between cooled rollers makes the surfaces smoother. When injection moulding blends with XLPE the product is smooth. XLPE can be used in many robust products, products without high demands of surface finish.

There are for example several products that are covered in a vehicle, like cable channels and fasteners and products in buildings and constructions, for example cable protection pipes and profiles. Another suitable product for recycled XLPE cable plastics is cable drums.

The proposed applications here below; cable drum, cable channel and pipe, have been tested and evaluated with recycled XLPE cable plastic within the RISE IVF (former SWEREA IVF) R&D Programme Wire and Cable [4] and [5].

Injection moulded cable drums

Recycled XLPE from cables can be used as raw material in injection moulded cable drums and thus replace some of the HDPE or PP material used in drums. Axjo Plastic AB uses recycled XLPE from cable scrap today in the production of cable drums (Figure 54). The XLPE improves the impact resistance and the cable drums meets the product requirements at low temperatures. For cable drums, cable plastic grinded to 4-5 mm can be used. Hence, there is no need for fine grinding of the XLPE.

The PP-TPE cable core of PP base can probably be used for cable drums and replace some of the polypropylene in the drum. An impact modifier might be needed to meet the requirements on impact resistance at low temperature. It is uncertain if the PP-TPE cable plastics, with PP based core and polyethylene jacket, can be used if mixed.

Figure 54 Injection moulded cable drum produced by Axjo Plastic AB with 25% recycled XLPE plastic from cables

Injection moulded cable channel

In a study performed, within the RISE IVF R&D Programme Wire and Cable, it has been evaluated that recycled XLPE from cables can be used in injection moulded cable channels for trucks [5]. Figure 55 shows a cable channel produced by Hellermann Tyton GmbH containing 50% XLPE and 50% PP. For this application, the XLPE was fine grinded and compounded with PP.

The PP-copolymer (PPCO) used as virgin standard material in this application could be replaced with a blend of recycled XLPE from cables and a virgin PP. It would most probably be possible to use the XLPE cable core or XLPE cable plastics in blend with PP for this application.

Most likely, it would be possible also to use a recyclate of PP-TPE cable core and PP in this application, possibly also the PP-TPE cable plastics with PP based core and polyethylene jacket. An impact modifier might be needed to ensure the impact resistance requirements.

Figure 55 Cable channel for a truck produced of a recyclate with 50% recycled XLPE cable plastic and 50% PP.

Extruded pipes and profiles

The PP-TPE cable core material would probably be suitable for pipes and profile extrusion. The flexibility of the cable plastics most probably limits the content to around 40%, depending on the product requirements. The XLPE core and XLPE cable plastic can probably be used for pipes or profiles if the plastic is fine grinded and compounded with HDPE. Extrusion of pipes with XLPE from cables in blend with HDPE have been tested within a project performed at RISE IVF [5], see Figure 56Figure 56 Pipe produced with 10 % (1 mm) XLPE in HDPE.. The benefit of using a blend with XLPE is the gain in impact resistance, which is an important property for pipes. A limitation is that the un-melted XLPE particles causes rough surfaces. However, the roughness will be inside the pipe due to the vacuum applied when extruding pipes. The pipe in Figure 56 was extruded with 10% recycled XLPE cable plastic added as powder into the extruder. If the XLPE and the HDPE would be compounded a pelletized, a higher content of XLPE can most likely be used.

Figure 56 Pipe produced with 10 % (1 mm) XLPE in HDPE.

In the Table 2-4, fourteen recycling options have been summarized. However, the cable plastic blends need to be tested in the real applications to ensure that the recyclate blends can meet the processing and product requirements.

Table 2 Recycling option; injection moulded cable drums

	Material alternative	**Shredding**	**Grinding**	**Fine grinding**	**Compound-ing**	**Replacing**
1	20% XLPE cable core	x	x			20% impact modified HDPE in I.M. drum
2	20% XLPE cable plastics	x	x			20% impact modified HDPE in I.M. drum
3	30% XLPE cable core	x	x			30% impact modified PP in I.M. drum
4	30% XLPE cable plastics	x	x			30% impact modified PP in I.M. drum
5	30% PP-TPE cable core	x	x			30% impact modified PP in I.M. drum, but additional impact modifier needed
6	30% TP cable plastics	x	x			30% impact modified PP in I.M. drum

Table 3 Recycling option; injection moulded channel

	Material alternative	Shredding	Grinding	Fine grinding	Compound-ing	Replacing
7	40% XLPE cable core	x	x	x	x	40% PPCO in I.M. channel
8	30% XLPE cable plastics	x	x	x	x	30% PPCO in I.M. channel
9	50% XLPE cable core	x	x	x	x	50% PPCO in I.M. channel
10	50% XLPE cable plastics	x	x	x	x	50% PPCO in I.M. channel
11	60% PP-TPE cable core		x		x	60% PPCO in I.M. channel
12	50% PP-TPE cable plastics	x	x		x	50% PPCO in I.M. channel

Table 4 Recycling option; extruded pipe

	Material alternative	Shredding	Grinding	Fine grinding	Compound-ing	Replacing
13	20% XLPE cable plastics	x	x	x	x	20% HDPE in EXT. pipe
14	40% PP-TPE cable plastics	x	x		x	40% PP in EXT. pipe

Environmental Impact

The climate impact, CO_2 savings have been calculated for the different options 1-14 (see Table 2-4). It was assumed that the cable plastic replaces virgin polymers in all the cases. Same colour in the table means same LCA modelling and thus the same end result. A 90% substitution factor was assumed for all cases, i.e. the recyclates are assumed to give 90% of the quality of the replaced material. The material losses of recyclate in the recycling processes are assumed to be 5% in case 1-6 and 7% in case 7-14 due to the extra process steps with some material losses. The results are reported in climate impact (kg CO_2eq) per kg of plastic waste (See Figure 57).

The climate impact, CO_2 saving, when the recycled cable plastic substitute virgin plastic is between 1.4 and 1.6 kg CO_2 per kg plastic recycled. Accordingly, substitution of virgin plastic has a high climate impact in saving CO_2 emissions. There were only small or no differences between the recycling options 1-14. It is important to recycle as much cable plastic as possible and it is the total amounts of plastic recycled that is important from a climate impact point of view, not the recyclate content in a specific product. The huge amounts of XLPE high, medium and low voltage cables already installed in community worldwide constitutes a significant source of valuable material for recycling after end-of-use.

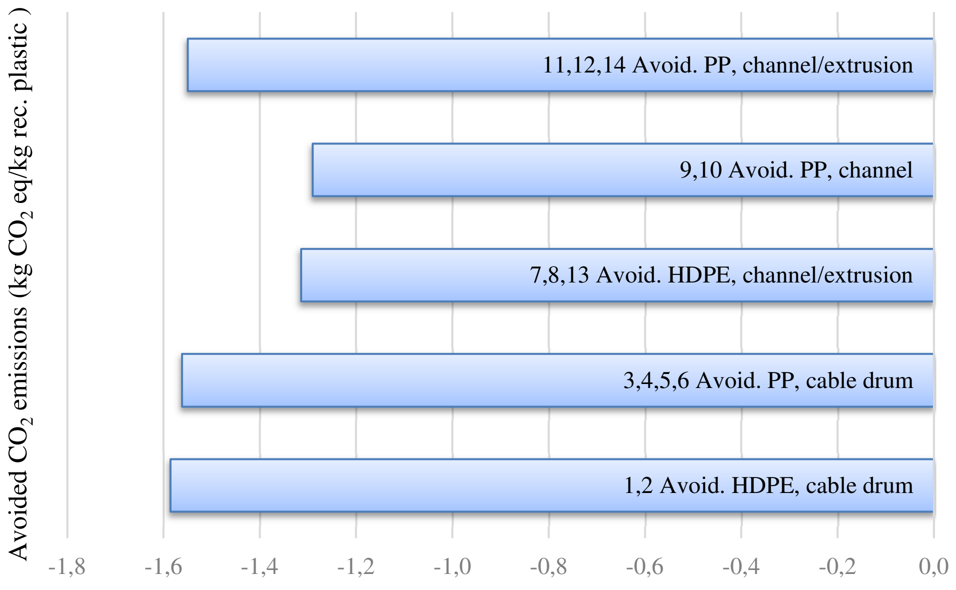

Figure 57 Avoided climate impact, kg CO_2 equivalents saved per kg recycled plastic.

The data used and Life cycle assessment (LCA) calculations are available from Borealis upon request. Data from the LCA database SimaPro have been used for the polymers and granulation impact.

Economic Impact

The economic savings when using the recycled cable plastic in a product and replacing virgin plastic have been estimated as shown in Table 5-7. The costs of the recycling steps were estimated from data coming from recyclers and manufactures of shredders and grinding equipment's for plastics (Rapid Granulator AB). The figures estimated includes machinery costs and operator costs but will vary depending on the size of the equipment, amounts of material processed and how automated the recycling process is. Shredding and grinding are assumed to be in-line which is most common and most cost-efficient. Only the plastics recycling is considered, not the cable stripping since the economic gain from the metal recycling is assumed to pay for the cable stripping.

The prices of virgin polymers used in the calculations are from the official INDEX in the ICIS Report, average prices of Q4 2020 and April 2021.

The economic impact, i.e. saving of Euro per kg plastic recycled, replacing virgin plastic, is very dependent on the recycling process steps needed. It is most cost-efficient if shredded and grinded cable plastic, 4-6 mm size, can be used and feed directly into the injection moulding machine or extruder without fine grinding and compounding. Thus, as much as 1,3 Euro per kg plastic might be saved.

Transports have not been included in these general cost estimations but can have a large impact and should be considered when calculating on specific cases. Then, recycled plastic transport versus virgin plastic transports should be compared.

Table 5 Estimated economic impact – Injection moulded cable drum

Product	**Material alternative**	**Shredding grinding**	**Fine grinding**	**Comp-ounding**	**Recycling cost (€/kg)**	**Price virgin plastic (€/kg)**	**Saving (€/kg)**
Cable drum Injection moulded	20-30% XLPE cable Core/Plastics replace impact mod. HDPE or PP	0,30			0,30	1,56	**1,26**
Cable drum Injection moulded	20-30% PP-TPE cable core/Plastics replace impact mod. HDPE	0,30			0,30	1,56	**1,26**

Table 6 Estimated economic impact – Injection moulded cable channel

Product	**Material alternative**	**Shredding grinding**	**Fine grinding**	**Comp-ounding**	**Recycling cost (€/kg)**	**Price virgin plastic (€/kg)**	**Saving (€/kg)**
Cable channel Injection moulded	30-50% XLPE cable plastics replace PPCO	0,30	0,35	0,35	1,00	1,56	**0,56**
Cable channel Injection moulded	30-60% PP-TPE cable core replaces PPCO	0,30		0,35	0,65	1,56	**0,91**

Table 7 Estimated economic impact – Extruded pipes and profiles

Product	**Material alternative**	**Shredding grinding**	**Fine grinding**	**Comp-ounding**	**Recycling cost (€/kg)**	**Price virgin plastic (€/kg)**	**Saving (€/kg)**
Extruded pipe	20% XLPE cable plastics replace impact. mod HDPE	0,3	0,35	0,35	1,00	1,56	**0,56**
Extruded pipe	20-40% PP-TPE cable core replace impact. mod PP	0,3		0,35	0,65	1,56	**0,91**

Main findings and conclusions

Preparation

- All blends produced with cable core or cable plastics were black. The carbon black in the semi-conductive material in the cable core recyclates dominates the colour of resulting blend.

Results

- All the blends of 50% plastic from the XLPE cable and PP-TPE cable respectively were injection moulded with good processability performance.

- The blends of 40% plastic from the XLPE cable and the PP-TPE cable respectively were extruded with good processability performance, but the sheets containing XLPE cable plastics were rough.

- The blends with XLPE cable plastic had excellent impact resistance, even at low temperatures. The XLPE works as an impact modifier in the blends with HDPE and in PP. New polymer materials were obtained.

- The PP-TPE cable core blends had higher degree of toughness (strain and stress at break) compared to the XLPE cable core and plastics blends. The PP-TPE cable plastics blend was less tough compared to the core blend due to the soft and flexible polyethylene jacket material.

- Heat ageing and reprocessing had no negative impact on the mechanical properties of the XLPE cable plastic blends. The properties were in some cases improved after ageing and reprocessing.

- The mechanical properties of the PP-TPE cable plastics blend were reduced after heat ageing and reprocessing. The recyclability of this blend is precarious.

Applications

- Applications suitable for the XLPE cable core and the XLPE cable plastics blends with HDPE or PP are robust durable product, like injections moulded cable drums and cable channels.

- Applications suitable for the PP-TPE cable core in blend with PP (impact modified) can be injection moulded products like cable drums and channels or extruded profiles or pipes.

Environmental Impact

- Substitution of virgin plastic with recycled cable plastic can avoid between 1.4 and 1.6 kg CO_2 per kg cable plastic recycled.

Economic Impact

- The economic saving when replacing virgin plastic with recycled cable plastic was estimated to be between 0,6 and 1,3 €/kg, depending on the application and methods used.
- The huge amounts of XLPE in high, medium and low voltage cables already installed in community worldwide constitutes a significant source of valuable material for recycling after end-of-use.

Advice for cable design and recycling

- Design the cables for recycling, with same type of polymer in the core and the jacket. Thus, the cable plastics can be recycled together. Various polyethylene's with different densities and crosslinked XLPE can be recycled together.

- Design the cables so that the metals and plastics in the cable can be easily separated when recycled.

- Sort the cables for recycling with respect to the plastics and the metals in the cables.

- Use cable stripping as recycling method if possible, to enable recycling of pure plastics and metals. This method also allows recycling of core and jacket materials separately if needed.

- If the same type of polymer is used in the core and jacket recycle them together, if not recycle them separately.

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Glossary and abbreviations

XLPE: Cross-linked Polyethylene

PE: Polyethylene

MDPE: Medium-Density Polyethylene

HDPE: High Density Polyethylene

PP: Polypropylene

PPCO: Polypropylene copolymer

Compounding: Blending

Recyclate: Recycled cable plastic blends

Compatible: Miscible

Miscible polymer blends: Homogeneous polymer blend

I.M.: Injection moulding

EXT: Extrusion

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