

# Remolding of Cross-Linked Polyethylene Cable Waste: Thermal and Mechanical Property Assessment

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#### Abstract

Plastic has entered nearly in all our manufacturing commodities, i.e. household, medical, automotive, and aerospace. It is offsetting metal, glass and cellulosic containers and is becoming the material choice for most disposable items. On the average 12% of our MSW are plastics (LDPE, Polypropylene, PET, Polystyrene). As its characterized with a high value waste stream and slowly degradable, efforts in reprocessing and reducing its negative environmental impact are increasing. As polymerization of methane, it draws a paramount amount of fossil fuel and when it burns its reactin enthalpy is equivalent to diesel combustion (43 MJ/kg). In attempt to recycle LDPE that mildly cross-linked for cable manufacturing, this work explores the changes of material properties following remolding, re-extruding/calendaring and injection. This waste can mount over 120 tons annually from one cable industry of single production line. Thermal analysis of the plastic using the Differential Scanning Calorimetry (DSC) to infer the melting and molding conditions is carried first. Second, tensile and dynamic samples preparation is conducted following shredding, sieving, and infusion/mixing in mini extruder and the HAAKE MiniJet II injected mold. Third, uniaxial static and dynamic tests are carried utilizing Instron tensile and the dynamic DMA 8000 machine. It was observed as the amount of waste infusion is increased the sample ductility and strength is mildly reduced. Dynamic tests showed that the molded XLPE has a higher viscosity than LDPE at phase shift of 10.75° for XLPE compared to 9.88° for LDPE. Finally, in the view of these results a visco-elastic material model is inferred for the reproduction of experimental results in static and dynamic loading conditions.

Keywords: Cross-linked polyethylene; compounding waste plastic extrusion; molding; Material characterization; recycling

#### 1. Introduction

The demand on plastic is increasing each year reaching 5% due to unlimited flexibility and properties made it to enter all modes of applications. The reported global plastic production is nearly 265 million tons in 2010 [1]. Continuous effort to regulate waste plastic recycling falls short to accommodate 50% of their rejected waste that comprises 10-12% of the MSW in US and EU countries [2]. This high fraction waste consist of nearly 23% low density polyethylene (PE), 17.3% low density polyethylene, 18.5 polypropylene (PP), 12.3% polyesterine, (PS/ extended PS), 10.7% polyvinyl chloride, 85% polyethelyne terephthalate and 9.7 of other types [3]. Most thermoplastic (amorphous) waste can be mechanically recycled or remolded, however only few studies focused on the changes in the material properties following remolding. Life Cycle Analysis (LCA) always favor mechanical plastic recycling over energy recycling, i.e., incineration, gasification, pyrolysis, because of the lower environmental burden [4]. Ryoshie et. al. [5] in his patent he studied the remolding of open foam plastic that consisted of carbon fiber risen with polycarbonate into a secondary parts. Their subsequent work to their patent showed a reduction in ductility following repeated remolding. A reduction of the mechanical properties is attributed to deterioration in risen/epoxy and shortening in fibers. In a US patent H. Hoedl [6] reported remolding of a different proportion unsorted mixes of thermoset and thermoplastic (cable, tire, risen etc.) above their softening temperature (80-160C°) after shredding and sieving into a power macro-homogenous mixes. His patented work suggested blinding with reinforced (fiber) or filler (wood/clay) material and possible impregnating the filler with adheshion- enhancing chemicals (phenolic risen, melamine or polyurethane etc.) for bonding and strength improvements. Higher end product that retains the original properties and durability of the virgin plastic mandates advanced automatic sorting including x-ray fluorescence, infrared spectroscopy, electrostatic water and air floatation [7, 8]. Postconsumer remolding of HDPE blowmolded bottle of Ambrose et al. [9] work resulted in even enhanced design specs of the virgin product assessed by both

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the chemical and physical properties. His work also showed a remolded PP gave a reasonable and sufficient material strength. Duarte [10] remolded the PET bottles while they yield a reasonable properties they suggested and used PET material as composite for other engineering application. Others tried to enhance specific thermal, mechanical or physical properties by utilizing different LDPE and HDPE blends. This include the work of Paula ta al. [11] who reported differences in processability, properties, chemical resistance, wettability by infusing different AL and PE virgin resins. Report on remolding PVC for tubing, cable and floorings industry with product at an equivalent property is becoming more practiced in these industries [12].

Cable industries generated substantial waste plastic amount in UAE and it is mainly LDPE and PVC. Qudaih et al. [13] have mixed different proportioned of virgin PE and crossed-linked polyethelyne and their results demonstrated a reduction in ductility as the amount of crossed-linked increases from 5 to 20%. Plastic structure consists of long molecules (chain) that linked together with carbon molecules as the backbone. Thermoplastic can undergo indefinite cycle of softening by heat and hard solid following molding. The thermosetplastic can be softened only once and when take up the shape of the mold [14]. Thermoplastics can be transferred to thermoset for specific reasons, i.e. insulation, higher strength, lower ductility etc. Polyethylene, in which the ethane is the carbon backbone, is converted into thermoset through crosslinking and postcuring process. Silane Cross-linked polyethylene (Si-XLPE) is a thermoset resin, used as insulation for electrical cables which improves it dialectical properties. Si-XLPE formed by infuses of siloxane bonds (Si-O-Si) in low density polyethylene (LDPE).

Lu et al. [15] used mechanochemical approach for decrosslinking of waste cross-linked polyethylene (XLPE) and tire rubber to product re-formable materials. The number of cross linking XLPE/TR (50/50) decreased significantly by mechnochemcial milling. La Mantia et al. [16] investigated the blending of raw material with waste plastic to obtain fillers. The experiment was done by mixing raw LDPE with plastic waste compounded of (33% PE, 39% PVC, and 28% PET). The blends were at 10, 25, and 50% of plastic waste with a higher content of plastics with LDPE. The results showed that all mechanical properties, except for elastic modulus decayed with the increasing of plastic waste content. Goto et al. [17] studied the de-crosslinking of Si-XLPE via chemical reaction in supercritical alcohol. In which a selective decomposition of siloxane bonds was studied to produce thermoplastic recycled polyethylene (PE) to offset the utilization of virgin material. Reaction was conducted using supercritical propanol with temperature and pressure under 370°C and 12MPa and reaction time of 30min. The gel fraction of final product became zero at temperature over 270°C, molecular weight dropped at temperature over 340°C. The gel fraction declined under increase pressure and fell to zero at pressure over 5MPa. Their results suggested at temperatures 270-340°C and pressure more than 5MPa decomposition of cross-linking element occurs.

The objective of this work is to assess the thermal and mechanical property of remolded different proportion of the mildly cross-linked cable and virgin LDPE plastics. Both uniaxial static and dynamic test samples were molded and tested under well controlled temperature utilizing Instron tensile and DMA800 machines. This follow up with inferring a proper visco-elastic material model to be able to predict structural behavior.

#### 2. Material and methods

Material and thermal analysis: A virgin LDPE and Si-XLPE waste samples are obtained from Ducab Inc. Abu Dhabi, United Arab Emirates. The virgin LDPE and Si-XLPE samples that prepared for thermal analysis is used in the form of 2mm granules and from shreds of Si-XLPE of 2.0 mm thin yarns using automatic low speed course teeth hack saw. The granules LDPE are the product of SABIC Holdings. Thermal analysis includes melting temperature determination and TGA and thermal stability identification. The melting temperature of LDPE and Si-XLPE are required for their remolding as well as in identification of the onset of their thermal degradation [7]. Simultaneous Thermal Analyzer (STA) is also carried out which combined both Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetric (DSC) that record the weight vs temperature and heat vs temperature evolutions using the Q600 SDT TA Instruments shown Fig. 1.





Fig. 1. Simultaneous Thermal Analyzer STA (Q600 SDT)

The experiment setup consists of placing the sample inside a suitable pan in a controlled temperature furnace. In the meantime, a heat flux and weight sensors measures properties as function of temperature. Inside the STA, there are two pans, a reference pan and a sample pan under each pan there is a thermocouple which reads the temperature during the test. Before the start of each run, the pan is balanced on a balance arm. The balance arm is calibrated to compensate for the differential thermal expansion between the arms. Samples of 5 to 20 mg is loaded in the sample cup and Nitrogen is used as purging gas at flow rate of 100ml per min while air is used as cooling. The samples are subjected to low heating rate of 2°C/min lasting over 1.5 hours and exceeding the sample melting point (nearly 110°C). In TGA the samples were subjected to 5°C/min heating rate until reaching 600°C to provide the proximate composition of the samples (moisture, volatile, fixed carbon & ash).

**Sample molding**: The sample subjected to melting initially followed with compounded using Thermo Scientific (HAAKE MiniLab II) depicted in Fig 2. The system is based on a conical twin-screw compounder with an integrated recirculation channel. The residence time of melt inside the extruder is determined based on the recirculation channel and the integrated bypass valve.



Fig. 2. Thermo Scientific (HAAKE MiniLab II)

The extruder is flexible to be used with co-rotating or counterrotating screws. At the end of the screw a bypass valve opens enabling the extruded sample to be drawn in strand as shown Fig. 2. The force feeder is applied to the HAAKE MiniLab to ensure continuous sample feeding and the feeding zone is cooled to avoid melting of the raw material in the feeder funnel. Temperature of the extruder is set at 160°C which is below the degradation/devolatalization LDPE temperature) to ensure the melting of sample. Screw speed is set at 50rpm, while pressure set at 210 bars and circulating/residence time is set to be 10 min. 2) the second stage involves the molding of the extruded LDPE and Si-XLPE into static and dynamic tests specimen using the injection molding machine Thermo Scientific HAKKE MiniJet II. The main parts of the machine are cylinder (reservoir), retaining pin, injection nozzle, mold, injection piston, and pneumatic piston. The injection piston transfers the pneumatic force to the melt inside the cylinder. The melt is forced through the injection nozzle to the mold. Two molds were used one for static/tensile test and the second for dynamic test.

The injection cylinder is filled with the extruder outlet as shown in Fig. 3. For the tensile mold, the temperature of the cylinder is set to be above the melting temperature  $(180^{\circ}C)$ . The temperature of the mold is set to be  $60^{\circ}C$  to avoid post-deformation in the sample due to abrupt change in temperature. Injection pressure set at 200 bars for 6 sec while posting pressure is set at 500 bars for 6 seconds for both the LDPE and infused samples. The cylinder temperature for the dynamic test sample is set at 200°C and the mold at  $80^{\circ}C$ . The injection pressure were set at 250 bars due to lower sample thickness (1mm vs 3mm), and posting pressure is set at 650 bars that remains for 6 sec.



Fig. 3. The feeding process of the melt and injection process

The Si-XLPE samples applied similar parameters except the injection pressure which is sat at 300 bars. The mold was placed in the cylinder inside the machine. The retention pin is placed in injection piston inside injection mold machine. The dynamic specimen parameters subjected to the following: 600 bars injection pressure, 650 bars posting pressure for 6 sec.

Mechanical testing method: Static properties for plastic samples such as tensile strength, yield strength, young modules, and maximum elongation were determined when the samples are subjected to a prescribed tensile strain (1.5mm/min) while simultaneously record the endure load until rupture. Tensile tests was conducted at room temperature using universal Instron-5966 tensile test machine . Specimens had gauge length of 15mm, 3mm width and 3mm thickens and results are reproduced on five samples for each compound. Dynamic properties of the samples such as tan  $\delta$  and the viscoelastic properties were studied by measuring storage and loss modules of each sample subjected to oscillatory or dynamic mechanical experiments which offer a powerful technique to study molecular structure and morphology. As the strain (or stress) vary sinusoidally the stress (or strain) vary sinusoidally as well. However the general case for polymeric/viscoelastic material the stress will be out of phase. Therefore  $strain(\sigma)/stress(\varepsilon)$  can be factored into two components in phase and out phase that lag by  $\pi/2$  rad to stress/strain. Using complex functions and imposing an oscillatory strain at frequency  $\omega$  and time t it can be written as:

$$\varepsilon^* = \varepsilon_o \exp(i\omega t) \tag{1}$$

The simple viscoelastic model of Maxwell two-element serialspring with stiffness E and dashpot with damping C gives the following strain-stress constitutive equation [Ref]:

$$\frac{d\varepsilon}{dt} = \frac{1}{E} \frac{d\sigma}{dt} + \frac{\sigma}{\lambda E}$$
(2)

Where the damping constant  $\lambda$  is equal to  $\eta/E$ . Further substitution and integration for the solution of stress gives that:

$$\sigma^* = \varepsilon^* \left[ \frac{E \,\omega^2 \lambda^2}{1 + \omega^2 \lambda^2} + \frac{i(E \,\omega \lambda)}{1 + \omega^2 \lambda^2} \right] \tag{3}$$

Where the complex  $E^*$  is composed from the two components:

$$E^* = \sigma^* / \varepsilon^* = E' + iE'' = (E'^2 + E''^2) \exp(-i\delta)$$
 (4)

Where  $\delta$  is the phase shift angle and dynamic and loss modulus are expressed as:

$$E' = \frac{E\omega^2 \lambda^2}{1 + \omega^2 \lambda^2}, E'' = \frac{E\omega\lambda}{1 + \omega^2 \lambda^2}, \tan\delta = E' / E'' = 1/\omega\lambda$$
 (5)

And hence substitute in equations 4 and 1 the stress is given as:

$$\sigma^* = \frac{E \,\omega \lambda \varepsilon_o}{(1+\omega^2 \lambda^2)^{\frac{1}{2}}} \exp i(\omega t + \delta)$$
(6)

Therefore, E,  $\lambda$ , E', E", can be evaluated from direct experimental measurements of strain and strain amplitudes ( $\varepsilon_0$ and  $\sigma_0$  and the phase shift ( $\delta$ ) under a prescribed frequency  $(\omega)$  value. Temperature play a strong reducing factor to the storage modulus of thermoplastic (amorphous polymer) an effect that is still strong but less extended on the cross-linked and thermoset (semi-crystalline) plastic. In particular the storage modulus continues to decrease with the increase of temperature while the loss modulus goes through an increase reaching a maximum value followed with a rapid decrease. The tan  $\delta$  therefore follows roughly the same trend as to the loss modulus and the maximum value marks the polymer glass transition temperature (see fig. 4). The dynamic tests are carried out using the Dynamic mechanical analyzer machine (DMA 8000) and under the tensional deformation mode. In this mode, the dynamic sample (length 10mm, width 9mm, and 1 mm thickness) is placed horizontally between a fixed and constant frequency oscillating clamp. The sample is housed inside a well-controlled temperature furnace ramping up the temperature from 25°C to 150°C at a heating rate of 5°C/min while the specimen undergoes 1Hz displacement oscillation of 0.05mm peak to peak amplitude.



Fig. 4. The decrease in E' and increase in tan  $\delta$  in LDPE

#### 3. Results and Discussion

**Thermal Analysis:** The results of DSC for LDPE and Si-XLPE waste are shown 5. The values for melting temperature, which appears as a depression (endothermic) in the heat flow, and the corresponding latent heat of melting, are summarized in Table 1.

Table 1. Thermal analysis results

Tested samples	Waste Si-XLPE	LDPE
Γ (melt), <sup>°</sup> C	106.26	106.88
h (diffusion), J/g	26.33	42.01



The values of melting temperature and heat of diffusion for LDPE is in general agreement with those reported by Tajeddin et al. [8] (Tm=  $105.07^{\circ}$ C, H= 849.84mJ) and as anticipated due to mildly cross-linking they are in close proximity to Si-XLPE. The heat of diffusion however for Si-XLPE is nearly half of the LDPE. The small variation in melting and the relatively low diffusion heat emphasized the low level of cross-linking used in the XLPE process and support the viability of the remolding. TGA results can also show the proximate composition of the sample as shown in fig 6 a and b, the summary of these measured data are listed in Table 2.

Table 2. STA	measured	data for	Si-XI	PE and	LDPE
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Tested samples	Waste Si-XLPE	LDPE
Moisture	1.327%	0.000%
Volatile	98.235%	98.946%
Fixed carbon	0.269%	0.374%
Ash	0.168%	0.679%
T (decomposition), °C	460.73	462.43
∆H (decomposition), J/g	300.9	434.8



Fig. 6b. Thermal decomposition of Si-XLPE waste

The TGA curve shows the onset of degradation of the LDPE & Si-XLPE that beyond 200°C and both possess a large volatile fraction (exceeds 97%) and low fixed-carbon fraction. The high volatile content makes plastic ideal feedstock for pyrolysis at relatively moderate temperature (500°C) under inert condition to yield liquid fuel [18]. Both material samples start to rapidly degrade above 400°C until 500°C at which all the material released into volatile. The proximate compositions of the samples are nearly the same suggesting similar remolding conditions. The thermal stability of the molded mix also investigated as shown in fig. 7. It can be recognized from the figure that the increase in the thermal stability is observed at a loading level of 10 wt% Si-XLPE. Therefore, as the weight of Si-XLPE infused into LDPE increases, the decomposition temperature and thermal stability of the resulting material increases. One needs to remark that the thermal properties observe a slight and tolerable range for reusing the material in cable insulation. Summary of the melting and heat of diffusion are summarized in table 3.



Fig. 7. TGA results of Si-XLPE-LDPE compounds and LDPE

Table 3. Melting temperature and the latent heat

Tested Sample	Melt. Temp. (°C)	<u>ΔTm (%)</u>	$\Delta h (J/g)$
LDPE (baseline)	109.53		52.87
Si-XLPE	108.17	-1.24	65.19
Extruded Composite			
5%	106.90	-2.40	54.63
10%	106.42	-2.84	53.76
15%	105.97	-3.25	52.10

#### Mechanical testing results:

Tensile test: The tensile test was conducted on five sets of the molded samples with each set consists of five identical trails. The first sample was molded from pure LDPE and is termed as the reference sample. The second sample was blanked from the final stage of production line of the Si-XLPE. The third and fourth samples were remolded by the infusion at 10% and 20% of head waste with pure LDPE on mass basis. The fifth sample was remolded at 100% head waste of Si-XLPE. The head waste is usually collected before the curing takes place in the water cooling channels and the whole reel basin water bath. Care was taken to obtain a homogenous raw material which retrieved from the same batch, i.e. reel, run out waste. The tensile test results are shown in fig. 8, and summarized in table 4. The initial stress-strain slope, the slope at 0.2%, and the slope at 0.5 strain of each sample were obtained to infer the overall modulus, the yield stress, and the tangent modulus at an advanced deformation point. The results showed that the deformation is altered with the infused waste seen by the lower value of the young modulus and yield point at 10 to 20% waste infusion. The lowest slopes (young modulus and yield) and highest deformation resulted from Si-XLPE (final product). The 100% waste sample shows lower modulus confirming the above observation yet with nearly 10% higher yield than the 20% waste infusion. This reversion in the yield stress however for the 100% XLPE fall within the variation in the standard deviation. The end product sample demonstrates the lowest hardness observed by the inferior slopes and ultimate stress and emphasizing the mismatch, but accepted, in the overall processing conditions compared to the infused samples. It should be emphasized that this variation is still reasonable considering the scaled up extrusion and post curing that the sample of the cable material experienced at the plant.

Table 4. Summarized results of tensile test, all stresses are in MPa

Tested sample	LDPE	Blanked	10%	20%	100%
	(ref)	Si-XLPE	XLPE	XLPE	XLPE
Young's modules	$61.18\pm$	$75.39 \pm$	$79.33\pm$	$77.36 \pm$	$75.37\pm$
	4.59	9.36	8.05	1.47	7.5
Yield stress( yield)	6.14±	$7.87 \pm$	9.31±	7.94±	9.11 ±
	0.65	0.22	0.74	0.93	1.43
Slope at 0.5	7.90±	$8.24 \pm$	$8.06 \pm$	$8.89\pm$	$7.69 \pm$
	1.26	2.48	1.50	1.60	1.54
Ultimate strength	$13.42\pm$	$16.13 \pm$	$18.19 \pm$	16.19±	16.36±
( ultimate)	1.32	1.45	1.22	2.40	1.83



Fig.8. Tensile test results for all extruded samples

Tensile test based results suggest that 10% head waste infusion will maintain the expected mechanical response and could offer a waste management strategy as it demonstrates slightly improved yield (9.31 vs 9.11MPa) and demonstrate a similar deformation trend across the plastic region. The ultimate strength for 10% XLPE is also improved (18.19 vs 16.36MPa). The Si-XLPE exhibit slightly more ductility after curing. As for the waste infused samples, they show that infusion is slightly extend the ductility and increase the value of the rupture. The 100% waste sample shows that strength and ductility of the material is the lowest which may be attributed to inhomogeneous and less cohesive bonding between polymer chains.

Dynamic Test: The dynamic test was conducted on the four extruded samples (as no blanked XLPE dynamic sample were found). The DMA800 machine measures the storage "in phase" modulus repressing the elastic behavior and the loss "out phase" modulus representing the viscoelastic behavior. The phase shift, tan  $\delta$ , measured by dividing the loss modules over Single temperature results are the storage modules. summarized in table 5 which obtained at 29°C. There is dominance in the storage over the loss modulus of nearly half order of magnitude near ambient temperature for this plastic. Typically, at low temperature the storage modulus behaves similar to the static modulus and it decreases as temperature increases, whereas the loss modulus goes through a maximum marking the glass temperature to the polymer. Polyethylene however have a low glass temperature (Tg) which is in the subzero region which at much lower temperature than the conducted tests. At this low temperature the polymer act pure elastic as there is no room to convert the applied load into internal energy. Beyond the Tg the plastic response dually as elastic and viscous. The resulted phase shift of LDPE is 9.88° and XLPE is 10.75° at 29°C which are in close proximity.

Table 5. Results of the dynamic test

Samples	LDPE	10% XLPE	20% XLPE	100% XLPE
Storage modulus	$239.46 \pm$	$260.96 \pm$	$225.52 \pm$	$235.80 \pm$
at 29°C, (MPa)	19.13	36.46	42.95	17.13
Loss modulus	$37.74 \pm$	$42.07 \pm$	$36.32 \pm$	$40.36 \pm$
at 29°C,(MPa)	0.90	4.82	2.61	4.04
Total modulus	$242.42\pm$	$264.39 \pm$	$228.45~\pm$	239.26±
at 29°C,(MPa)	19.01	36.06	42.82	16.99
Damping tand	$0.158\pm$	$0.158 \pm$	$0.163 \pm$	$0.171 \pm$
at 29 C	0.01	0.03	0.01	0.01
Phase shift ( $\delta$	$9.88 \pm$	$10.00 \pm$	9.73±	$10.75 \pm$
(degree)	0.92	1.81	0.93	1.17

The behavior of the total modulus with respect to the temperature is shown in fig. 9. It shows a rapid decline in the modulus with the increase of temperature to all four samples which is a common trend for most polymers. The tan  $\delta$  temperature trend inherit such temperature sensitivity due to the rapid loss of the storage modulus but at slightly slower, then at a faster, base than the decrease in the loss modulus. The phase change for each sample was extracted by plotting the storage versus the loss modulus and taking the corresponding slope at each temperature as depicted in fig. 10. The dynamic test results are summarized in table 5.



Fig.9. Total Modulus and Tan delta change with temperature



Fig.10. Storage modulus versus loss modulus

The value obtained by the dynamic test emphasizing the lower total modulus for 10% XLPE compared to all other sets. Note that the static modulus and dynamic storage modulus are related by equation 5  $(\tan \delta = E'/E'' = 1/\omega\lambda)$  under Maxwell model. The dynamic data resulted in almost twice the value for the modulus than the one reported by the static test. This shows inability for the static test alone in estimating the modulus. Furthermore, the high obtained value (260 Mpa) for the storage 10% XLPE emphasizing the dependency of the measuring method and inability to directly compare results of the storage and total modulus in the dynamic and static test. Table 4 resulted in a much lower values for the modulus based on static test when compared to table 5 that based on dynamic test. This variation between the modules for the dynamic and static tensile test is due to different tests conditions, samples size and setup. This is one reason to the presence of several methods and equipment for plastic property assessment. Chanda and Roy who stated that it is unusual for plastic when it is properties solicited by different instruments to yield different material properties [20]. However, when all samples run on the same machine a conclusive trend is easily obtainable.

### 4. Conclusion

In this work the infusion of waste (Si-XLPE) with raw material (LDPE) is investigated to support sustainable manufacturing and promote zero plastic waste for the cable industry. In this work, an assessment of the thermal and mechanical behavior of the remolded waste Si-XLPE was conducted. Initially the melting temperature of the baseline and head waste is determined via the DSC and found both are nearly the same at 106°C. This suggested the mild cross-linking and feasibility of remolding. Secondly, tensile and dynamic samples were prepared for the baseline and different head waste infusion fraction. Their thermal stability is assessed and confirmed by inspecting the sample DSC curves at high temperature next to the onset of pyrolysis. As the melting points as well the decomposing curves of the molded samples observed to be in close proximity it is again confirm the low level of crosslinking of XLPE.

The Infusions of cross-linked waste with virgin polyethylene at different mass percentage (10%, 20%) were compounded and molded into standard dumbbell-bar and smaller rectangular for static and dynamic mechanical analysis. The mechanical testes concluded that as the mass percentage of head waste is increased the ductility of is extended to some extend where the 100% is considered the most ductile suggesting weaker adhesion forces between these polymers. The static stress-strain result shows a small to medium variation (10-15%) in the young modulus, yield stress and rupture point of remolded plastic properties from the baseline.

Dynamic sample results also demonstrate a small variation in the total modulus and tan  $\delta$  from the baseline. These results suggesting remolding the head waste in the cable industry can reduce their environmental impact. The overall conclusion of this work emphasize the potential usage of the XLPE cable waste as a filler or re-compounding it into cable product due to small variation in thermal, static, and dynamic properties. The change in property is tolerable against the original product. The infusion provides another life for XLPE which saves million barrels of fossil fuel and converting cable industry into a greener and near zero waste industry.

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#### References

- [1] T. E. p. Industry, "Plastic the Facts 2011," 2010.
- [2] W.-t.-E. Labratory, "Poster Abu dhabi Waste Current fate and Energy Recovery Options."
- [3] Associate of Plastics Manufactures in Europe (APME), 2004 Plastic recovery perspective: plastic consumption and recovery in Western Europe (www. Plasticeurope.org)
- [4] The use of air tabling and triboelectric separation for separating a mixture of three plastics Original Research Article Minerals Engineering, Volume 18, Issue 15, December 2005, pp. 1350-1360

- [5] H. Ryoshi and M. Okamura, "heat insulation material and method for producing same", US patent no. 5,575,871, Nov. 19 1996.
- [6] Herber K. Hoedl, "Manufactur of Molded Composite Product from Scrap Plastics, US patent no. 5,075,057,Dec. 24 1991.
- [7] Safat Siddique, Jamal Khatib, Inderpreet Kaur, "Use of recycled plastic i concrete: A review", Waste Management, vol. 28 (2008), pp. 1835-1852 <u>http://dx.doi.org/10.1016/j.wasman.2007.09.011</u>
- [8] Yarahmddi, N., Jakubowicz, I., Martnsson, L., 2003, "PVC floorings as post-consumer products or mechanical recycling and energy recovery". J. Polymer degradation and Stability, Vol. 79 (3), 2002, pp. 439-448. <u>http://dx.doi.org/10.1016/S0141-3910(02)00360-9</u>
- [9] Charles Ambrose, Rechard Hooper, Anthoney Potter, M. Singh, "Diversion from landfill: quality produts from valuable plastics", J. Recourses, Conservation and Recycling, Vol. 36 (4), 2002, pp.309-318. http://dx.doi.org/10.1016/S0921-3449(02)00030-7
- [10] Antonio F. Avila and Marcos V. Duarte, "A mechanical analysis on recycled PET/HDPE composites", J. Polymer degradation and Stability, 80 (2), 2003 373-382. <u>http://dx.doi.org/10.1016/S0141-3910(03)00025-9</u>
- [11] Paula M. S, Reodrigues F. M., Bernardin A. M., Fiori M. A. and Angeioletto E. " Characterization of aluminized polyethelyne blends via mechanical recycling, J. Materia Science and Engineering 403, 2005, 37-41 <u>http://dx.doi.org/10.1016/j.msea.2005.05.060</u>
- [12] Yarahmddi, N., Jakubowicz, I., Gevert, T. 2001, "Effect of repeated extrusion on the properties and durability of rigid PVC scrap". J. Polymer degradation and Stability, Vol. 73 (1), 2002, pp. 93-99 <u>http://dx.doi.org/10.1016/S0141-3910(01)00073-8</u>
- [13] R. Qudaih, I. Janajreh, S. E. Vukusic, "Recycling of cross-linked polyethylene cable waste via particulate infusion, J. Advances in Sustainable manufacturing, 2011, pp. 233-239
- [14] C. Lu, X. Zhang, and M. Liang, " Mechanochemical recyling and processing of waste crossslinked polymers: Wate tire rubber and wast XLPE from cable scraps", the 5<sup>th</sup> ISFR, Oct 11-14, 2009, Chedgdu, China
- [15] R. J. Crawford, "Plastic Engineering," in Encyclopedia of Physical Science and Technology - Polymers, ed, pp. 457 - 474.
- [16] F. La Mantia, C. Perone, and E. Bellio, "Blends of polyethylenes and plastics waste. Processing and characterization," *Recycling of Plastic Materials, FP La Mantia, ed,* pp. 131-36, 1993.
- [17] T. Goto, S. Ashihara, T. Yamazaki, I. Okajima, T. Sako, Y. Iwamoto, M. Ishibashi, and T. Sugeta, "Continuous Process for Recycling Silane Cross-Linked Polyethylene Using Supercritical Alcohol and Extruders," *Industrial & Engineering Chemistry Research*, vol. 50, pp. 5661-5666, 2011. http://dx.doi.org/10.1021/ie101772x

- [18] H. Lobo and J. V. Bonilla, Handbook of plastics analysis vol. 68: Crc Press, 2003. http://dx.doi.org/10.1201/9780203911983
- [19] R. Q. I. Janajreh, M. Al Shrah, "Pyrolysis of Si-XLPE Waste," presented at the The 10th Global

Conference on Sustainable Manufacturing, Istanbul, turkey, 2012.

[20] M. Chanda and S. K. Roy, "Plastic Properties and Testing," in *Plastic Technology Handbook*, ed: CRC Press, 2007, pp. 3-34.