DEVELOPMENT OF RECYCLED PLASTIC COMPOSITES FOR STRUCTURAL APPLICATIONS FROM CEA PLASTICS

by

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A thesis submitted to the

Graduate School-New Brunswick

Rutgers, The State University of New Jersey

In partial fulfillment of the requirements

For the degree of

Master of Science

Graduate Program in Mechanical & Aerospace Engineering

Written under the direction of

Thomas Nosker & Mitsunori Denda

And approved by

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New Brunswick, New Jersey

October, 2015

ABSTRACT OF THESIS

Development of Plastic Composites for Structural Application from CEA Plastics

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Plastic waste from consumer electronic appliances (CEAs) such as computer and printer parts including Polystyrene (PS), Acrylonitrile Butadiene Styrene (ABS), Polystyrene (PS) and PC/ABS were collected using handheld FTIR Spectrophotometer. The blends of these plastics with High Density Polyethylene (HDPE) are manufactured under special processing conditions in a single screw compounding injection molding machine. The blends are thermoplastics have high stiffness and strength, which may enhance the mechanical properties of HDPE like tensile modulus, ultimate tensile strength, tensile break and tensile yield. These composites have a potential to be used for the future application of recycled plastic lumber, thus replacing the traditional wood lumber.

ACKNOWLEDGEMENTS

I would also like to thank my thesis advisor Prof. Thomas Nosker, of the Material Science & Engineering Department at Rutgers, who introduced me to the project and encouraged me to devote my thesis to it. He has shown immense support, guidance and enthusiasm throughout the course of my thesis. I would first like to thank my thesis co-advisor, Prof. Mitsunori Denda, for giving me the opportunity to work with him.. My heartfelt thanks to the other member of my thesis committee, Prof. Howon Lee.

I would also like to thank Dr. Jennifer Lynch for guiding me throughout my thesis, her direction and motivation essential for every step of this project. I would also like to thank Guy Watson of NJDEP office of Solid Waste & Recycling for Project Support. I must notably mention Rachit Mehta, Arya Tewatia, Meredith Taghon and Justin Hendrix toward their contribution in setting up the preparatory experiments and in helping me prepare my thesis and presentation. They have been there to help and guide me at every time that I have needed them.

I would like to thank a number of graduate students and friends at Rutgers, who, be it through friendship, counsel or supportive guidance have made my stay at Rutgers more wonderful and one to remember. Finally, I would like to thank my family who has been supportive and available for me throughout the course of my student life.

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Introduction

1.1 Motivation

Recent Studies have estimated the direct cost of corrosion to just the military in United States of America to be nearly $ 300 billion dollars per year [1]. For structural applications, it is expected of the material to sustain heavy loads. Traditional construction materials like wood and steel are time-tested and have centuries of data characterizing their attributes. The other factor which contributed to their extensive use was their availability in abundance. But problems associated with wood are short lifetime which used outside, so for longevity the wood has to be treated with hazardous chemicals. These chemicals are poisonous have a negative impact on environment. Furthermore, limitations on timbering in environmentally sensitive areas due to concern with endangered species and national forests, has caused wood prices to escalate at many times the inflation rate [2]. The Technical advances and developments in the area of materials science and engineering have resulted in new materials and composites based on thermoplastics, carbon fiber, glass fiber, and other fiber reinforced products. These advancement combined with plastic recycling technology produces a premium performance material for application of railroad crossties and bridges including corrosion resistance, longevity, low maintenance, lower lifetime costs, and environmental friendliness [3]. The other advantages of using this material is reduction in plastic land fill. In a typical 10-year outdoor exposure of wood in lumber application, properties drop by 25% to 50%. For polyethylene based plastic lumber is typically about 10% of the

above value [4]. Properties of these materials, as long as they do not contain significant percentage of wood or paper fiber, have shown to be more or less stable in outdoor exposures over 11 years [5].

1.2 Background

Polymers can be organized into thermoplastics or thermosets. In our research, we are primarily concerned with thermoplastics due to their ability to be reheated and molded and CEAs manufacturing can use them multiple times, thus classifying them as recyclable materials. PVC, polyethylene (PE), polystyrene (PS) and polycarbonate (PC) are all types of thermoplastic resins. In contrast to thermoplastic resins, thermosets can be heated and molded once, and are therefore not recyclable. If thermosetting resins such as phenolic resin, and melamine resin are hardened, they can never become soft again. Because thermoplastics can be re-melted, they have the ability to be easily processed and recycled.

Plastic is less expensive and can be processed at lower temperatures and less energy compared to wood or steel. It is a lenient material that is easily modifiable, and can be used in different scenarios. Compounding involves combining a base plastic resin with other components, which makes the base resin effectual, inexpensive, process with less input energy, and look aesthetically pleasing. Extrusion, blow molding, injection molding and compression molding are the types of processing that are commonly performed on plastic samples. Something to keep in mind is that the processing temperature must be above glass transition and melting point temperatures. Likewise, the pressure for injection molding must be at a level where the plastic is forced through the nozzle

creating a sizeable mold. The computer parts are made by injection molding the thermoplastics.

1.3 Goal & Approach

The goal of this project is to examine the mechanical properties of blends of HDPE and CEA plastics. Reinforcing the polyethylene material with stiffer polymers by melt processing under typical plastic lumber processing conditions in single screw compounder injection molding machine have shown to increase the strengths to levels matching or exceeding those treated wood with 10 year exposures [4]. The CEA plastics like PC/ABS, PS, PC and ABS are all stiffer and stronger than HDPE and all could processed without difficulty to form blends [4].

Plastics can be characterized by FTIR spectroscopy. FTIR spectrophotometer is used to identify unknown plastics when compared against a library of known plastics. With recent technological breakthrough, a handheld FTIR spectrophotometer has been introduced in the market which makes it easy to sort and identify unknown plastics. We developed a library with the handheld FTIR spectrophotometer that consisted of a broad spectrum of common CEA plastics. The handheld FTIR spectrophotometer was brought to a plastic de-manufacturer to scan and identify the common CEA plastics found in the recycled waste stream. After blending the CEA plastics in different compositions with high-density polyethylene (HDPE) through novel process combining compounding and injection molding.

Mechanical properties of plastic blends are determined through a series of tests. The American Standard Test Methods (ASTM) sets international standards that are precisely

followed during any testing. The machines display information on how plastic acts under different loading situations. Testing gives us a clear idea of the tensile, compression, flexural and shear properties of our composite material. Data is collected and presented in force versus displacement curves, as well as stress versus strain curves, giving us an idea of the modulus, ultimate strength, stress at fracture, strain at fracture, and toughness of the polymer blend composite samples.

1.4 Technical Specifications

The plastic lumbers from recycled plastics before being used for structural applications must be comparable with a wooden lumber's materials specifications. The material of lumber must have at least 3000 psi (20.68 MPa) as ultimate strength for its application as bridge lumber and at least 170,000 psi (1.172 GPa) as its tensile modulus for its application as a railway crosstie [6] [7]. Table 1 shows values of Tensile Modulus of pure HDPE, ABS, PC, PS & PC/ABS.

Plastic Type	**Tensile Modulus (GPa)**	**Ultimate Strength (MPa)**
HDPE	0.8	15
ABS	2.3	40
PC	2.6	70
PS	3	40
PC/ABS	1.7	29

Table 1 Tensile Properties of pure HDPE & CEA plastics [8]

1.5 FTIR Spectroscopy

FTIR spectroscopy primarily passes infrared radiation to the unknown sample where some of light is absorbed in order to obtain a near-infrared (NIR) to far-infrared (FIR) spectra, which then collects the wavelengths instantaneously [8]. This allows us to match any unknown plastic with an established library. FTIR spectroscopy has come a long way in the past decade from the desktop units in the laboratory environment to a now portable handheld device that can be used anywhere to identify plastic such as the de-manufacturing plant we went too. This is important since it is now portable & economically viable option to identify CEA plastics and use them to make recycled plastic lumber. Since a majority of computer housings are now a standard black color, it was important for us to find the right device to help identify CEA plastics accurately since not all devices can accurately identify black CEA plastics made out of black material. The FTIR spectrum of sample is compared with FTIR spectrums stored in the library to identify the molecular interactions of each polymer [Figure 2]

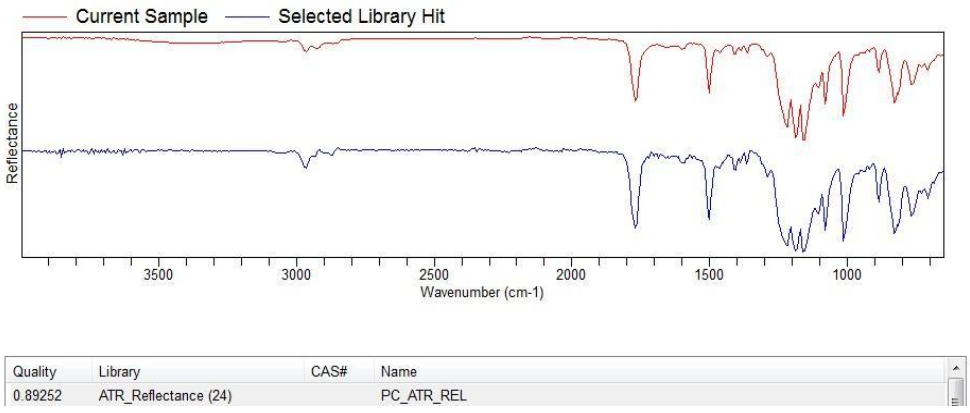


Figure 1 Reflectance Spectrum of Polycarbonate

1.6 Injection Molding

Developed by AMIPP researchers at Rutgers University, a novel injection molding machine is based on screw injection molding. The major parts of the injection molding machine are the novel plastication unit, clamping unit, and the mold itself.

The injection molding process begins with placing the polymer pellets into the hopper. The polymer pellets are melted down in barrel by heater bands and are then put through a screw powered by a hydraulic screw drive and gearing. The mold closes and the polymer is injected through the mold cavity by the screw. Once the mold cavity is filled, the holding pressure is maintained to prevent material shrinkage. While this is occurring, the screw turns and melts & mixes processes the next sample to feed into the mold cavity. Once the molding cavity is cool enough, it will open the mold and eject the sample.

1.7 Tensile Testing

Tensile test method determines the tensile properties of reinforced and unreinforced plastics. It tests the ultimate strength and strength modulus in the form of standard dogbone shaped specimens under defined conditions of pretreatment, temperature, humidity, and testing machine speed [9].

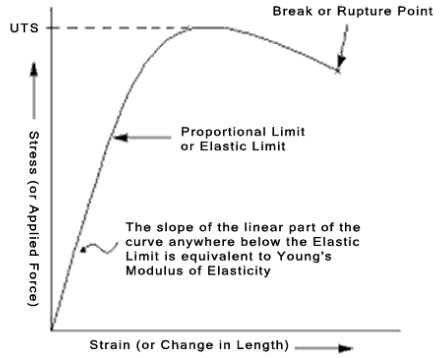


Figure 2 Stress v/s Strain relation [10]

Figure shows relation between stress (or applied force) and strain (or change in length). The Young's modulus of elasticity is measure of stiffness of the material, but it only applies in the linear region of curve. The Ultimate Tensile Strength is the maximum load the specimen sustains during the test. If the material is loaded further beyond the linear region permanent deformation takes place in the sample. It ultimately leads to fracture of material sample [10].

1.8 Scanning Electron Microscopy

The SEM has a large depth of field, which allows more of a specimen to be in focus at one time in comparison to traditional optical microscope. The SEM also has much higher resolution because it uses electromagnets instead of lenses, thus the researcher has much more control in the degree of magnification. This gives clear images, make the scanning electron microscope one of the most useful instruments in research today. [11]

The SEM produces a largely magnified image by using electrons instead of light to form an image. A beam of electrons is produced at the top of the microscope by an electron gun. The electron beam follows a vertical path through the microscope, which is held within a vacuum. The beam travels through electromagnetic fields and lenses, which focus the beam down toward the sample. [11]

Once the beam hits the specimen, electrons and X-rays are ejected from the sample. Detectors collect these X-rays, backscattered electrons, and secondary electrons and convert them into a signal that is sent to a screen similar to a television screen. This produces the final image.

Chapter 2

Equipment

2.1 FTIR Spectrophotometer

A handheld FTIR spectrophotometer device Agilent Technologies ExoScan 4100 was used for characterizing waste plastics at CEA De-manufacturer. It came with two heads, ATR & Diffuse. These heads had specific uses based on their surface texture. For the ATR (Attenuated Total Reflectance) head, it is used only for smooth surfaces. For the diffuse head, it is used only for rough surfaces. Once the texture was identified with the correct head attached, the sample was clamped onto the FTIR device. The clamp is only attached to the FTIR spectrophotometer when the sample is small in width and length. Otherwise, it was used without the clamp for unreasonably large CEAs that could not fit within the width and length distance of the clamp.

Figure 3 Agilent Technologies ExoScan 4100

2.2 Injection Molding

A Negri Bossi V55-200 Injection Molding Machine was used for injection molding the dogbone samples. The machine is based on single screw injection molding with spiral fluted extensional mixer (SFEM).

Figure 4 Negri Bossi V55-200 Injection Molding Machine

2.3 Universal Testing Machine

MTS QTest/25 with controller universal testing machine was used to perform tensile testing on the samples produced. Data collection is done with integration of TestWorks 4 software using a 25 kN rated load cell. The load cell has a load of 5620 lbf with calibration & sensitivity values as 15.566 kN & 2.39 mV/V respectively. The

extensometer 632.11b-20 was used to measure tensile modulus. The extensometer had full scale value 0.5444247234322495 inches & a calibration value equal to 1 inches.

Figure 5 MTS QTest/25 Elite Controller

2.4 Scanning Electron Microscope

A Zeiss Sigma Field Emission SEM with Oxford EDS Leo was used for morphology analysis of samples. The sample images were taken at different resolution, as indicated on Figure 23-27

Figure 6 Zeiss Sigma Field Emissions SEM with Oxford EDS Leo

Chapter 3

Experimental Procedure

3.1 FTIR Spectrophotometer

For this project we use the ATR head because it gives quality spectra, while the diffuse head had noise and disturbance in the spectrum graph. ATR has a diamond in middle which when kept in contact with a plastic to be characterized gives us FTIR spectra based on its chemical composition. Then recorded the proper method and spectra of each sample into the computer. The method depends on whether we are collecting data or identifying an unknown sample. The methods themselves must have 64 background scans, and the sample scans can vary from 8 to 64 depending on the time interval and processing time. The spectra ranges from 4000 to 650 (cm-1). We can get FTIR spectrums in three different ways: absorbance, transmittance, and reflectance. When we collected the data, we found that the reflectance gave the best results. This is because the minimum hit quality for the absorbance spectrum is 60%, while hit quality for the reflectance spectrum is 70% and can go up to a maximum of 80%. This is why we chose to use FTIR in reflectance spectrum rather than absorbance spectrum. We made sure that the spectra was not unclear or ambiguous, to ensure an accurate spectra was collected. Then we used an unknown sample that was identified with the ATR_Reflectance.a2m library based on several scan modes: derivative similarity, minimum hit quality, y-axis, and derivative gap. We concluded that the higher the minimum hit quality the better the results. The derivative algorithm gap is supposed to be high, ranging from 10 to 25, to

allow a quality spectra. If we needed to analyze the results in a different method (reflectance or absorbance), we could re-analyze them within the software, without performing a test with the FTIR device. Figure 3 shows 96% quality similarity in reflectance spectra between Polystyrene Sample (red) & Black color Polystyrene (blue) spectra stored in ATR_Reflectance.a2m library.

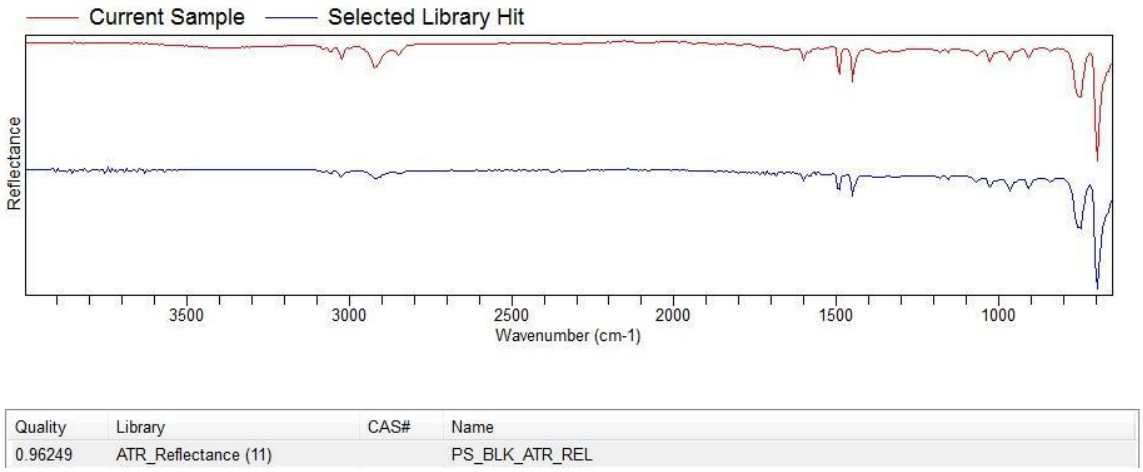


Figure 7 PS Reflectance Spectrum with 96 % quality of PS in the Library

Figure shows 70.5% quality similarity in reflectance spectra between ABS Sample (red) & Black color ABS (blue) spectra stored in ATR_Reflectance.a2m library.

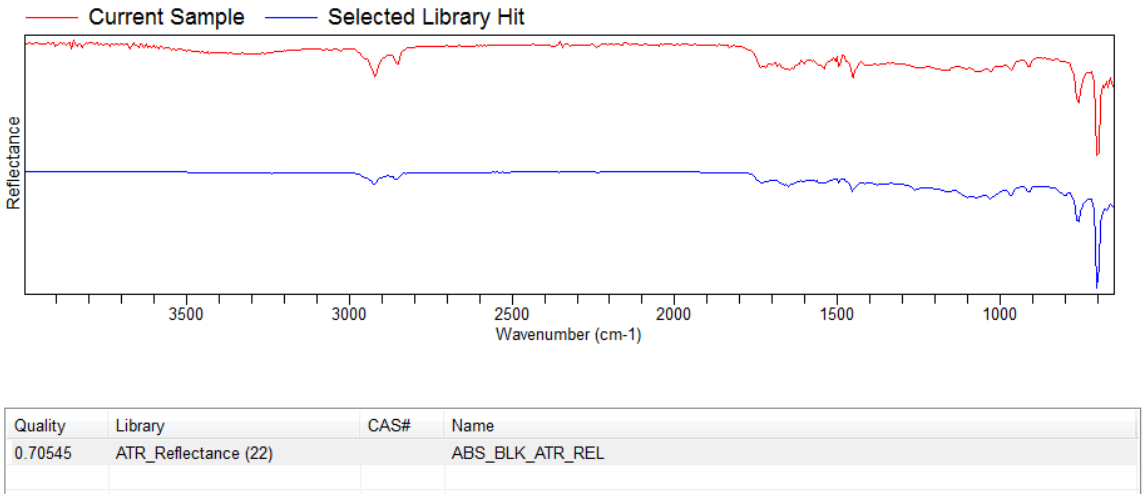


Figure 8 ABS Reflectance Spectrum with 70.5 % quality of ABS in the Library

Figure shows 89% quality similarity in reflectance spectra between Polycarbonate Sample (red) & Polycarbonate (blue) spectra stored in ATR_Reflectance.a2m library.

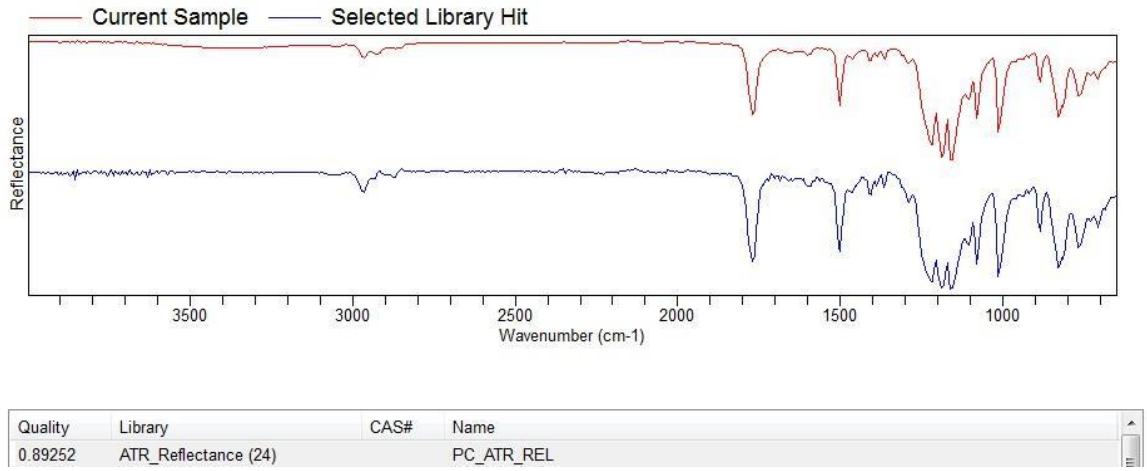
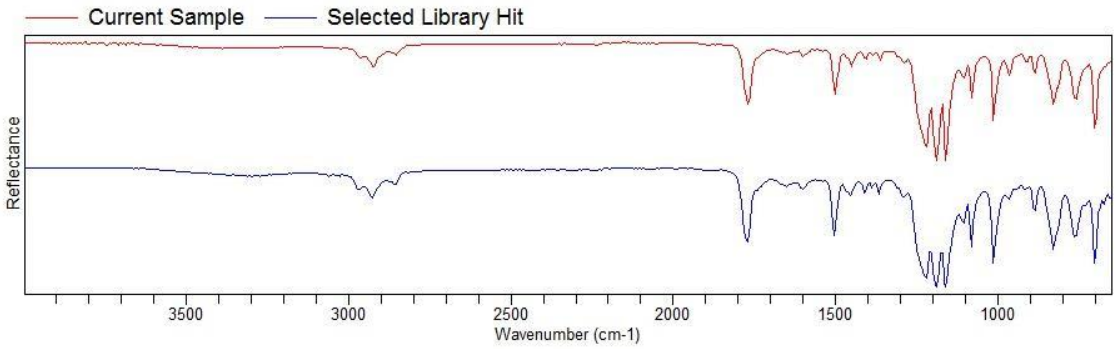


Figure 9 PC Reflectance Spectrum with 89% quality of PC in the library

Figure 6 shows quality similarity in reflectance spectra between PC/ABS Sample (red) & one of the types of sample PC/ABS (blue) spectra stored in ATR_Reflectance.a2m library.



Quality	Library	CAS#	Name
0.86703	ATR_Reflectance (9)		PCABS_XCY620_BLACK_ATR_REL
0.86418	ATR_Reflectance (8)		PCABS_C1200_NATURAL_ATR_REL
0.85714	ATR_Reflectance (7)		PCABS_C1300_NATURAL_ATR_REL
0.85436	ATR_Reflectance (10)		PCABS_C8002_BLACK_ATR_REL

Figure 10 PC/ABS Reflectance Spectrum

The plastic wastes obtained from Tech Recyclers by weight composed of, 58% was ABS, 15% was PC, 22% was PS, 1% was PC/ABS, and 4% were different plastics not used in this research. Therefore, it is important to have an accurate idea of the composition of CEA plastics. Table 1 shows exact composition of CEA plastic collected from the Tech Recycler.

Total Weight	Weight Total (lbs)	Weight Total (kg)	Weight %
ABS	23.45	10.64	58
PC	6.06	2.75	15
PS	9.12	4.15	22
PVC	1.9	0.86	4
PC/ABS	4.71	2.14	1
Total Weight	45.25	20.52	-

Table 2 Composition of Plastics gathered for research from Tech-Recycler

3.2 Injection Molding

2kg batches are made for all the granulated CEA plastic. Mixture of 10, 20, 30, 35, and 40 percent of the CEA plastics with 90, 80, 70, 65, 60 percent of HDPE by weight were injection molded respectively. We used a weighing scale to measure the blend of each percentage for the CEA plastics. Table 3 shows batch sized for injection molding.

CEA Plastic	**ABS**	**PS**	**PC**	**PC/ABS**
Total Weight (kg) (Weight needed in 2kg batches)	10.65	2.75	4.152	2.15
10%CEA/90% HDPE	0.2 kg/1.8kg	0.2 kg/1.8kg	0.2 kg/1.8kg	0.2 kg/1.8kg
20%CEA/80% HDPE	0.4 kg/1.6kg	0.4 kg/1.6kg	0.4 kg/1.6kg	0.4 kg/1.6kg
30%CEA/70% HDPE	0.6kg/1.4kg	0.6kg/1.4kg	0.6kg/1.4kg	0.6kg/1.4kg
35%CEA/65% HDPE	0.7kg/1.3kg	0.7kg/1.3kg	0.7kg/1.3kg	0.7kg/1.3kg
40%CEA/60% HDPE	0.8kg/1.2kg	0.8kg/1.2kg	0.8kg/1.2kg	0.8kg/1.2kg

Table 3 Batch Size for Injection Molding

When using the injection molding machine, the first ten of each sample was discarded to allow a proper mixing of the CEA plastic pellets and the HDPE resin. Every time we change the CEA plastic (eg. PC to ABS) in the injection mold, we filtered the injection mold with HDPE to avoid sample contamination. For each plastic sample, we changed the specifications of the injection mold machine to get the best possible plastic specimen without flashing, which is excess plastic that tends to cover the edges of the specimen. Likewise, in order to get a full specimen that is not deformed and fills out the entire mold completely, we had to change the specimen specifications. The specifications of the injection mold machine include: temperature, injection time, shot size, filling time, clamp force, cycle time, and maximum injection pressure [Table3-6].

Injection Molding

Date 6-11-2014

Materials PS/HDPE

Recycled PS

Exxon HDPE 7960

	(Set) Actual	Temperature (F)			
Zone	**1**	**2**	**3**	**4**	**5**
Nozzle	(430) 397	(430) 402	(445) 404	(445) 408	(445) 410
3	(430) 440	(430) 433	(430) 431	(430) 431	(430) 431
2	(430) 456	(430) 440	(430) 444	(430) 442	(430) 444
1	(420) 422	(425) 420	(425) 428	(425) 424	(425) 422
Date	**6/11/2014**	**6/11/2014**	**6/11/2014**	**6/11/2014**	**6/11/2014**

Sample	**10/90**	**20/80**	**30/70**	**35/65**	**40/60**
T, (F)	455	442	444	442	444
Injection Time, sec	2.64	2.21	0.93	0.98	1.29
Shot Size, inch	1.3	1.26	1.28	1.22	1.24
Filling Time, sec	1.4	1.3	5.1	1.7	1.2
RPM	*380*	*380*	*380*	*380*	*380*
Cooling Time, sec	*30*	*25*	*25*	*25*	*25*
Clamp Force, kN	230	210	270	250	*240*
Cycle Time, sec	45.8	40.3	39.1	39.1	39.4
Initial Paramters:	**10/90**	**20/80**	**30/70**	**35/65**	**40/60**
Shot Size, inch	1.25	1.22	1.19	1.19	1.19
Max Injection Pressure step 1, psi	620	600	575	575	575
Max Injection Pressure step 2, psi	620	600	575	575	575
Hold Pressure, psi	*400*	*400*	*400*	*400*	*400*
Hold Time, sec	*5*	*5*	*5*	*5*	*5*

Table 4 Specifications of Injection Molding for PS/HDPE

Injection Molding

Date 6-5-2014

Materials (ABS/PC)/HDPE

Recycled (ABS/PC)

Exxon HDPE 7960

	(Set) Actual		Temperature (F)		
Zone	**1**	**2**	**3**	**4**	**5**
Nozzle	(400) 397	(400) 402	(400) 401	(400) 399	(400) 399
3	(430) 428	(430) 428	(430) 428	(430) 428	(430) 428
2	(430) 437	(430) 431	(430) 428	(430) 429	(430) 429
1	(380) 386	(380) 388	(380) 390	(380) 384	(380) 384
Date	**6/5/14**	**6/5/14**	**6/5/14**	**6/5/14**	**6/5/14**

Sample	**10/90**	**20/80**	**30/70**	**35/65**	**40/60**
T, (F)	437	431	428	429	429
Injection Time, sec	5.71	9.72	32.5	2.96	2.96
Shot Size, inch	1.35	1.35	1.34	1.3	1.3
Filling Time, sec	1.5	1.4	1.5	1.3	1.3
RPM	*380*	*380*	*380*	*380*	*380*
Cooling Time, sec	*30*	*30*	*30*	*30*	*30*
Clamp Force, kN	220	200	301	276	*276*
Cycle Time, sec	49.1	52.7	74.5	47.4	47.4
Initial Paramters:	**10/90**	**20/80**	**30/70**	**35/65**	**40/60**
Shot Size, inch	1.3	1.3	1.3	1.25	1.25
Max Injection Pressure step 1, psi	600	500	520	500	500
Max Injection Pressure step 2, psi	600	500	520	500	500
Hold Pressure, psi	*400*	*400*	*400*	*400*	*400*
Hold Time, sec	*5*	*5*	*5*	*5*	*5*

Table 5 Specifications of Injection Molding for ABS-PC/HDPE

Injection Molding

Date 6-4-2014

Materials ABS/HDPE

Recycled ABS

Exxon HDPE 7960

	(Set) Actual	Temperature (F)			
Zone	**1**	**2**	**3**	**4**	**5**
Nozzle	(400) 404	(400) 402	(400) 399	(400) 399	(400) 401
3	(430) 455	(430) 442	(430) 429	(430) 431	(430) 428
2	(430) 444	(430) 444	(430) 435	(430) 431	(430) 433
1	(380) 379	(380) 377	(380) 377	(380) 375	(380) 379
Date	**6/4/2014**	**6/4/2014**	**6/4/2014**	**6/4/2014**	**6/4/2014**

Sample	**10/90**	**20/80**	**30/70**	**35/65**	**40/60**
T, (F)	444	442	435	431	433
Injection Time, sec	6.6	3.15	4.21	4.42	4.1
Shot Size, inch	1.92	1.83	1.86	1.82	1.82
Filling Time, sec	2.8	3.1	2.6	2.6	2.5
RPM	*380*	*380*	*380*	*380*	*380*
Cooling Time, sec	*30*	*35*	*35*	*35*	*35*
Clamp Force, kN	390	346	290	280	*270*
Cycle Time, sec	49.7	51.7	52.4	54.4	53.5
Initial Paramters:	**10/90**	**20/80**	**30/70**	**35/65**	**40/60**
Shot Size, inch	1.88	1.8	1.82	1.78	1.78
Max Injection Pressure step 1, psi	710	650	680	575	575
Max Injection Pressure step 2, psi	710	650	680	575	575
Hold Pressure, psi	*400*	*400*	*400*	*400*	*400*
Hold Time, sec	*5*	*5*	*5*	*5*	*5*

Table 6 Specifications of Injection Molding for ABS/HDPE

Injection Molding

Date 6-6-2014

Materials PC/HDPE

Recycled PC

Exxon HDPE 7960

	(Set) Actual	Temperature (F)			
Zone	**1**	**2**	**3**	**4**	**5**
Nozzle	(400) 401	(400) 402	(400) 399	(400) 399	(400) 408
3	(410) 440	(430) 437	(430) 431	(430) 429	(430) 442
2	(430) 458	(430) 460	(430) 453	(430) 444	(430) 458
1	(390) 386	(390) 388	(390) 386	(390) 384	(390) 388
Date	**6/6/2014**	**6/6/2014**	**6/6/2014**	**6/6/2014**	**6/6/2014**

Sample	**10/90**	**20/80**	**30/70**	**35/65**	**40/60**
T, (F)	458	460	455	444	456
Injection Time, sec	5.69	6.4	5.94	3.71	4.67
Shot Size, inch	1.89	1.91	1.89	1.83	3.3
Filling Time, sec	2.9	2.9	2.8	3.3	3.3
RPM	*380*	*380*	*380*	*380*	*380*
Cooling Time, sec	*35*	*35*	*35*	*35*	*35*
Clamp Force, kN	290	280	330	320	*360*
Cycle Time, sec	53.8	57	54.3	50.7	55.5
Initial Paramters:	**10/90**	**20/80**	**30/70**	**35/65**	**40/60**
Shot Size, inch	1.85	1.87	1.85	1.86	1.88
Max Injection Pressure step 1, psi	780	720	750	720	710
Max Injection Pressure step 2, psi	780	720	750	720	710
Hold Pressure, psi	*400*	*400*	*400*	*400*	*400*
Hold Time, sec	*5*	*5*	*5*	*5*	*5*

Table 7 Specifications of Injection Molding for PC/HDPE

3.3 Tensile Testing

Tensile Tests were performed using ASTM D638 Standard Test Method for Tensile Properties of Plastics. The speed for the test was set at 5.08mm/s. The average dimensions (thickness and width) of five Type I specimens are noted down at the beginning of the procedure. The test specimens are then placed in the grips of the testing machine, and are aligned along the long axis of the specimen. The grip separation, which is the length-wise distance between the two grips of the tensile machine, is noted down after applying a load between 6 to 10 Newton for toe correction. The grips are tightened firmly to prevent slippage of the specimen during the test. It is important to refrain from tightening the grips too tightly, to avoid deformation of the specimen. An extensometer is then attached with a maximum strain error of 0.0002 mm/mm to middle of gage length of the specimen with the help of ¼ inch (6.4mm) extra heavy force latex bands. Before starting the test it is important to ensure that the reading of the extensometer is the same, before and after the removal of the pin. The test is started after zeroing all the values i.e load, crosshead and extensometer. The extensometer stops recording the displacement when its reading reaches 0.76 mm and hence has to be removed. The test is continued until the specimen breaks in the center of the gage length, otherwise the results are discarded and the same procedure is repeated.

This test is used to calculate tensile strength, elongation at yield (mm), stress at yield (MPa), strain at yield (%), load at yield (N), load at break (N), stress at break (MPa), strain at break (%). The definition which are calculated by tensile testing of plastics are:

i. Tensile Strength—Calculate the tensile strength by dividing the maximum load in Newton or pounds by the average original cross-sectional area in the gage length segment of the specimen in square meters/inches. The results are expressed in pounds per square inch [9].

ii. Load at Yield—Calculate by reading load indicator at yield point. This is represented in Newton [9].

iii. Load at Break—Calculate by reading load indicator at break point. This is represented in Newton [9].

iv. Percent Elongation at Yield—Calculate the percent elongation at yield by reading the extension (change in gage length) at the yield point. Divide that extension by the original gage length and multiply by 100 [9].

v. Percent Elongation at Break—Calculate the percent elongation at break by reading the extension (change in gage length) at the point of specimen rupture. Divide that extension by the original gage length and multiply by 100.Nominal strain is the change in grip separation relative to the original grip separation expressed as a percent [9].

vi. Nominal strain at break—Calculate the nominal strain at break by reading the extension (change in grip separation) at the point of rupture. Divide that extension by the original grip separation and multiply by 100 [9].

vii. Modulus of Elasticity—Calculate the modulus of elasticity by extending the initial linear portion of the load extension curve and dividing the difference in stress corresponding to any segment of section on this straight line by the corresponding difference in strain. All elastic modulus values shall be computed

using the average original cross-sectional area in the gage length segment of the specimen in the calculations. The result shall be expressed in psi (pounds/force per square inch/meter) [9].

3.4 Scanning Electron Microscopy

The freshly fractured sample surfaces of 10%ABS/90%HDPE & 35%ABS/65%HDPE are treated with liquid nitrogen to remove any surface contaminants. The treated samples are kept desiccator under vacuum for 24 hours. The samples are cut near the fractured section so that loaded on stubs using carbon tape in such way that the fractured face lies on the top. These are further coated with gold so as to make them conductive to electrons. The two images of each sample at 2μm and 10 μm resolutions are taken.

Chapter 4

Result

4.1 Tensile Modulus

ABS/HDPE

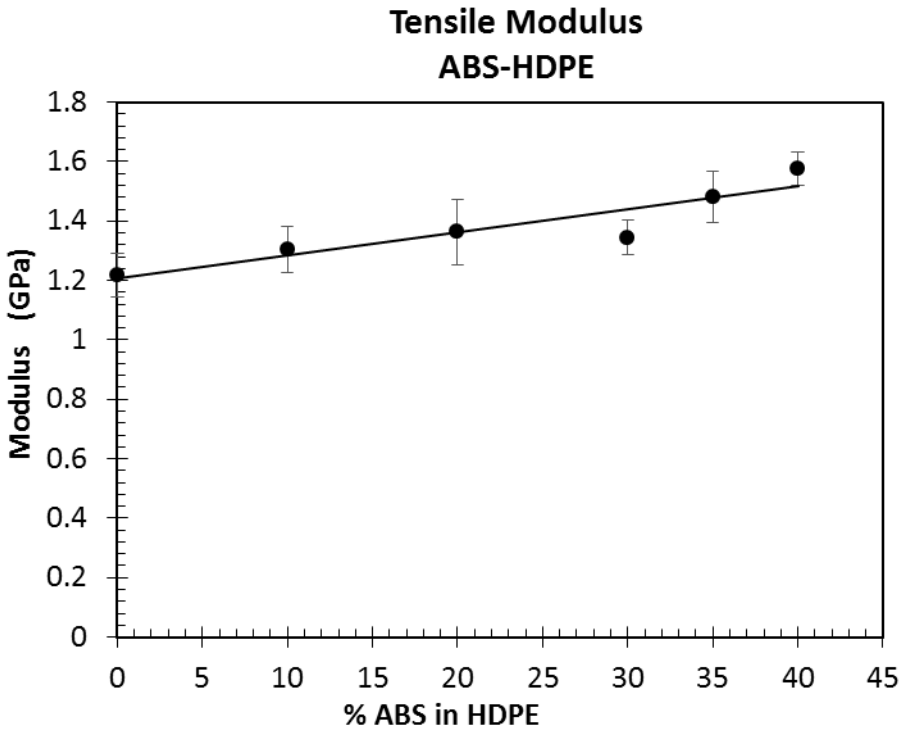


Figure 11 Tensile Modulus of ABS-HDPE

PC/HDPE

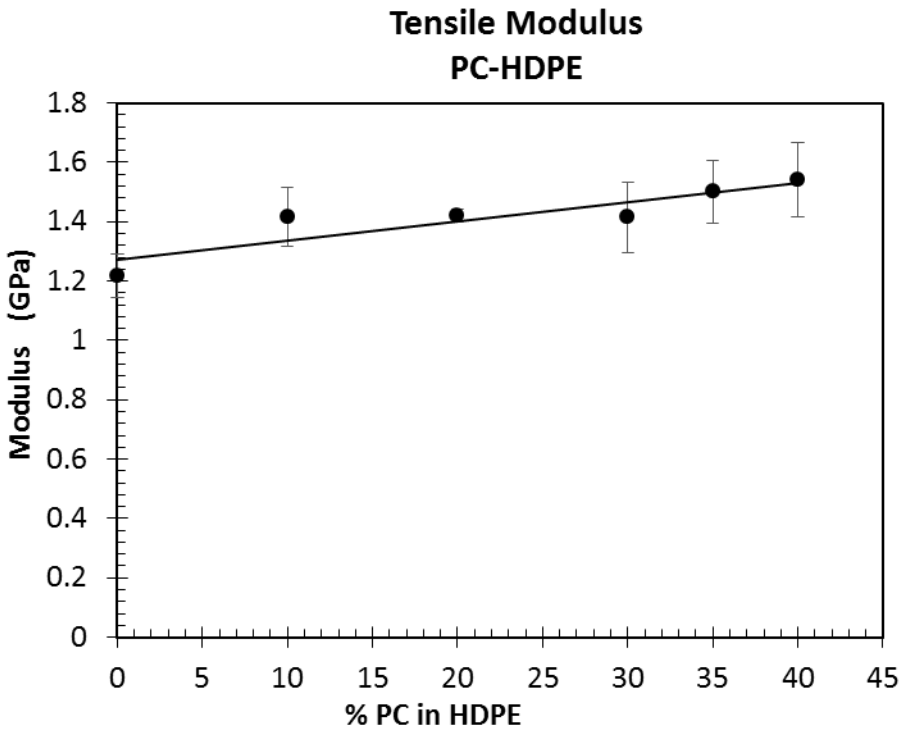


Figure 12 Tensile Modulus of PC-HDPE

PS/HDPE

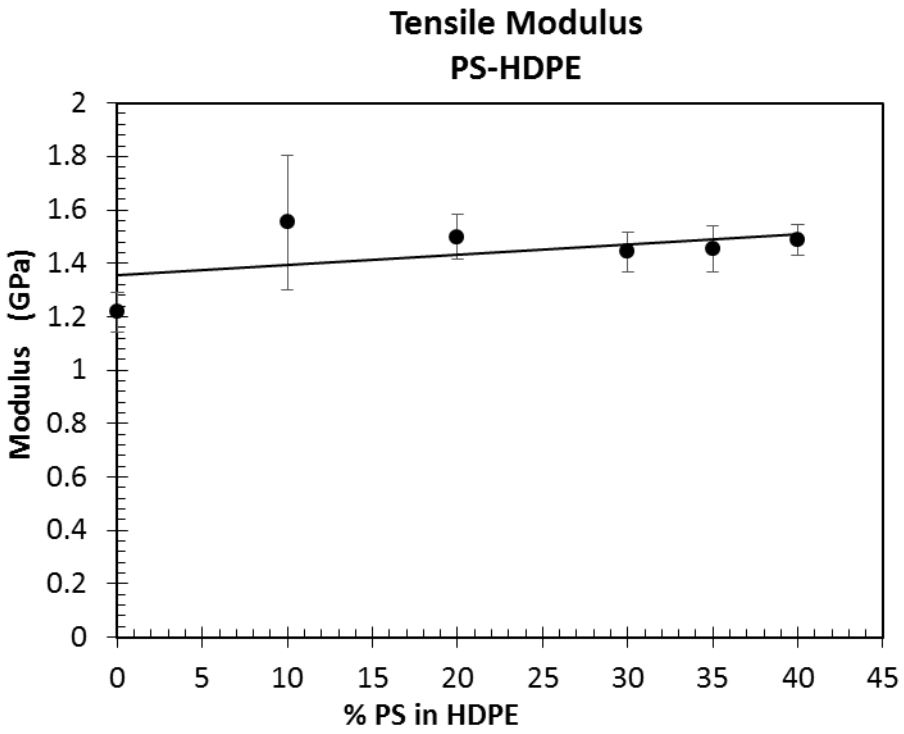


Figure 13 Tensile Modulus of PS-HDPE

PC-ABS/HDPE

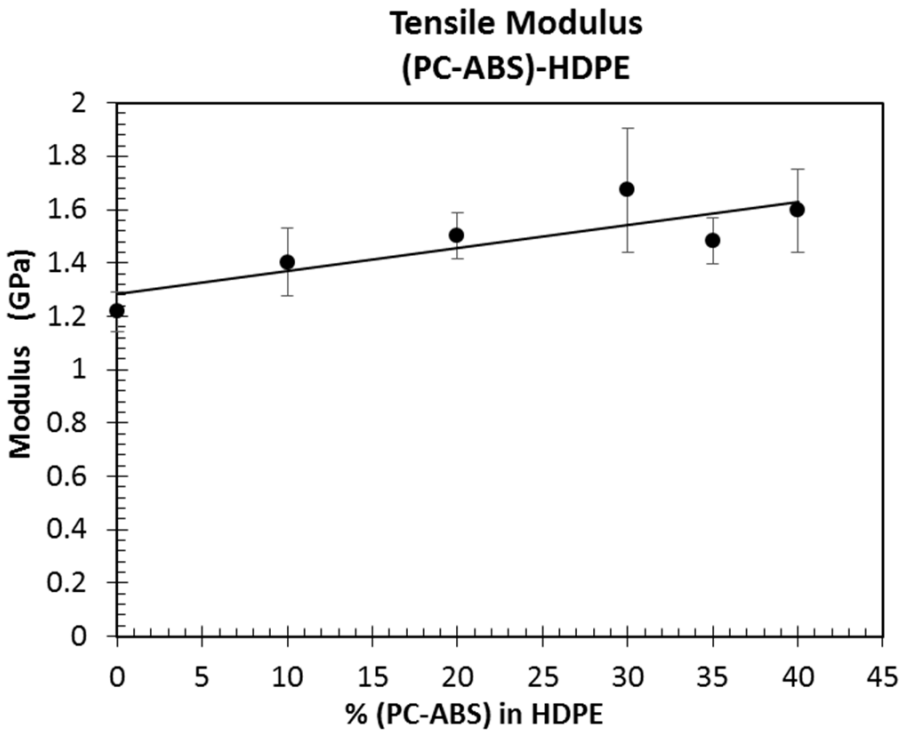


Figure 14 Tensile Modulus of PC-ABS/HDPE

4.2 Tensile Yield

ABS/HDPE

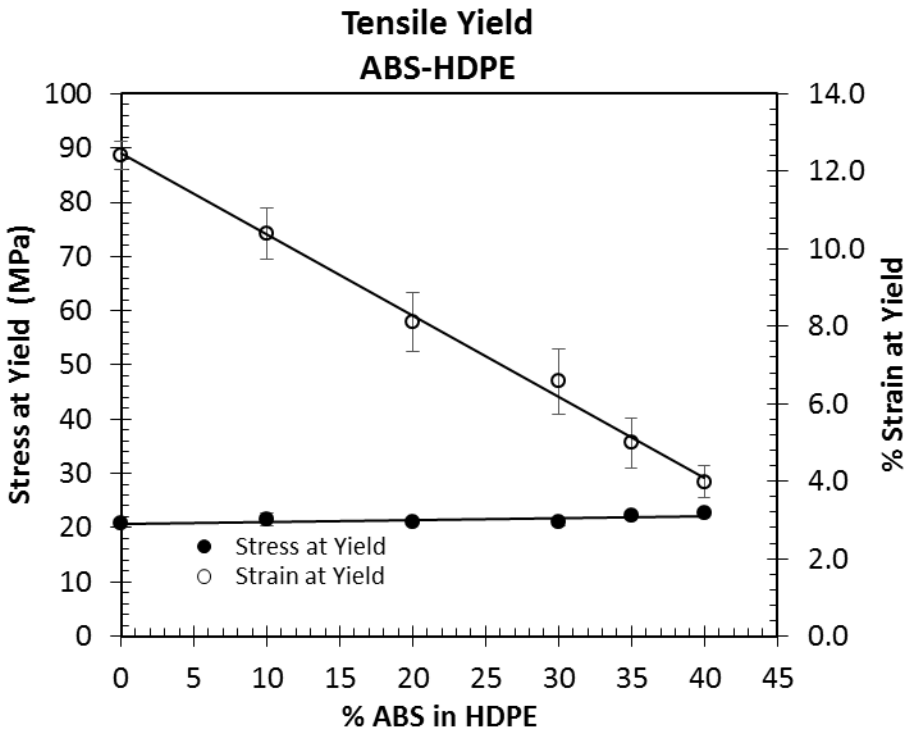


Figure 15 Tensile Yield of ABS-HDPE

PC/HDPE

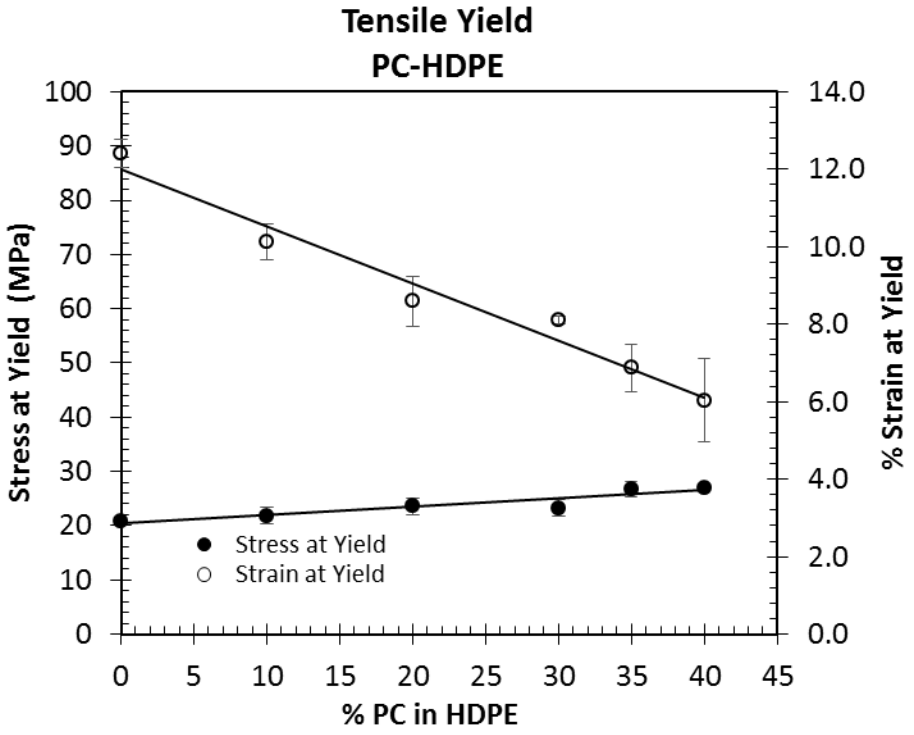


Figure 16 Tensile Yield of PC-HDPE

PS/HDPE

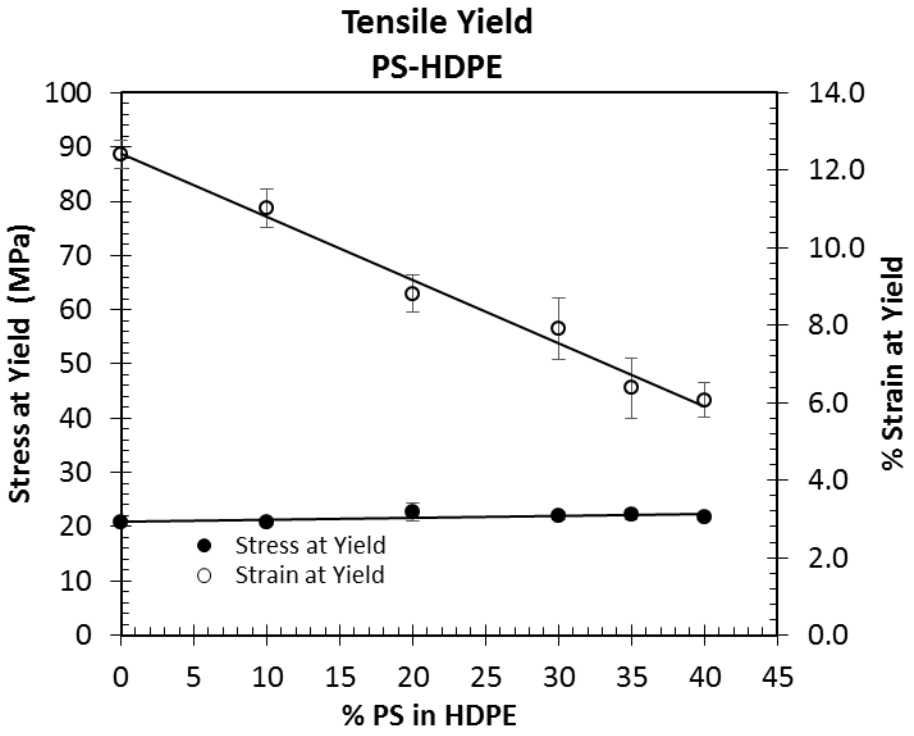


Figure 17 Tensile Yield of PS-HDPE

PC-ABS/HDPE

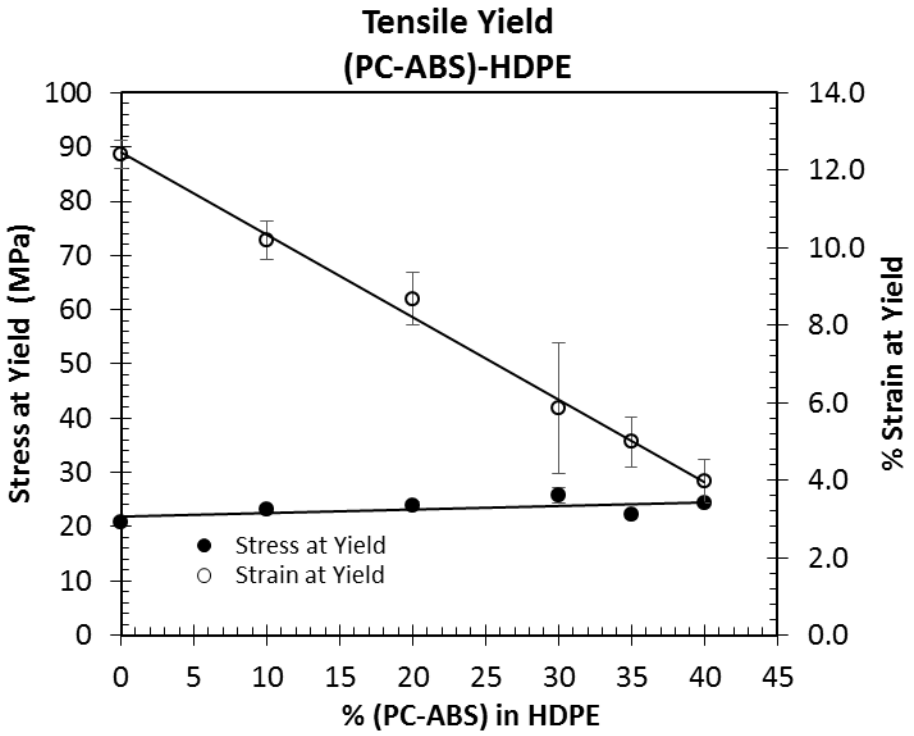


Figure 18 Tensile Yield of PC-ABS/HDPE

4.3 Tensile Break

ABS/HDPE

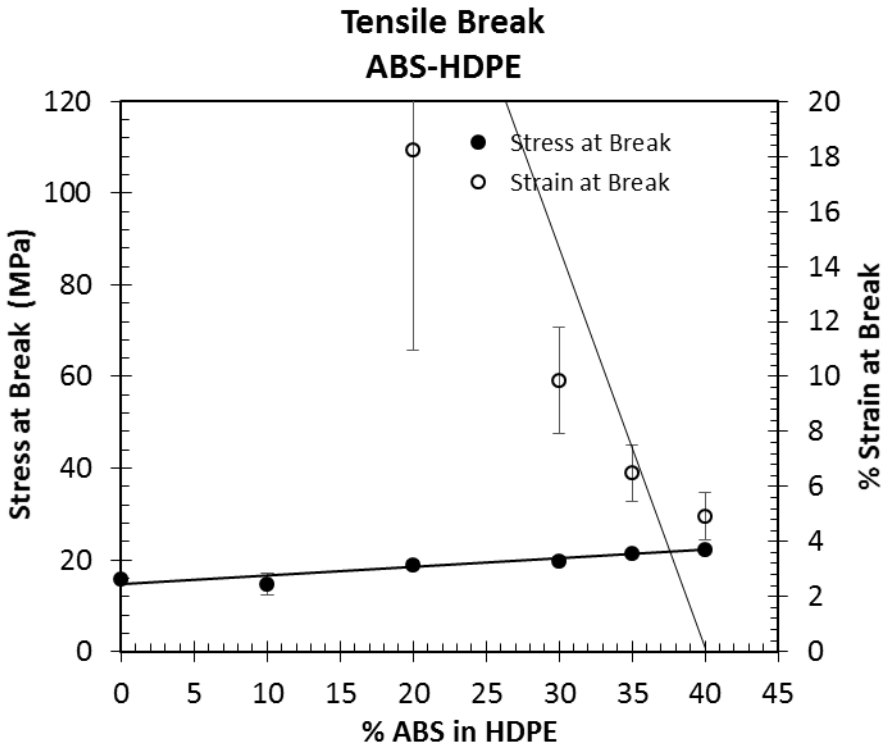


Figure 19 Tensile Break of ABS-HDPE

PC/HDPE

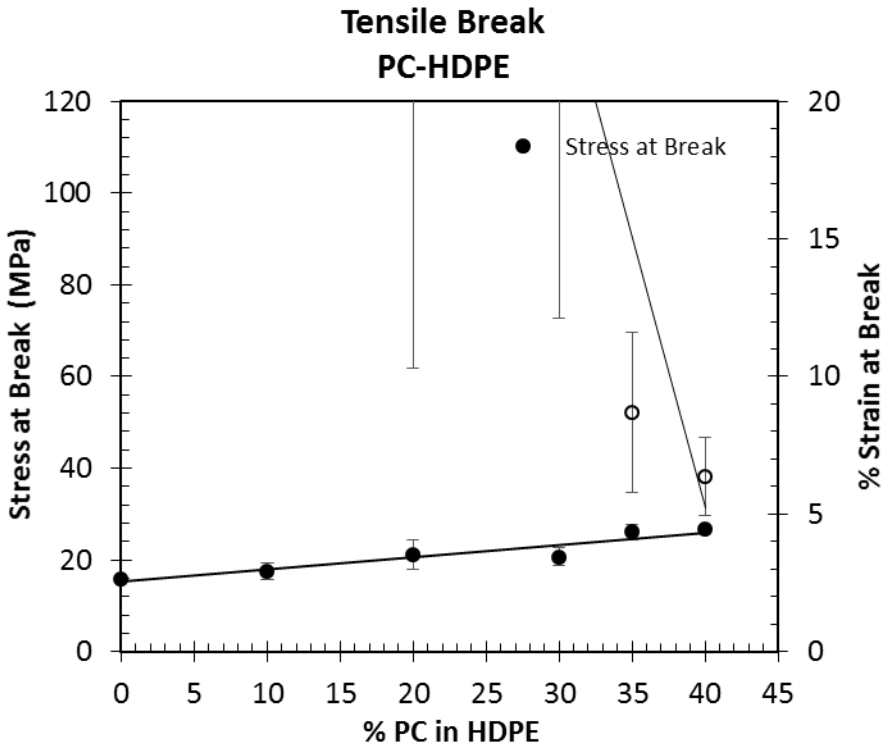


Figure 20 Tensile Break of PC-HDPE

PS/HDPE

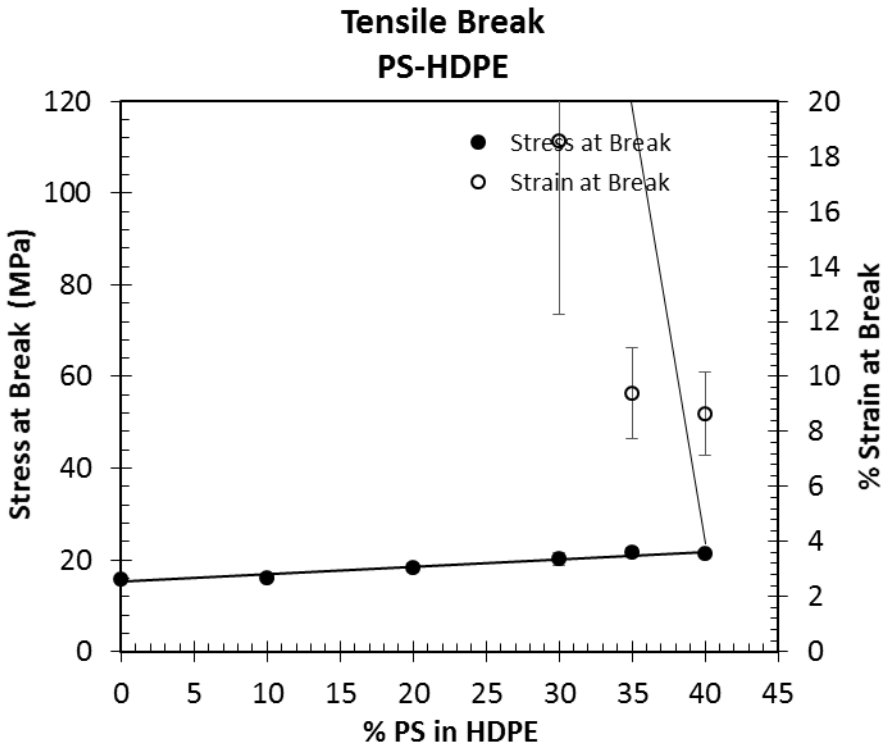


Figure 21 Tensile Break of PS-HDPE

PC-ABS/HDPE

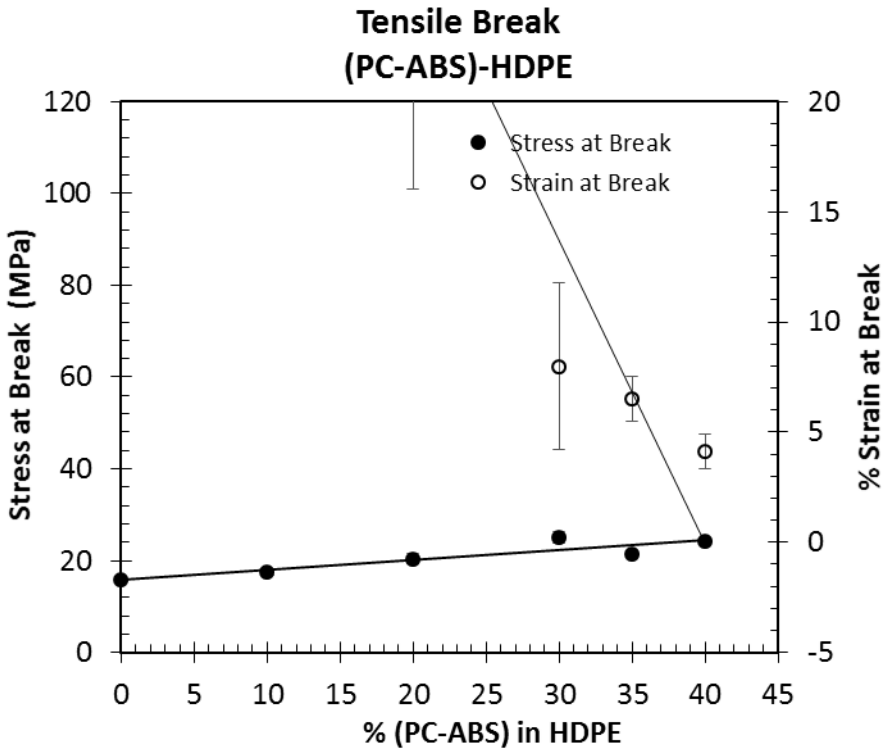


Figure 22 Tensile Break of PC-ABS/HDPE

4.4 Stress Strain Curve

ABS/HDPE

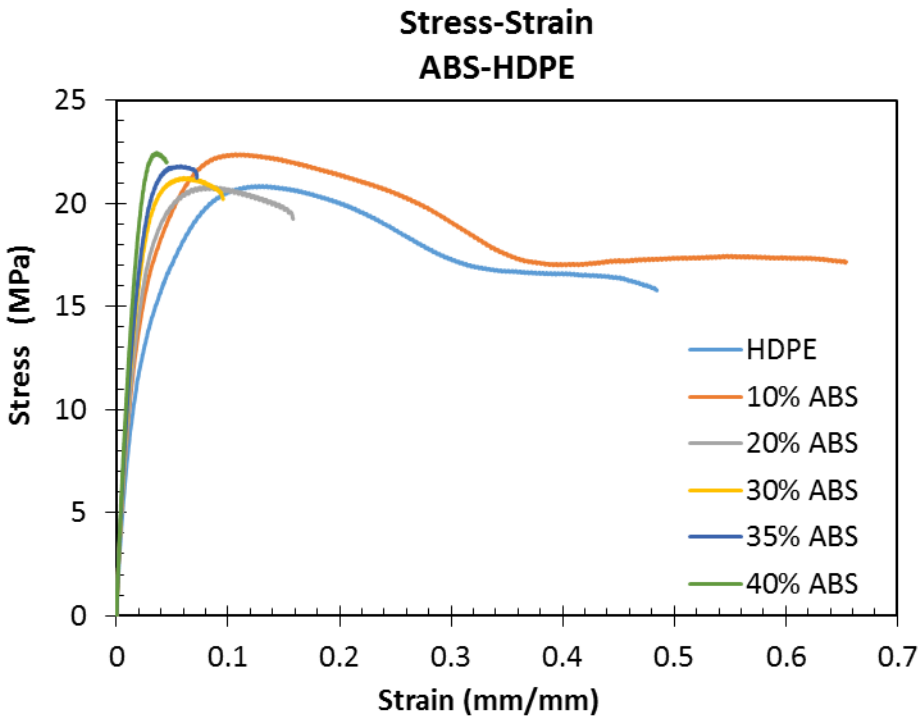


Figure 23 Stress-Strain curve of ABS-HDPE

PC/HDPE

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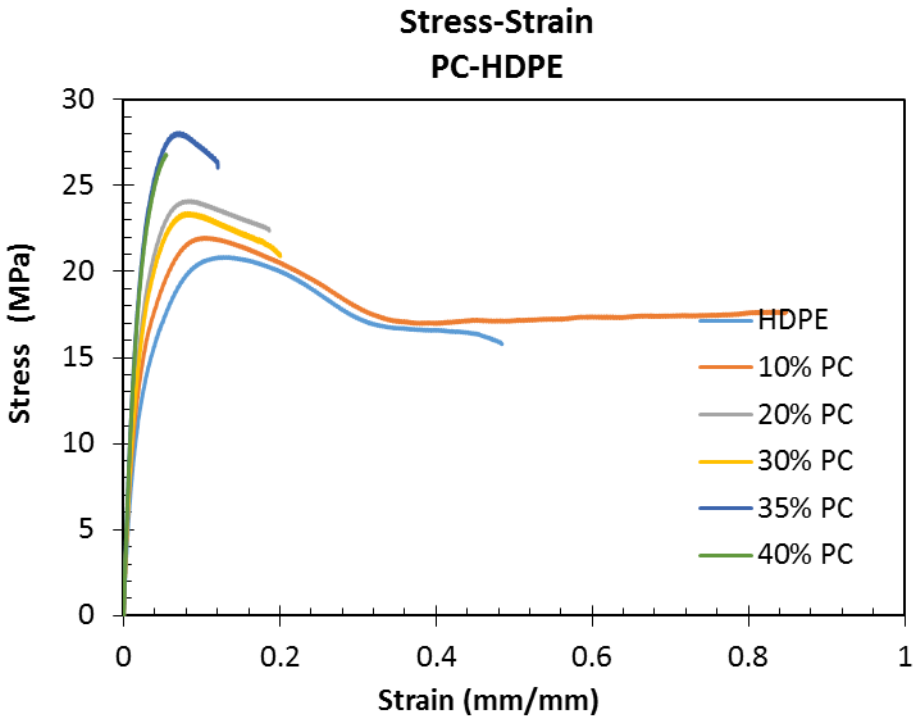

Figure 24 Stress-Strain curve of PC-HDPE

PS/HDPE

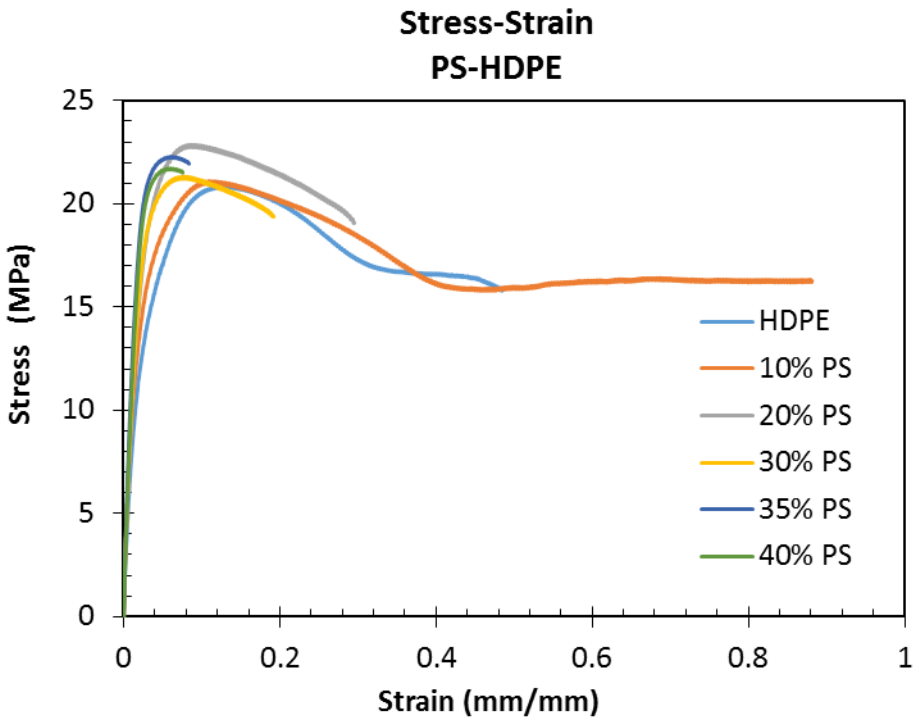

Figure 25 Stress-Strain curve of PS-HDPE

PC-ABS/HDPE

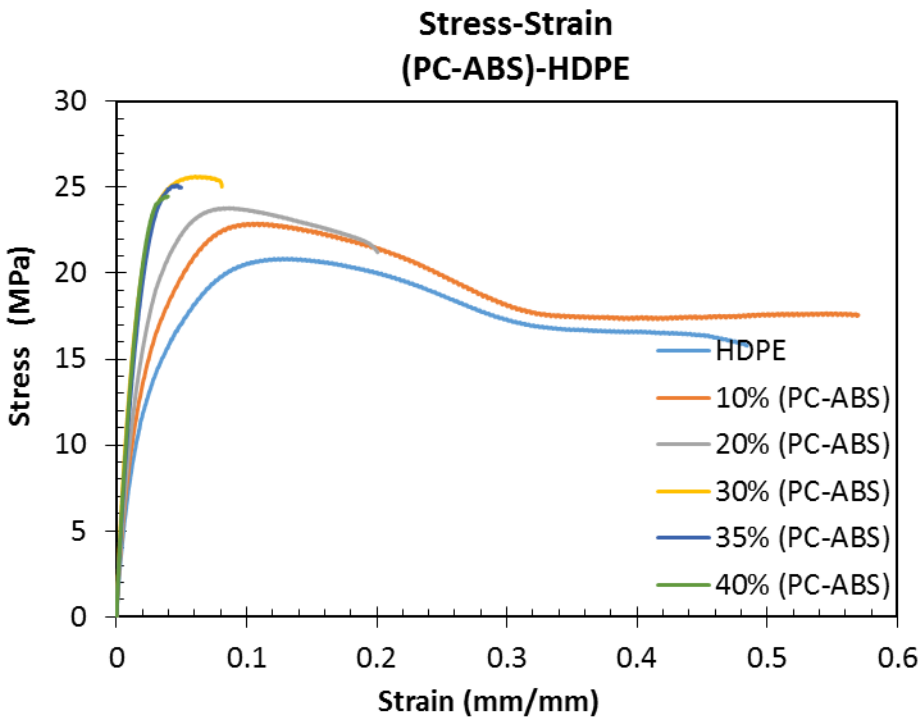

Figure 26 Stress-strain curve of PC-ABS/HDPE

4.5 Morphology

The SEM images show that as the composition of in 10% ABS in HDPE both phases are dispersed [Figure 23-24]. But for 35%ABS in HDPE shows continuous phases for both ABS and HDPE.

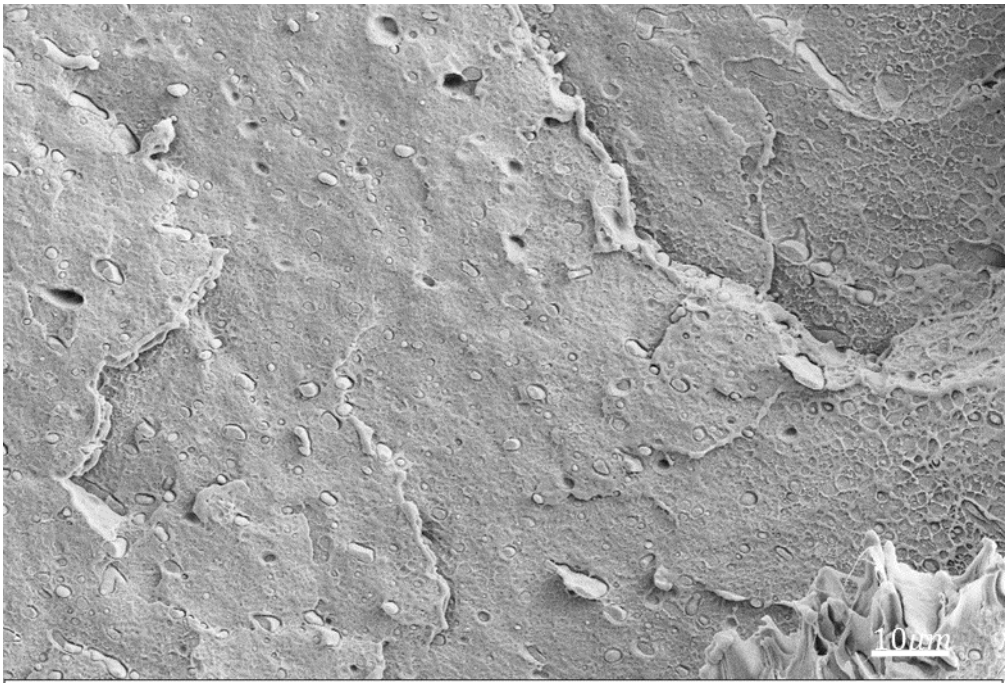

Figure 27 SEM image of 10%ABS/90% HDPE at 2**µm** Resolution

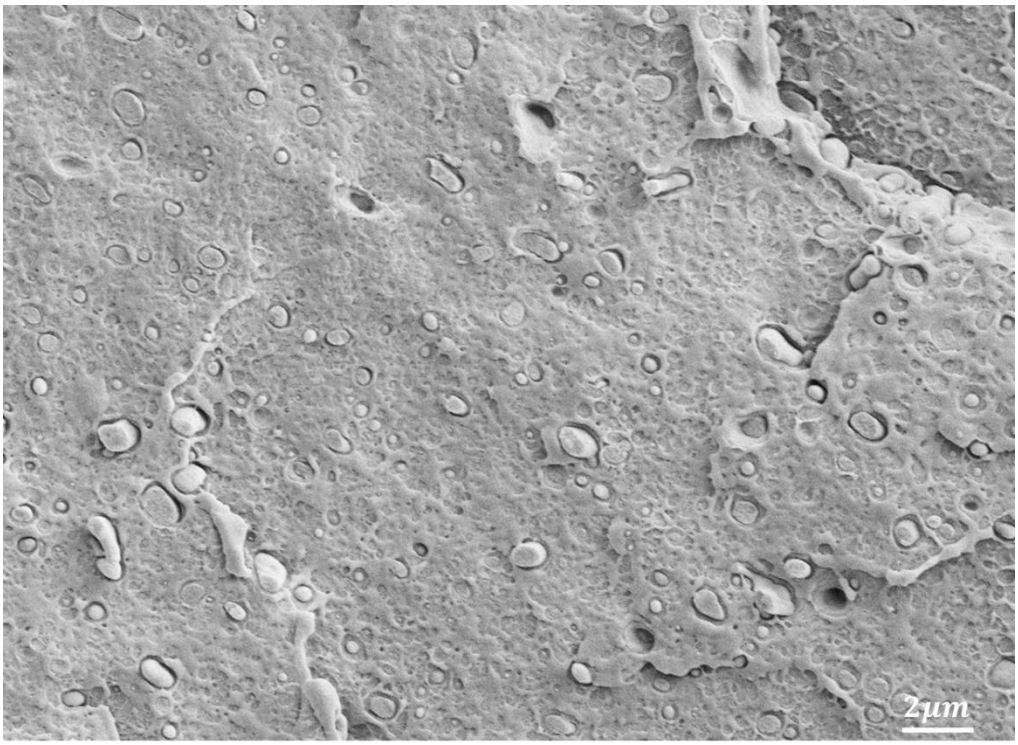

Figure 28 SEM image of 10%ABS/90% HDPE at 10**μm** Resolution

Figure 29 SEM image of 35%ABS/65% HDPE at 10**μm** Resolution

Figure 30 SEM image of 35%ABS/65% HDPE at 2**μm** Resolution

Chapter 4

Discussion

HDPE was regarded as the control of the composites tested, with the goal to create a CEA Plastics-reinforced HDPE composite with enhanced properties as compared with HDPE alone.

4.1 Tensile Modulus

The higher tensile modulus values indicate higher stiffness. HDPE achieved an average modulus of 1.22 ± 0.07 GPa [12]. All of the samples' moduli were comparatively greater than HDPE's average modulus value.

ABS/HDPE

While analyzing the data for ABS-HDPE samples, the sample's moduli increases with increasing composition of ABS except for a minor drop at 30% ABS-HDPE sample. The modulus values obtained for ABS-HDPE samples ranges from 1.30 to 1.58 GPa [Figure 7]. The average modulus value for composition percentages of 10, 20, 30, 35, 40 are 1.30 ± 0.08 GPa, 1.36 ± 0.11 GPa, 1.34 ± 0.06 GPa, 1.48 ± 0.09 GPa, 1.58 ± 0.06 GPa.

PC/HDPE

While analyzing the data for PC-HDPE, the sample's moduli remains constant with increasing percentage of composition of PC upto 30% PC-HDPE but increases with further increase in composition. The modulus values obtained for PC-HDPE samples ranges from 1.42 to 1.54 GPa [Figure 8]. The average modulus value for 10%, 20%, 30%, 35%, 40% composition are 1.42 ± 0.10 GPa, 1.42 ± 0.11 GPa, 1.42 ± 0.12 GPa, 1.50 ± 0.11 GPa, 1.54 ± 0.13 GPa.

PS/HDPE

While analyzing the data for PS-HDPE, the sample's moduli remains constant with increasing composition of PC initially then it drops for 30% PS-HDPE sample & it again begins to increase with further increase the composition. The modulus values for PS-HDPE samples ranges from 1.44 to 1.55 GPa [Figure 9]. The average modulus value for 10%, 20%, 30%, 35%, 40% composition are 1.55 ± 0.25GPa, 1.50 ± 0.09 GPa, 1.44 ± 0.07 GPa, 1.45 ± 0.9 GPa, 1.54 ± 0.06 GPa.

PC-ABS/HDPE

For PC-ABS-HDPE, the sample's moduli, the modulus exemplified an increasing trend, with a slight decrease for the 30% PC-ABS/HDPE sample. The modulus values for PC-ABS/HDPE ranges from 1.40-1.67 GPa [Figure 25]. The average modulus value for 10%, 20%, 30%, 35%, 40% composition are 1.40 ± 0.13GPa, 1.50 ± 0.09 GPa, 1.67 ± 0.23 GPa,1.48 ± 0.09 GPa, 1.60 ± 0.16 GPa. The highest modulus strength was shown by the 30% PC-ABS-HDPE sample.

4.2 Tensile Yield

At yield, HDPE's average stress load was 21 ± 0.1 MPa [12], while the strain percentage reached an average of 12.4 ± 0.36% [12].

ABS/HDPE

The ABS-HDPE stress at yield remained constant at 21 MPa up to 30% ABS-HDPE sample but increasing with further increase of composition while its strain decreased rapidly with increasing composition of ABS; the strain percentage values of ABS-HDPE ranged from 10.4% to 3.99% .The stress at yield for ABS/HDPE ranges from 21 MPa to 23 MPa [Figure 11].

PC/HDPE

The PC-HDPE blend's stress at yield increases with increase in composition of with minor drop at 30 % PC-HDPE sample while its strain decreased with increasing composition of PC; the strain percentage values of PC-HDPE ranged from 10.13% to 6.04. The stress at yield varies from 22 MPa to 27MPa [Figure 12]. 35% & 40% PC/HDPE sample have highest strain at yield.

PS/HDPE

The PS-HDPE blend's stress at yield increases slightly initially then becomes constant with increase in composition while its strain its strain percentage values of PS-HDPE

ranged from 11.01% to 6.07%. The stress at yield ranges from 21MPa to 23MPa [Figure 13].

PC-ABS/HDPE

When PC-ABS was mixed with HDPE the blend displayed similar trends to their original components (PC and ABS); there were slightly increasing stress values along with dramatically decreasing strain percentage values. The values for the stress at yield ranged from 23 to 26 MPa, while the values for the strain percentage at yield decreased from 10.18% to 3.97% [Figure 14].

4.3 Tensile Break

Tensile break point indicates the point at which the specimen has fractured. All of the samples, including PS/HDPE, PC/HDPE, ABS/HDPE, and PC-ABS/HDPE, were observed to have the same trend in their respective tensile break plots. With increasing concentration of the respective CEA plastic, the stress increased while the strain percentage decreased. A decreasing percent strain at fracture can indicate a decrease in a material's ductility. The virgin resin, HDPE, had an average stress load of 16 ± 0.3 MPa with a strain percentage average of 49.88 ± 6.62% [12].

ABS/HDPE

The stress values of ABS-HDPE blends at the breaking point increased from 15 to 22 MPa with an increase in composition of ABS, and its strain percentage values rapidly decreased from 64.01% to 4.91% [Figure 15].

PC/HDPE

The stress values of ABS-HDPE blends at the breaking point increased from 17 to 27 MPa with an increase in composition of ABS, and its strain percentage values rapidly decreased from 122.79 to 6.37% [Figure 16]. PC-HDPE exemplified the ability to retain most stress while also allowing the highest % strain at fracture.

PS/HDPE

The stress values of PS/HDPE blends increases steadily with the composition upto 35% PS with a drop from 35% to 40% PS. Its strain percentage values rapidly decreased from 236.13 % to 8.64% .The stress values of PS/HDPE ranges from 16 to 22 MPa.[Figure 17].

PC-ABS/HDPE

The PC/ABS-HDPE had a maximum stress at 30% PC-ABS; there was a quick decline from 30% to 35% PC-ABS, then a steady incline. While its strain percentage values decreases from 53.52 to 4.12% [Figure 18]. This leads to the implication that 30% PC-ABS has optimal ultimate strength over higher concentrations of PC-ABS in HDPE.

4.4 Stress Strain Curve

Stress-strain curves convey the modulus value, ultimate tensile strength value, stress at fracture, strain at fracture, and toughness of a plastic specimen; they indicate the tensile properties of each sample of recycled plastic composites. Stress is the force per unit area and strain is amount of deformation that a material experiences. Stress-strain curves, comparing each plastic composite sample to HDPE, were developed to convey the tensile

properties evaluated during tensile testing. The stress-strain curve comparing the properties of the various samples of PS-HDPE to the control sample of HDPE indicates that amount of stress experienced by all samples were relatively similar, varying between 21 and 23 MPa [12].

ABS/HDPE

The stress-strain curve comparing ABS-HDPE samples to HDPE samples, signifies that stress experienced was between 21 to 23 MPa [Figure 19]. 10% ABS-HDPE withstood the most amount of strain in comparison to all other samples. ABS-HDPE samples with percent compositions of 20%, 30%, 35%, and 40% ABS were able to withstand the least amount of strain before fracture. This indicates that ABS-HDPE plastic composites with higher percent compositions of ABS withstood more stress, but withstood less strain before fracture.

PC/HDPE

The stress-strain diagram depicting the samples of PC-HDPE in comparison to HDPE conveys that the amount of stress experienced by all the samples was between 21 to 27 MPa [Figure 20]. 30%, 35%, and 40% PC-HDPE samples were able to experience the most of amount of stress. 10% PC-HDPE was able to withstand the most amount of strain in comparison to other samples. This signifies that PC-HDPE plastic composites with higher percent compositions of PC can withstand less strain than those with lower percent compositions of PC.

PS/HDPE

The stress-strain curve comparing the properties of the various samples of PS-HDPE to the control sample of HDPE indicates that amount of stress experienced by all samples was relatively similar and was between 21 to 23 MPa [Figure 21]. However, the amount of strain at which each sample fractured varied; PS-HDPE composites with 35% and 40% PS composition fractured earlier than other samples. This demonstrates that when increasing the percent composition of PS in the PS-HDPE composite, the amount of strain withstood decreases.

PC-ABS/HDPE

The stress-strain diagram comparing PC-ABS/HDPE samples indicates trends found in the previously mentioned stress-strain diagrams. PC-ABS/HDPE samples with 30%, 35%, and 40% PC/ABS experienced the most stress, but withstood the least amount of strain before fracture [Figure 22]. The amount of stress for the samples varied between 20 to 25 MPa. The maximum strain withstood before fracture was experienced by 10% PC/ABS-HDPE. This further demonstrates that PC/ABS-HDPE plastic composites with higher percent compositions of PC/ABS can withstand more stress than strain.

Chapter 5

Conclusion

When considering materials for structural applications like bridges & railway crossties it seems logical to use wood as a basis for comparison because of its widespread use and proven performance. Wood was originally selected because of its empirical results, natural abundance, and easy processing. However, it is important to note that the optimum material for a crosstie has not been established yet, and deviations from wood do not imply that other materials will not perform adequately [7].

We compared the Young's Modulus of our Isotropic material with the ones reported by a paper on the mechanical property performance of composite railroad ties. The Young's modulus calculated from the results of the compression test requires that was 1172.11MPa (170,000 psi) or greater be used. After analyzing the results from tensile testing, we realized that the all composition of all CEA plastics have higher modulus value than the required 1.172 GPa. The ultimate strength of all compositions was also compared to the paper reporting on material specifications for bridge applications. The Ultimate Strength of all compositions of ABS/HDPE, PC/HDPE, PS/HDPE & PC-ABS/HDPE has higher value than required 20.68MPa (3000 psi). Furthermore, we concluded all CEA plastic composites are promising candidates for the plastic lumber industry. Overall, this research helps develop alternatives to wood and steel. The plastic lumber industry currently uses plastic composites as an alternative to traditional materials; however, our research proves that recycled plastic composites derived from CEAs can be used in the plastic lumber industry as well. Analysis of the mechanical

properties of recycled plastic composites, through tensile testing, allows us to determine appropriate applications.

The other thing this research proves if any stiffer polymer is reinforced into Polyethylene to form a blend the mechanical property of the blend is enhanced only in our special adapted machines. Recycled plastic lumber poses various advantages such as being environmentally friendly by reducing the amount of waste produced.

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