News

The Society of Plastics Engineers

ENGINEERING PROPERTIES & STRUCTURE DIVISION

October 2009

Plastics Hall of Fame Welcomes EPSDIV Member

Dr. Donald E. Witenhafer of College Station, Texas, has been elected to the Plastics Hall Of Fame in recognition of his pioneering technical achievements that saved the polyvinyl chloride (PVC) industry.

The PVC industry was threatened when it was discovered that the vinyl chloride monomer used in making PVC is a human carcinogen and is dangerous when humans are exposed to it. Environmental groups urged the immediate banning of PVC.

At the time of the discovery, Witenhafer was a polymer scientist working for the B. F. Goodrich Company of Akron, Ohio, the world's largest producer of PVC resins. His research resulted in three key patented breakthroughs that were used to save the industry and protect the public.

He invented steam stripping columns, which remove the dangerous residual, un-reacted, vinyl chloride monomer from the manufactured PVC resins. He also invented the first water based, absorbing, clean reactor wall coating that made it possible to run successive polymerization batches without opening the polymerization vessel. Thus workers no longer entered vessels to scrape polymer buildup off the walls and were no longer exposed to the dangerous monomer. He also invented the use of a steam pressure process to apply these coatings to the reactor walls.

Dr. Donald Witenhafer

Worldwide, almost all PVC plants today use a water based, absorbable clean reactor coating, similar to that invented by Witenhafer, applied with steam pressure. In the well-designed Goodrich 16,500 gallon reactors, over 700 batches are normally polymerized before the vessel is opened for cleaning. Throughout the world, steam stripping columns are used in the vast majority of PVC plants to remove the residual monomer to below one part per million.

No new cases of liver cancer associated with vinyl chloride have been reported in the last 25 years. The volume of PVC resin produced in the world has tripled to about 75 billion pounds per year.

Each year, we recognize the Best Student Paper presented at ANTEC. This year's winner, Mary Moriarty, is seen center above. She is congratulated by Pierre Moulinie, left and EPSDIV Chair Sadhan Jana, right. The paper, *Mechanical Properties of a Recycled Post-Consumer Product with Complex Construction*, is reproduced on page 6 of this newsletter.

INSIDE THIS ISSUE

Exciting Plans Underway to Make 2010 Successful

Chairperson Sadhan Jana

Greetings to all our members! Thank you for being loyal members of Division 26: Engineering Properties and Structures Division (EPSDIV), one of the largest technical divisions of SPE. We are proud to sustain most of our membership roll due to a long standing relationship with you and the focus on the most important technical issues being faced by the industry.

Encouraging New Members

Our total membership (primary and secondary) of 1019 in August 2009 is 15 per cent down compared to 1207 members in August 2008. During the same period SPE membership went down by 17 per cent.

In the past, our division helped in the launching of several other successful technical divisions of SPE and thus lost some of our membership with it. However, the situation in past several years has been very different. The issue of declining membership was discussed in our board meetings last year. As an action item, our membership committee headed by **David Zumbrunnen** and **Rajen Patel** prepared a useful pamphlet for distribution to prospective members. The pamphlet describes the purpose and the benefits of EPSDIV membership and provides a list of important events that EPSDIV organizes every year. These pamphlets were distributed to the attendees of ANTEC 2009 in Chicago.

In conjunction, I would like to take this opportunity to seek your help in reaching out to new members. Kindly encourage your colleagues and friends working in polymer industry to become members of SPE and EPSDIV. The following web address provides detailed information on how to become a member of SPE: www.4spe.org/membership.

Silver Pinnacle Award

Our board is very proud to share with you the news that we once again received the 2008-2009 Silver Pinnacle Award. This award is given to divisions or sections "that successfully create and deliver member value during the year. Sections and Divisions are reviewed in four categories of achievement: organization, technical programming, membership and communication."

Our 2009-2010 goal is to qualify for the Gold Pinnacle Award. To achieve this goal, our TOPCON committee headed by **Pierre Moulinie**, **Kevin Kit**, and **David Zumbrunnen** is working hard to put together a web-based seminar series later this Fall. We will soon announce the details of this event. We hope your continued support will make this event successful.

Board Election Results

We thank you for bringing back by re-election three members: **Richard Bopp**, **John Trent**, and **Sing-Chung Wong** to the board. They contributed significantly in the past in various capacities. I am sure their current association with the board will be as productive. Of special mention are the roles played by **John Trent** as the newsletter editor and **Sing-Chung Wong** as the co-chair of the technical program committee for ANTEC 2009. We also thank you for electing **Brian Landes** to succeed **Don Witenhafer** as the councilor. It was difficult for us to see Don Witenhafer leave the board after so many years of exemplary service. We all felt elated when he showed up at EPSDIV awards reception at ANTEC 2009 with a gold medallion that he just received as a 2009 inductee of Plastics Hall of Fame. Please do not forget to congratulate Don if you see him in your area.

Two of our fellow board members, **Rajen Patel** and **Raj Krishnaswamy**, were elected as SPE Fellows. Congratulations Rajen and Raj!

ANTEC 2010, TOPCON

Our ANTEC 2010 technical program committee chaired by **Ashish Batra** and **Jason Lyons** has already prepared an exciting line-up of topics and a list of excellent speakers. Our TOPCON committee is putting together a plan for a web-based seminar series, the first time in EPSDIV history. We all hope that you will assist us in our goal in reaching out to your colleagues and friends who are not EPSDIV or SPE members yet. In addition, if you or your company would like to sponsor an EPSDIV event, kindly let us know.

Thank You

Before closing, I wish to thank two individuals; **Jeff Gillmor**, the past chair of the board, and **Pierre Moulinie**, the chair elect of the board. Jeff kept the board together at a very difficult economic time and made sure that our focus on service to EPSDIV and SPE membership was maintained. Pierre, in addition to his role as awards committee chair and as member of TOPCON committee, agreed to serve as chair-elect this year and hence as the chair of the 2010-2011 board amid stringent commitment required by his professional obligation.

— Sadhan Jana

Mentoring the Next Generation

Brian Landes, Councilor

The most recent SPE council meeting (June 2009) was held at the joint ANTEC/NPE Meeting in Chicago. This marked my first meeting as your division councilor.

Because there are a variety of resources that SPE has available to incoming volunteers, I entered the two-day schedule feeling completely prepared. These resources include leadership training, planning guides, and communication tools. But even more helpful was the knowledge, guidance, and wisdom passed on to me from our exiting councilor, Don Witenhafer. Don did all of the things no tool or reference material could. He mentored me.

We talked several times before the meeting as he described the role, the expectations, and the responsibilities. Once at the meeting Don made sure to personally introduce me to many of the other councilors, and SPE leaders. He took the time to make sure I was comfortable in the setting, familiar with the available resources, and most importantly plugged in to the lifeline of SPE — exemplifying that what makes SPE so valuable is the people.

Over the course of the two-day meeting, I was impressed by the passion Don has for the continued success of SPE, and all of the people that comprise it. Don — thank you. Thank you for the leadership, insight, energy, and years of commitment that you have invested in our division, and SPE as a whole.

We continue to be challenged by the economic conditions around the globe. SPE has made significant cost reductions this year, including: relocation of Headquarters, reduction of staff employees, reduction in the number of council meetings, and allowing virtual

Continued on page 4

Continued from page 3

Councilor's Report

participation at council meetings. While the measures of cost cutting can help to stabilize the current situation, they can not succeed as a long-term renewal strategy. SPE will be focusing on two major growth initiatives: 1) International memberships, sections, and conferences; 2) Recruiting and mentoring the next generation of SPE members.

We continue to be challenged by the economic conditions around the globe.

We need everyone's help to achieve these initiatives. Do you have ideas on more effective ways to communicate with and attract the next generation of SPE members? Are there coworkers, colleagues, or friends around you who would benefit from the resources, expertise, networking, and mentoring that SPE can offer? I have experienced and benefited both professionally and personally from people in SPE who have taken the time to mentor me. Now it's time for me — and for all of us to take our turn. The future of SPE is depending on it — let's get started!

Brian Landes, Division Councilor

Financial Report from July 1, 2008 to June 30, 2009

Emmett Crawford, Treasurer

BALANCE AS OF JULY 1, 2008	**$ 38933.74**
Cash, checking, savings, investments	
INCOME	**ACTUAL**
Interest	894.90
SPE Rebate	2514.56
ANTEC Sponsorships	5250.00
TopCon	965.59
Total Income	**$ 9625.05**
EXPENSES	
Board Meetings	2747.76
Newsletter Production	1070.00
TOPCON	739.78
ANTEC Session Sponsorship	2924.05
Councilor Travel	1268.46
Teleconferences	531.12
Total Expenses	**$ 10281.17**
CASH FLOW	**$ -656.12**
ENDING BALANCE AS OF JUNE 30, 2009	**$ 38277.62**

EPSDIV Members Recognized

—A Message from Society Award Chair, Murali Rajagopalan

We would like to congratulate Drs. Raj Krishnaswamy and Rajen Patel for receiving their Fellow of the Society award nominated by EPSDIV at 2009 Antec meeting for their technical contributions in the area of polymer science.

Dr. Rajen Patel
Fellow of the Society

Rajen is recognized for his work in the advancement of metallocene catalyst technology.

His research work has led to new structure-properties models in metallocene catalyzed polyethylenes, enabling rapid application developments of metallocene catalyzed polyethylene resins.

As a result of his innovative research in the area of the fundamentals of heat seal and hot-tack properties of sealants, sealants have become one of the primary applications of metallocene catalyzed resins, leading to fast packaging line speeds, improved package integrity and security and energy savings at many packaging companies.

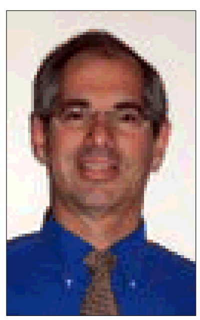
He is also one of the pioneers in the development of a brand new XLA elastic fiber for apparel applications, and was recognized for this work as Dow Chemical's inventor of the year in 2004.

Dr. Rajendra K. Krishnaswamy
Fellow of the Society

Raj is recognized for his research activities in the area of the structure and property relationship in new polyolefins and bio-degradable polymers.

He led the development of PHA molecular architecture and product formulation technology to enable the production of blown film (for the first time ever) on a commercial scale.

He was instrumental in manipulating the melt rheology of PHA so they can be processed using conventional polymer processing equipment, and has made many important contributions in the field of polymer crystallization.



Dr. Frank Cangelosi
SPE Honored Service Member

Frank is being recognized for his long-term service to the Engineering Properties and Structure Division and the Polymer Modifiers and Additives Division.

He held a variety of positions in both Divisions, and served them both as Chair. He helped to establish the $1,000 EPSDIV John O'Toole Best Student Paper Award, and established the Division's Corporate Sponsorship Award program.

A few years ago, when PMAD encountered a leadership crisis, Frank's stepped in to help revitalize the board. He was also a key contributor to the development of the PMAD Challenge – a program designed to increase interest in plastics additives among SPE Student Chapters.

We would also like to take a great pride to congratulate Dr. Frank Cangelosi for receiving his Honorable Society Service Member (HSM) for his unrestrained support to the EPSDIV, PMAD and SPE activities.

Watch for it!

EPSDIV is Planning a TopWebCon!

— Submitted by Pierre Moulinie

We are looking to organize web-based presentations and seminars to educate our membership and reach out to students who are performing research or have projects in plastics.

While nothing can beat face-to-face discussions, TopWebCons give opportunities for interactions without travel expenses.

We're looking to start this new initiative soon, so if you're working on something exciting and new, we encourage you to contact us!

Contact Pierre Moulinie (pierre.moulinie@bayerbms.com), Kevin Kit (kkit@utk.edu) or David Zumbrunnen (zdavid@clemson.edu)

ANTEC 2010 Tentative Program

—Submitted by Dr. Ashish Batra and Dr. Jason Lyons, Technical Program Chairs

We plan to organize six symposiums on the following topical areas:

- Filtration and Membranes;
- Materials in the field of Alternate Energy;
- Controlled Morphology Polymers and Polymer blends;
- Nanocomposites; Biomaterials;
- Plastics in Electronics.

These symposiums will run along with conventional symposiums on:

- Polyolefins;
- Flexible Packaging;
- Alloys and Blend;
- Materials Characterization;
- Thermoplastics,
- Polymer Analysis.

Six invited keynote speakers from industry and academia will participate. We greatly appreciate the submission of papers from members in the above mentioned areas. Please submit your paper at *www.abstractsonline.com/submit/login.asp?mkey=%7b5F2183CE-F424-4867-893E-4186EB56461B%7d* by **November 13, 2009 at 5 pm Eastern**.

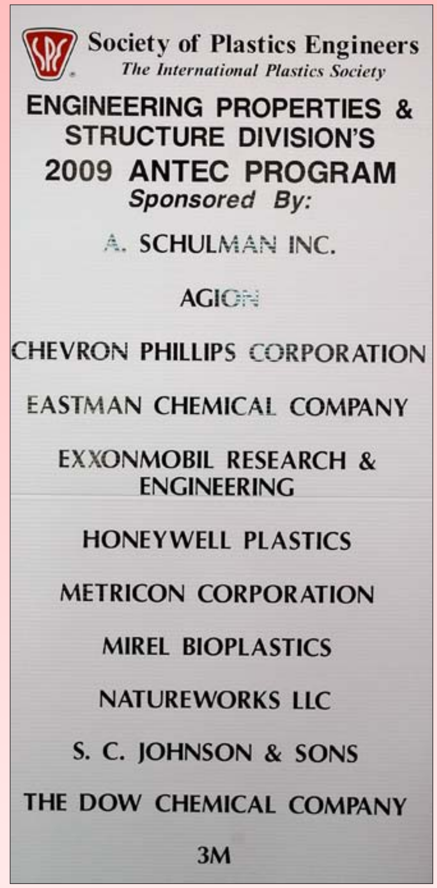
Members are encouraged to contact Technical Program Chairs, Dr. Ashish Batra (abatra@dow.com) and Dr. Jason Lyons (jason.lyons@arkema.com) with questions and comments on technical programming or to participate as session moderators.

Submit your papers to be part of ANTEC 2010. Seen above Technical Program Chairs, Dr. Ashish Batra, left, and Dr. Jason Lyons seen right, encourage members to be part of ANTEC 2010.

Thank you!

to Our ANTEC 2009 Sponsors

Our ANTEC sponsors, listed below, contributed greatly to EPSDIV's success at ANTEC 2008. We thank them and appreciate their support.



ANTEC 2010

Deadline

for papers

November 13, 2009

ANTEC 2010

May 16-20, 2010

Orlando World Center Marriott Resort

& Convention Center

Orlando, Florida USA

Mechanical Properties of a Recycled Post-Consumer Product with Complex Construction

Andrew J. Donovan, University of Massachusetts, Lowell, MA
Mary E. Moriarty, University of Massachusetts, Lowell, MA

Abstract

Many consumer products have a complex construction with multiple types of materials. This makes it difficult to recycle the products if the materials are not easily separated. A mixed recycling study was conducted for a particular multi-material product to determine the degree of material segregation required to obtain a recycled feedstock with useful properties. Toothbrushes were selected as the product for this study. These were collected from a commercial take-back program and were separated by material. Different formulations were compounded with virgin material at varying percentages and molded into ASTM test specimens for mechanical property testing.

Introduction

Commercial take-back programs allow consumers to return used products to stores or companies in order to be reused. The toothbrush used in this study contains mostly polypropylene (PP). It has a handle and packaging cap, which are composed of recycled PP products from other take-back programs. Included in the toothbrush's construction are nylon bristles, and metal alloy staples. The package of the toothbrush contained a cellulose acetate tube, a polyethylene terephthalate (PET) film, and the occasional paper price tag. Along with these materials, an undetermined amount of contamination was present, as these toothbrushes had been used and returned to the company for recycling.

Items consisting of multiple materials pose an interesting challenge for those who want to recycle them into a blend. The various materials may or may not be compatible, which could cause processing, and property issues. Also, the level of contamination could vary, which can make reproducibility of properties more difficult. Sorting of plastics has been an easy solution for recycling. Macrosorting is the separating of materials while still in the product form. Microsorting is the separation of materials when in granule form. Using different types of sorting, a greater variety of blends can be created which can produce desirable properties. [1, 2]

This study is directed at determining whether this product with a complex material construction can be recycled to produce a material with mechanical properties similar to commercial resins.

Materials

The materials used for this study were obtained by granulating post-consumer toothbrushes. In addition, a virgin PP was used in some samples to determine if there was an enhancement of properties.

- Virgin (20 MFR) polypropylene
- Post-consumer Toothbrushes and packaging which included:
  - Polypropylene handles
  - Nylon bristles
  - Metal alloy staples (for bristle fastening)
  - Cellulose acetate package
  - PP package caps
  - PET film
  - Paper price tags
  - Assorted contaminates (toothpaste, shoe polish, etc)

Methodology

Preparation

The toothbrushes and packaging were macrosorted into numerous batches. The 'Everything' batch had all of the post-consumer materials included. The 'No Cellulose' batch was made by simply removing all cellulose packaging. The 'No Nylon' batches were created by cutting off the heads of the toothbrushes using a band saw. The heads were then discarded which removed all of the nylon and metal from the samples. The resulting handles were granulated along with cellulose acetate packaging material.

The 'Clean PP' batches were created by microsorting. All materials were granulated and the regrind was separated using a water separation method. The materials were placed in a tub of water. The solution was agitated for six minutes. After letting the mixture settle for another six minutes, the only material that floated was the polypropylene. A sieve was used to extract the polypropylene from the water. The water also cleaned the materials of their contaminates.

All batches were then granulated to approximately 0.6 cm granules using a Milacron TF68 granulator. A sample of this can be seen on the left half of Figure 8.

Continued on next page

Virgin polypropylene was mixed into batches at different weight percentages (0%, 10%, 20%, and 30%) to create 1.36 kilogram (3 pound) formulations and the resulting mix was dried at 90 degrees Celsius for seven days. PP was added instead of a compatiblizer since it is common, inexpensive, and it will not add to the immiscibility of the blends.

Processing

A Killion (32mm) single-screw extruder (L/D=24:1) was used for melt compounding. Refer to Table 1 for process temperatures. A strand die without a screen pack was used to produce a strand. A screen pack was not used because the metal staples and other contaminants would collect and clog the extruder. The water-cooled extrudate was then reduced to pellets using a Reduction Engineering Granulator (model: 604) and again dried at 90 degrees Celsius for seven days. A sample of the virgin polypropylene was extruded and pelletized as a control sample.

A Milacron-Fanuc Roboshot (s-2000i55B), 55 ton injection molding machine was used to prepare the test specimens. A family mold containing 3.2mm thick flexural and tensile bars was used. Parameters were kept constant for all formulations during processing. Table 2 shows the process parameters used in this portion of the study. Approximately 40 pairs of test specimens were collected from each formulation. Virgin PP material was also molded as a control sample.

Testing Methods

The length and width of the flexural bars were measured to determine mold shrinkage. Cavity dimensions of the mold were measured and the percent shrinkage was calculated for the direction of flow as well as perpendicular to flow.

A Shore D Durometer was used to test material hardness in accordance to ASTM D 2240. Two flexural bars from each batch were used in this study. Three measurements were taken across each flexural bar. Data were collected and comparisons between batches can be seen in Figure 4.

A Kayeness Inc Galaxy I Extrusion Plastometer was used to determine the Melt Flow Rate of the material batches following ASTM D 1238 (230 degrees Celsius, 2.16 kg). Samples for the MFR study were taken from the repelletized batches used in injection molding.

A Testing Machines, Inc. pendulum impact tester was used to determine the Izod impact properties of each formulation. Ten flexural specimens were cut in half, and then notched following Test Method A of the ASTM-D 256 standard. The cut samples were segregated into two sets for each formulation, near the gate and away from the gate. Both sets were tested. The test was conducted using a 0.138 kilogram-meter (1foot-pound) pendulum at 3.35 meter/sec (11/ft/sec).

An Instron Universal Testing Machine, model 6025, was used to determine tensile properties following a modified ASTM-D638. Blue Hill software was used to assimilate these data. Batches were treated as brittle materials and tested at 5mm/minute.

Interpretation of Data

Adult and children's toothbrushes were evaluated in the study. Adult toothbrushes averaged 14.75 grams weight. The child's version averaged 8.5 grams weight. Water separation of these two generations lead to the belief that the first generation had a filler, which made the first generation PP sink in the bath. Water separation also cleaned the blends of foreign contaminants, helped with processing and changed the material properties. In particular, the hardness study showed a constant, even amount of hardness for all of the samples.

The drying temperature was determined by finding a close overlap between all materials in the blends. Matweb databases provided information on PP, polyamides, and cellulose acetate. The exact grade and brand of the post-consumer materials is not known since it is a company secret. [3]

The toothbrushes had a variety of different colors, which created an extrudate varying in shades of gray. Virgin PP processed the easiest, while Clean PP also processed well. Any mixtures containing cellulose acetate "foamed" at the die orifice and had a very large die swell. In most cases, the metal staples and paper price tags usually worked their way to the strand surface. The flow of non-cellulose acetate materials was good and the surface was shiny. A sample of post-extruded granules can be seen on the right half of Figure 8.

Since cellulose acetate and PP are immiscible, processing the two lead to fibrous strands that fractured easily (Everything and No Nylon batches). Cellulose acetate in the blends collected at the surface of the strands, and due to its orientation, did not pelletize well. All materials were processed slowly and pulled into a thin strand to achieve better pellet samples. Some mixtures produced inconsistent strands with varying thicknesses. Dissecting these larger sections revealed paper, metal, and groups of nylon bristles.

The paper did not burn at the temperatures used to extrude and mold the samples. Nylon bristles did not melt as the extrusion process occurred at a temperature lower than its melt temperature (215- 254 degrees Celsius). [3]

Continued on page 9

Continued from page 8

After processing each batch, the extruder was purged with virgin polypropylene. The granulator was also thoroughly cleaned after processing to prevent sample cross-contamination.

Extruding samples prior to injection molding allowed for homogenous mixing and even particle size distribution. The cellulose acetate packaging, when ground, turned into flakes. Regrind flakes do not feed well into the molding machine, clogging the hopper.

Test Results

The results of the hardness study are given in Figure 1. The data shows that increasing the amount of virgin polypropylene within the samples created a harder part. The greatest hardness occurred in the No Cellulose samples. The presence of cellulose acetate softened the materials.

The results of the shrinkage study did not show any variation between the blends and their level of shrinkage. The samples had more shrinkage parallel to the flow as compared to perpendicular to the flow, which is typical of injection molded parts. None of the samples had a shrinkage value greater than 1.3%. The range of the shrinkage was approximately 0.3% for all of the blends.

The results of the impact study are given in Figure 2. There was no difference between the impact strength of the gated and non-gated samples. The collected data were averaged together to obtain a generalization of the impact resistance of the materials.

The results of the Melt Flow Rate (MFR) study are given in Figure 3. Data showed the virgin control samples having lower MFR than the mixed batches. However, all the formulations exhibited relatively good flow behavior. The PP Clean, Everything, and the No Nylon formulations had a decrease in flow as virgin polypropylene was added. No Nylon formulations have a less drastic drop than the other two samples. Flow behavior for the No Cellulose formulations however, had a different reaction to the virgin additive. As the percentage of virgin polypropylene increased, the flow increased. The data for No Cellulose-20% virgin may be erroneous, as it does not agree with the other values. This error could be due to the clogging of the extrusion plastometer die orifice by metal staples during testing.

The results of the tensile study are given in Tables 3 through 6 and Figures 4 through 7. Data showed that variation in these formulations was minimal. In most cases it is observed that as the concentrations of the virgin material are increased, the properties trended towards that of the virgin specimens.

Conclusions

The mechanical properties of different blends of materials with added virgin polypropylene were studied. The following conclusions can be drawn from these studies:

- Grinding, washing, and water separating the toothbrushes to remove contaminants and other materials can create a useful polypropylene blend.
- Cellulose acetate complicates melt processing of mixed materials. Removing this material from a product would simplify recycling methods.
- Increasing the percentage of virgin polypropylene improves some properties.
- When forming multiple materials into a blend, processing at the melt temperature of the polypropylene induced desirable properties by not allowing the other materials to melt and, possibly having them to act as filler or fiber reinforcement.

Acknowledgements

The authors would like to thank the following people: Professor Robert Malloy for his guidance throughout this study; Professor Stephen Orroth, Professor Nick Schott, and Assistant Professor Stephen Johnston for assistance with machinery and theory; David Rondeau and Charles Currie for their technical support; and James Moran for technical writing help.

References

1. L.A. Utracki, *Polymer Blends Handbook*, **2**, pp. 1140-1160 (2002).
2. C.A. Harper, *Modern Plastics Handbook*, pp. 2.19-12.21 (2000).
3. http://www.matweb.com.

Table 1: Extrusion Processing Temperatures (^{O}C)

Die	Clamp	Zone 3	Zone 2	Zone 1	Melt Temperature
230	210	190	160	140	230

Continued on page 10

Table 2: Injection Molding Processing Parameters

Temperatures (^{o}C)				
Nozzle	**Zone 3**	**Zone 2**	**Zone 1**	**Feed throat**
204	176	162	148	48

Transfer position	1.27 cm	**Cooling Time**	7 seconds
Shot Size	5.58 +.254 cm	**Sprue Break**	On
Injection Velocity	7.62 cm/sec	**Back Pressure**	1.72 MPa
Pack Pressure	27 MPa	**at 11 sec**	

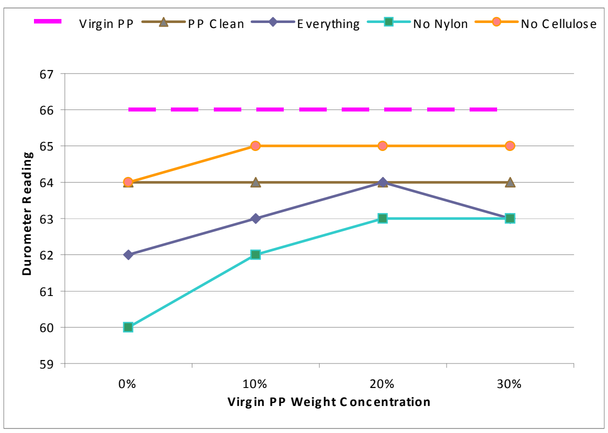


Figure 1: Results from hardness study.

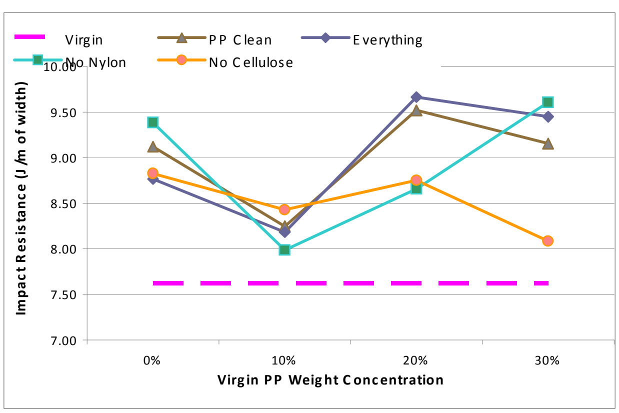


Figure 2: Results from impact study.

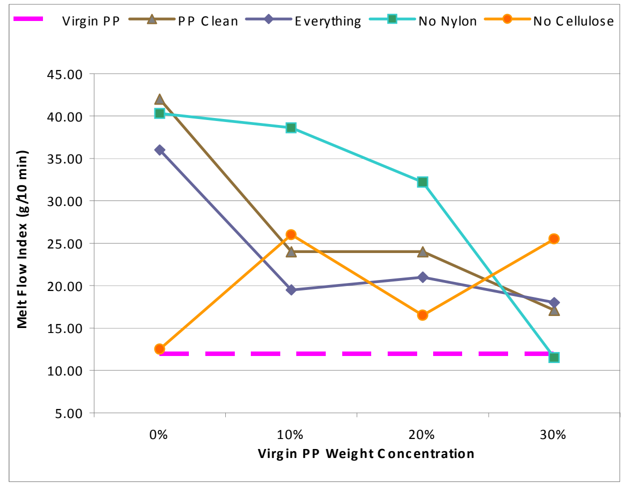


Figure 3: Results from melt flow study

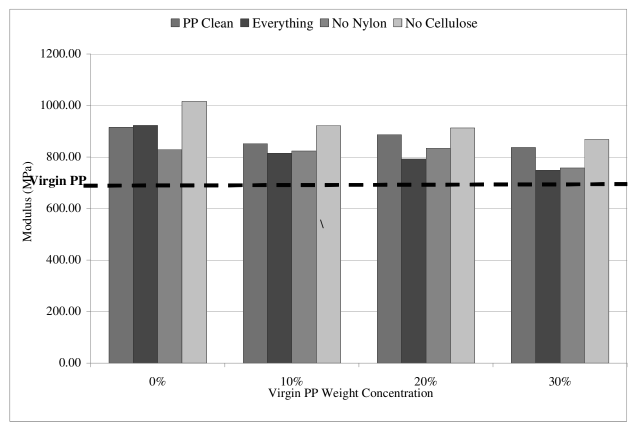


Figure 4. Mean Young's Modulus.

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Table 3- Average Values for Young's Modulus.

Formulation	Mean Young's Modulus (MPa)	Standard Deviation (MPa)	Coefficient of Variation (%)
Virgin Polypropylene	**712.85**	42.89	6.02
PP Clean 30%	**837.42**	101.54	12.13
PP Clean 20%	**886.85**	109.96	12.40
PP Clean 10%	**852.30**	141.77	16.63
PP Clean 0%	**915.81**	77.39	8.45
No Nylon 30%	**758.30**	22.73	3.00
No Nylon 20%	**834.57**	71.25	8.54
No Nylon 10%	**823.64**	94.84	11.51
No Nylon 0%	**828.86**	158.00	19.06
No Cellulose 30%	**868.23**	162.79	18.75
No Cellulose 20%	**912.80**	100.42	11.00
No Cellulose 10%	**921.48**	109.34	11.87
No Cellulose 0%	**1015.84**	98.36	9.68
Everything 30%	**748.70**	101.77	13.59
Everything 20%	**792.55**	110.14	13.90
Everything 10%	**815.38**	75.37	9.24
Everything 0%	**922.46**	113.86	12.34

Table 4- Average Values for Tensile Strain at Yield.

Formulation	Tensile Strain at Yield (%)	Standard Deviation (%)	Coefficient of Variation (%)
Virgin Polypropylene	**15.36**	0.40	2.58
PP Clean 30%	**12.84**	0.39	3.08
PP Clean 20%	**11.98**	0.36	2.99
PP Clean 10%	**11.23**	0.56	4.97
PP Clean 0%	**9.85**	0.53	5.41
No Nylon 30%	**9.81**	0.14	1.39
No Nylon 20%	**7.74**	0.38	4.97
No Nylon 10%	**6.63**	0.22	3.27
No Nylon 0%	**7.99**	0.24	2.98
No Cellulose 30%	**11.22**	0.37	3.29
No Cellulose 20%	**10.18**	0.87	8.55
No Cellulose 10%	**9.76**	0.48	4.91
No Cellulose 0%	**9.78**	0.56	5.70
Everything 30%	**8.39**	0.38	4.53
Everything 20%	**7.23**	0.22	3.11
Everything 10%	**7.08**	0.22	3.05
Everything 0%	**5.30**	0.29	5.39

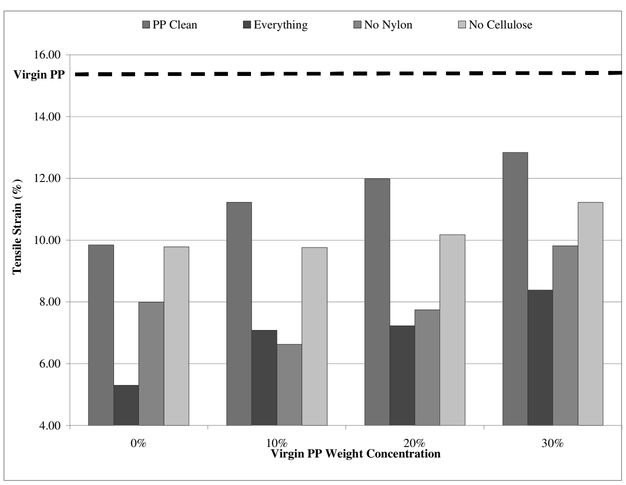

Figure 5: Tensile strain at yield.

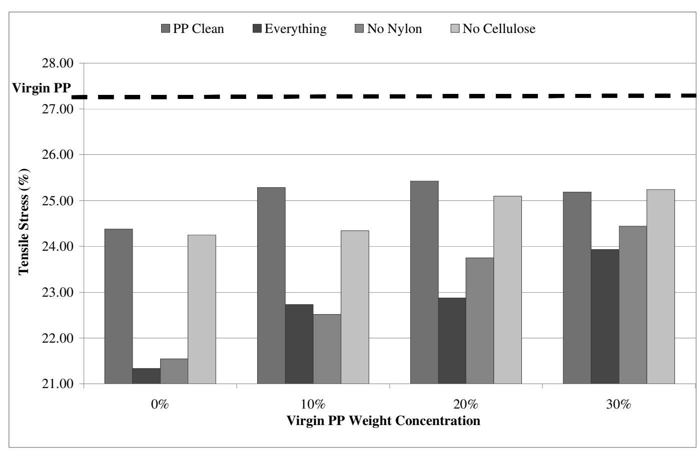

Figure 6: Tensile stress at yield.

Continued on page 12

Table 5- Average Values for Tensile Stress at Yield.

Formulation	Tensile Stress at Yield (%)	Standard Deviation (%)	Coefficient of Variation (%)
Virgin Polypropylene	**27.27**	0.52	1.92
PP Clean 30%	**25.18**	0.64	2.55
PP Clean 20%	**25.43**	0.92	3.60
PP Clean 10%	**25.28**	0.62	2.44
PP Clean 0%	**24.38**	0.73	3.00
No Nylon 30%	**24.44**	0.28	1.14
No Nylon 20%	**23.75**	0.60	2.51
No Nylon 10%	**22.52**	0.84	3.75
No Nylon 0%	**21.54**	0.76	3.52
No Cellulose 30%	**25.24**	0.32	1.28
No Cellulose 20%	**25.10**	0.50	1.99
No Cellulose 10%	**24.35**	0.90	3.68
No Cellulose 0%	**24.26**	1.00	4.12
Everything 30%	**23.93**	1.28	5.35
Everything 20%	**22.88**	0.90	3.94
Everything 10%	**22.73**	0.80	3.52
Everything 0%	**21.34**	0.58	2.74

Table 6- Average Values for Tensile Strain at Break

Formulation	Tensile Strain at Break (%)	Standard Deviation (%)	Coefficient of Variation (%)
Virgin Polypropylene	**104.46**	3.80	3.64
PP Clean 30%	**92.32**	64.22	69.56
PP Clean 20%	**77.71**	31.37	40.37
PP Clean 10%	**49.66**	17.98	36.21
PP Clean 0%	**16.09**	2.74	17.05
No Nylon 30%	**10.37**	0.30	2.85
No Nylon 20%	**8.10**	0.63	7.84
No Nylon 10%	**7.01**	0.43	6.16
No Nylon 0%	**8.14**	0.32	3.89
No Cellulose 30%	**20.72**	3.13	15.13
No Cellulose 20%	**14.82**	3.17	21.40
No Cellulose 10%	**13.99**	0.55	3.92
No Cellulose 0%	**13.88**	1.01	7.30
Everything 30%	**8.92**	0.56	6.32
Everything 20%	**7.73**	0.09	1.12
Everything 10%	**7.58**	0.59	7.81
Everything 0%	**5.67**	0.67	11.84

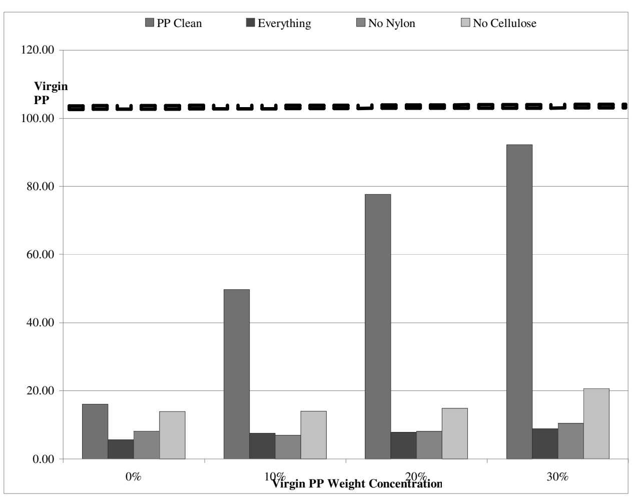

Figure 7: Tensile strain at break.

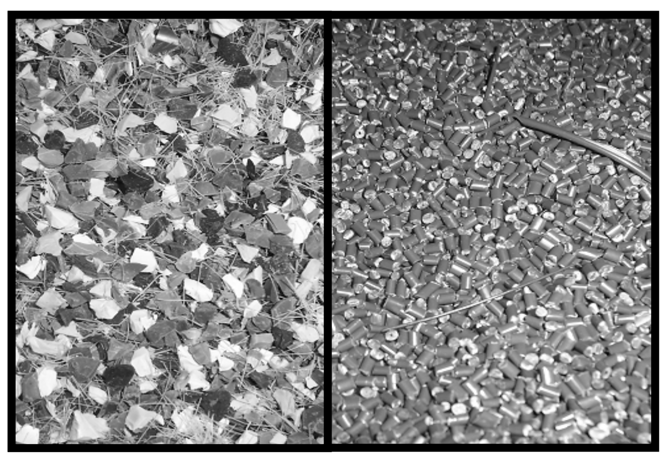

Figure 8: The regrind before (left) and after extrusion and pelletizing (right).

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