

News



The Society of Plastics Engineers

ENGINEERING PROPERTIES
& STRUCTURE DIVISION

October 2013

A Tribute to Don Witenhafer September 20, 2013



Top to Bottom & left to right Photos: Don teaching at SPE ANTECs, Past EPSDIV Chairpersons, Attending an EPSDIV technical talk, EPSDIV Board Meeting, EPSDIV Division Meeting & Reception, EPSDIV TPC Meeting.



Donald Edward Witenhafer passed away Friday, September 20, 2013. He will be greatly missed!

Don earned his Ph.D in Polymer Science from Case Western Reserve University in 1968 and joined B.F. Goodrich where he worked in PVC for over twenty years. After spending five years with SC Johnson Wax as manager of polymer research, he went into consulting mostly in PVC and had been doing so for over fifteen years.

Dr. Donald E. Witenhafer, most recently a member of SPE-South Texas Section and a long standing member of SPE-EPSDIV, was 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

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Greetings Fellow EPSDIV Members!

I am honored to serve you in a dual capacity this year as chairperson and on-going newsletter editor. Thank you for being loyal members of our Division. Our focus this year is to increase your participation in our division, which is vital to our existence and growth. Throughout this newsletter you will find many ways to get involved and make an impact.

Our Board of Directors had its annual face-to-face board meeting at ANTEC 2013 in Cincinnati, Ohio. This meeting provided the opportunity to welcome newly elected and returning board members for a three year term, and to say thank you for jobs well done by our out-going chairperson, (Josh) Shing-Chung Wong, and ANTEC-2013 TPCs, Milan Ivosevic and Theresa Hermel-Davidock.



Thank you Josh

Get Involved!



Thank you Milan & Theresa

The Board welcomes our new TPCs for ANTEC-2014, Mridula (Babli) Kapur and Sharon Wu. Their report, provided on page three of this newsletter, outlines yet another exciting program in store for our members this year. The TPC committee needs your help, so please consider getting involved by volunteering to be a moderator, paper reviewer or by suggesting key-note speakers for ANTEC-2014.

The Board is grateful for the many *corporate sponsors* that supported our technical program during ANTEC-2013. They are listed on page 6 of this newsletter. Our division continues to present strong technical programs at ANTEC that reinforce increased membership and professional growth. We encourage everyone to actively recruit more members for our division and please plan to personally attend our upcoming annual division meeting. It will be held on either Monday or Tuesday evening, during ANTEC-2014. During this meeting, I will be pleased to recognize the recipients of our Best Technical Paper Award, Sahil Gupta and R. A. Weiss, of the University of Akron, and T. C. M. Chung, of the Pennsylvania State University. Their paper entitled "**The Effect**

Of Hydroxyl-Functionalization on the Structure and Properties of Polypropylene" is reprinted at the end of this newsletter.

We are all saddened by the passing of our dear friend and colleague, Don Witenhafer. He served faithfully for many years as an EPSDIV board member, Councilor and past chairperson.

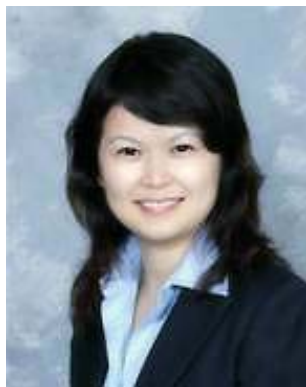
We will sincerely miss Don's cheerful presence and distinguished leadership among us, and we will always cherish the memories of his energetic commitment and manifold contributions to EPSDIV, the scientific community, and our society at large. Page one of this newsletter is dedicated to the memory of Don.

John S. Trent

 ANTEC® 2014



April 28th – 30th
Rio All Suites Hotel & Casino
Las Vegas, Nevada



TPC Co-Chairpersons

Mridula (Babli) Kapur and Sharon Wu

The TPC members (Daniel Liu, Jason Lyons, Sharon Wu, and Babli Kapur) met on Sept 12th to prepare for ANTEC 2014, April 28th - 30th, in Las Vegas, Nevada. Topics discussed were: new focus areas; need for quality papers; need to secure key note speakers aligned with the identified focus areas; and to secure moderators and commitment from EPSDIV members to review papers, early in the process.

A Way To Get Involved!

Please Contact Babli (979-238-5684) or Sharon (979-238-2604) to volunteer as Moderator, Suggest Key-note Speakers or Review Papers

We really need your help!

ANTEC 2014 EPSDIV Focus Topics

In addition to the EPSDIV core strength areas listed below, several new/expanded focus areas were identified based on academia research activities, industry trends and the number of technical papers submitted last year.

Core Focus Areas & Strengths

- Structure – Processing – Property Relationships (19)
- Testing & Characterization (Mechanical/ Chemical / Thermal) (5)
- New Polyolefins & Polymers: Copolymers, Blends, Composites (?)
- Polymer Nanotechnology & Nano composites (5)
- Green technologies and sustainable source polymers (continue or incorporate in Natural materials, recycled polymers (?))
- Polymer Modeling (6)

Proposed New & Expanded Focus Areas

- Light-weighting Initiatives
- Smart Materials (ANTEC 2013 New Technology Forum)
- Novel Morphologies and Structures (6)
- Natural Materials
- Health (ANTEC 2013 New Technology Forum)
- Structure Properties of Recycled Polymers
- Nonwovens

New Technology Forum

The new technology forums (Smart Materials and Polymer Applications in Health) were well received at ANTEC 2013. The proposal is to hold collaborative new technology forums with other sections.

- Smart Polymers Forum: **Contact Prof. Sadhan Jana @ 330-972-8293**
- Polymers in Microelectronics: **Contact Sharon Wu @ 979-238-2604**
- For new technology forum ideas: Contact **Babli Kapur @ 979-238-5684**

Key Note Speakers

The following key note speakers have confirmed ANTEC 2014 attendance:

- Polymer structure and properties - **Dr. Hsinjin (Edwin) Yang** from Underwriters Laboratories
- **Arthur Bobovitch**, VP R&D and Quality, Syfan SAAD Ltd, Israel
- **Hari Reddy**, VP R&D Bemis

Speakers sought to ensure balanced academia and industry representation for the following areas:

- Light weighting initiatives – speaker from Kraft Foods, ConAgra or Frito-Lay – **Contact Babli Kapur**
- Novel morphologies and structures – **Contact Jason Lyons @ 610-878-6604**
- Speakers on polymer modeling & nanotechnology from academia – **Contact Sharon Wu**
- Polymer structure and dynamics – **Contact Babli Kapur**
- Nanotechnology – **Contact Babli Kapur**

Proposals to obtain key note speakers from contacts in other sections were also discussed specifically as follows:

- Smart Materials
- Polymer Testing & Characterization – Polymer Additives Division
- Polymers in Energy – Advanced Energy Division

Suggested Honor Symposia

The proposal is to hold joint Honor Symposia with other Divisions. Candidates proposed for the Honor Symposia are:

- Jim DeRudder, Principal Scientist, Sabic Innovative Plastics, polymer additives background
- Don Baird, Co-Director Center for Composite Materials and Structures, Virginia Tech
- Don Witenhafer, In Memory

Financial Report

from July 1, 2012 to June 30, 2013



BALANCE as of July 1, 2012 (cash, checking, savings, investments)	\$ 33964.35
INCOME	ACTUAL
Award Sponsorships	\$ 1000.00
SPE Rebate	2484.70
ANTEC Sponsorships	2488.70
TOTAL INCOME	\$ 5973.40
EXPENSES	
BOD Meetings	951.47
Newsletter Production	1584.00
Awards	646.00
Councilor Travel	1378.81
Misc (Bank Fees)	36.00
ANTEC	4682.24
TOTAL EXPENSES	\$ 9278.52
CASH FLOW	\$ (3305.11)
ENDING BALANCE as of June 30, 2013	\$ 30659.24

Submitted by Emmett Crawford, EPSPDIV Treasurer 2013-2014

Tribute Continued from Page 1

vinyl chloride monomer used in making PVC was a human carcinogen and was dangerous when humans were exposed to it. Environmental groups urged the immediate ban of PVC.

At the time of the discovery, Don was a polymer scientist working for the B. F. Goodrich Company of Akron, OH, 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, unreacted, 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. Workers no

longer needed to enter the vessels to scrape polymer buildup off the walls, limiting their exposure to the dangerous monomer. He also invented a steam pressure process to apply these coatings to the reactor walls. Worldwide, almost all PVC plants today use a water based, absorbable clean reactor coating similar to that invented by Don, 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. For these many contributions, Dr. Witenhafer was installed into the Plastics Hall of Fame at the NPE 2009 meeting in Chicago on June 22nd.

A Tribute to a Leader, a Mentor, but most of all a Friend



In the journey of life, there are literally thousands of people who we meet that have an influence on whom we become. These encounters can be brief, perhaps a one-time conversation on a subway ride home. They can also last for years, maybe over those cups of coffee at the beginning of each work day. However, the ones that matter the most are the encounters with people who have cared enough to challenge us, teach us, and invest in us during our journey. This past week, I was saddened to learn that Don Witenhafer, one who had invested in me, had passed away.

Don was recognized by the International Plastics Industry and our Society for his significant scientific and business contributions. I can't begin to describe all of them here. As remarkable as these achievements were, they weren't what I will remember the most about him. Through his life journey, Don showed me what mattered to him – it was the people he met – the people that he could invest in.

I first met Don at an ANTEC meeting in the 1980's. I had the fortune of sitting in front of him during a presentation. We had never met each other. He tapped me on the shoulder and said "of all the people in this room, you were the one that I did not want to sit in front of me." (For those of you who do not know me, at my height I can block someone's view sitting down). That was Don's way of opening a conversation with me, a complete stranger. After the talk, he continued to clarify height "etiquette" on the way out of the room. "If we end up in the same session again I want you to ask any question you have for the speaker AFTER I do. If you go first I won't be able to reach the microphone. If I go first you can either bend way over or sit down to ask your question." He said all of this with his famous grin – and it made me grin too. Don had taken a step, created an opening, to acknowledge me. In a sea of strangers, it made me feel like someone worthy of notice. We each grabbed water, and headed to a nearby table to continue our discussion. Don stood; I sat (upon his recommendation)! We spent the next 30 to 40 minutes finding out about one another. Little did I know he was already scheming to redirect my journey.

Over the next days of that ANTEC, and the next years of ANTEC meetings, Don introduced me to, and got me actively involved in the EPSDIV Board, TPC, SPE Committees, and now Council.

In each area, Don walked along side me (sometimes he made me sit), and made sure that I came to know the people and the procedures to be effective in each role. He would always introduce me with humorous descriptors or glowing accolades (many of which he made up) that would make all of us smile, and feel pretty optimistic about the road ahead. He had a passion for connecting people and their lives. He had a gift for finding an opening to welcome you.

In SPE, Don was a leader. In SPE, Don was my mentor. In life, Don was my friend. I know that many of you are saying the same thing for the same reasons today. In the journey of life, the encounters that we remember are with people who have cared enough to challenge us, teach us, and invest in us —to make our journey more than it ever would have been without their influence. Thank you, Don, for all of the encounters. We will all greatly miss you.



- Brian Landes



**Thank you to our ANTEC-2013 EPSDIV Technical
Program Sponsors!!!**

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Call for ANTEC 2014 Papers

April 28-30, 2014

**Convention Center at the
Rio All-Suites Hotel
Las Vegas, Nevada USA**

Society of Plastics Engineers is pleased to announce our Call for Papers for ANTEC® 2014! **SPE is soliciting papers in the following areas:**

Advanced Energy
Alloys & Blends
Applied Rheology
Automotive
Bioplastics
Blow Molding
Color & Appearance
Composites
Decorating & Assembly
Electrical and Electronic
Engineering Properties & Structure
Extrusion
Failure Analysis & Prevention
Flexible Packaging
Injection Molding
Joining of Plastics & Composites
Marketing & Management
Medical Plastics

Mold Making & Mold Design
Nano/Micro Molding
Non-Halogen Flame Retardants
Plastic Pipe & Fittings
Plastics Educators
Plastics Environmental
Plastics in Building & Construction
Polymer Analysis
Polymer Modifiers & Additives
Process Monitoring & Control
Product Design & Development
Radiation Processing of Polymers
Rotational Molding
Thermoforming
Thermoplastic Elastomers
Thermoplastic Materials and Foams
Thermoset
Vinyl Plastics

Paper Deadline: October 25, 2013 – 5 p.m. Eastern

Authors must submit a Paper (saved as .pdf) by the Paper Deadline in ANTEC format. Further information may be found at www.antec.ws.

Papers will be reviewed by the Technical Program Committee and Authors notified of status or required revisions by November 22, 2013.

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THE EFFECT OF HYDROXYL-FUNCTIONALIZATION ON THE STRUCTURE AND PROPERTIES OF POLYPROPYLENE

Sahil Gupta and R. A. Weiss, The University of Akron, OH 44325
T. C. M. Chung, The Pennsylvania State University, University Park, PA 16802

Abstract

Hydroxyl-modified polypropylenes (PPOH) with side chains containing OH groups were synthesized by the copolymerization of propylene with undecenyl-oxytrimethylsilane monomer. Copolymers with OH concentration ranging from 1.3 to 3.9 mol% were produced and their properties compared with unmodified polypropylene. The presence of intermolecular H-bonding between the OH groups affected the base polypropylene structure as well as its thermal and rheological properties. As predicted by Flory's theory of melting point depression in copolymers, the melting point reduced with increasing [OH]. While the crystal structure remained unaffected, the crystal size reduced by approx. 15%. Crystallinity for PPOH polymers was also reduced by as much as 40% because of the hindrance to the ordered packing of backbone chains into the lamellar structure. On the other hand, the rheological properties such as the melt strength and the elasticity increased for the PPOH polymers. PPOH with only 3.9 mol% OH groups displayed a gel-like rheological behavior suggesting the formation of a weak elastic network in the melt.

Introduction

Yuan et al. [1] recently reported the synthesis of hydroxy isotactic polypropylene (PPOH) which exhibited improved dielectric properties compared to the current state-of-the-art polymeric dielectric – biaxially oriented polypropylene (BOPP). The energy density of those materials was as much as 2-3 times that of BOPP. This paper describes the effect of incorporation of OH groups on the structure and thermal and rheological properties of polypropylene.

Polymer Synthesis and Characterization

5 different polymers, shown in Table 1, were used in this study. The synthesis and structure of these polymers is shown in Fig. 1, and a detailed synthesis procedure is described elsewhere [1]. The PPOH random block copolymers were prepared by the heterogeneous Ziegler-Natta (Z-N) polymerization of propylene with the undecenyl-oxytrimethylsilane comonomer. An intermediate silane was produced that was further hydrolyzed under acidic conditions to the corresponding PPOH copolymer. These are designated as PPOH-c,

where c is the concentration (in mol%) of the comonomer unit or the OH groups in the polymer chain.

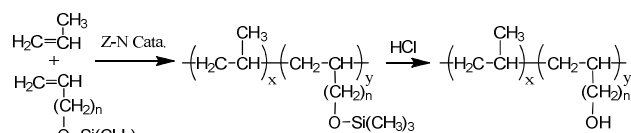


Figure 1. Heterogeneous Z-N synthesis of PPOH (n=10).

Table 1. Molecular characteristics of PP and PPOH polymers.

Polymer	[OH] ¹ mol%	M _n ² kDa	M _w ² kDa	M _z ² kDa	PDI	M _v ³ kDa
PP	0	38	385	1479	10.2	–
PPOH-1.3	1.3	16	243	1405	14.8	–
PPOH-1.4	1.4	27	488	2235	17.9	–
PPOH-1.7	1.7	–	–	–	–	388
PPOH-3.9	3.9	–	–	–	–	301

¹ from ¹H-NMR spectra

² from HTGPC with PS standards; PPOH-1.7, PPOH-3.9 could not be dissolved

³ using the Mark-Houwink-Sakurada equation: $[\eta] = KM^a$, $[\eta]$ is measured in Decalin dilute solution at 135°C with a Cannon-Ubbelohde viscometer

The specimens were compression molded at 200°C, quenched to room temperature at ~40°C/min and then annealed under vacuum at 80°C for 24 hrs for characterization purpose. Fourier transform infrared spectroscopy (FTIR) was performed to check for the existence of H-bonding between OH groups. Thermal characterization was carried out by differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA) and thermogravimetric analysis (TGA). The crystal structure was studied with wide angle X-ray diffraction (WAXD) and small angle X-ray scattering (SAXS). Rheological characterization was done using small-amplitude oscillatory shear (SAOS) measurements with a TA Instruments ARES G-2 rheometer.

Results and Discussion

Existence of H-bonding

FTIR absorption spectrum (Fig. 2) from 4500-3000 cm⁻¹ shows 2 spectral peaks corresponding to O-H

stretching. The first peak at 3637 cm^{-1} with a low intensity corresponds to the stretching vibration of OH group in non H-bonding systems, while the second peak at 3332 cm^{-1} corresponds to the stretching vibration of OH group in the H-bonding systems [2,3]. The second peak is characterized by an increase in intensity and a much wider spectrum compared to the first peak. Both these peaks are missing in PP. This provides a proof that H-bonding exists between the polar OH groups in PPOH, and only a small percentage of the OH groups are actually free from the H-bonding effect at any given time. The H-bonding strength also seems to increase with [OH], based on the peak intensity.

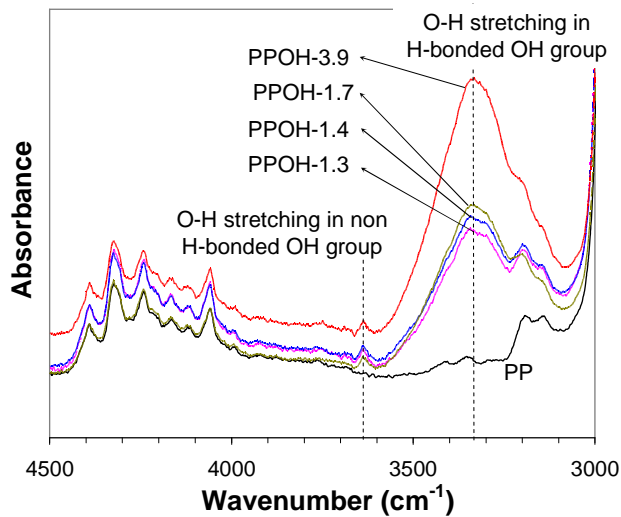


Figure 2. FTIR spectra of PP and PPOH polymers. O–H stretching vibration peak at 3332 cm^{-1} confirms the presence of H-bonding in PPOH. A much smaller intensity peak at 3637 cm^{-1} indicates that majority of the OH groups are involved in H-bonding.

Thermal Characterization

The thermal properties of all polymers are listed in Table 2. The degradation temperature (T_{deg}), corresponding to a 1% loss in initial weight, is above 300°C for both PP and PPOH polymers. The incorporation of the comonomer or the OH group does not seem to influence the thermal stability of the PP. On the other hand, the melting point (T_m) decreases with the incorporation of the comonomer from 163°C for PP to 157°C for PPOH-3.9, and consistent with the predictions based on Flory's theory of the melting point depression of copolymers [4]. The reduction in melting point is due to the reduction in crystal thickness (l_c), as observed with SAXS, caused by the incorporation of comonomer in PP. The percent crystallinity (ϕ_m) calculated from DSC reduces from 50% for PP to as low as 35% for PPOH-1.7 i.e. a reduction of approximately 40%. The sharp decrease in ϕ_m of PPOH copolymers compared to PP homopolymer

Table 2. Thermal characteristics of PP and PPOH polymers.

Polymer	T_{deg} °C	T_m °C	T_g °C	T_{α^*} °C	ϕ_m (%)	
					DSC ^a	DSC ^b
PP	343	163	2.4	98	50	49
PPOH-1.3	324	158	0.7	68	38	35
PPOH-1.4	352	157	0.5	67	37	34
PPOH-1.7	324	157	2.7	65	35	32
PPOH-3.9	325	157	2.7	65	37	34

^a from 1st heating in DSC @ $10^\circ\text{C}/\text{min}$ on annealed samples

^b from 2nd heating in DSC @ $10^\circ\text{C}/\text{min}$ after 1st cooling from the melt at the same rate

is due to the inability of the crystal structure to accommodate the side chain substituent for the hydroxyl functionality. The presence of side chains disrupt and hinder the regular and tight packing of the polymer backbone chain into the lamellar structure. Comparing the crystallinity obtained from the 1st and the 2nd heating runs from the DSC, it is observed that the thermal annealing at 80°C does not have much effect on the crystallinity of PP homopolymers but increases the crystallinity in all the PPOH copolymers by approximately 3%. This indicates that the presence of side-chain results in a less perfect crystal structure upon quenching from the melt and, thus, a greater scope of crystal perfection by molecular rearrangement upon thermal annealing.

The glass-transition temperature (T_g) measured using DMA initially reduced from PP to PPOH polymers with low [OH] and then increased for the last two PPOH polymers with higher [OH], which can be explained on the basis of a competition between van der Waals (VDW) interactions and the H-bonding interactions, both of which raise the T_g . VDW interaction strength reduces with [OH] due to the presence of side chains in PPOH polymers that increases the free volume, whereas the H-bonding strength increases with [OH]. In addition to T_g , another thermal transition, termed as the α^* -transition, is observed for all the polymers. This transition is especially observed in semi-crystalline polymers between the T_g and T_m , and is associated with the slippage of crystal planes over one another in the direction of deformation [5]. It is observed that T_{α^*} shows a trend similar to percent crystallinity (ϕ_m) i.e. it lowers from PP to PPOH copolymers. As discussed before, not only ϕ_m but also the crystal size (l_c) reduces with an increase in [OH]. The reduction in both ϕ_m and l_c might correspond to a lower thermal energy requirement for producing crystal-crystal slip at a given frequency of deformation, and hence explain the observed trend.

Structural Characterization

WAXD data (after background correction) is shown in Fig. 3 for all the polymers. The data indicates the presence of α -monoclinic crystal structure [6] in both PP and PPOH copolymers i.e. the incorporation of OH

functionality has no effect on the PP crystal structure. The lattice spacing (d_{hkl}) calculated using the Bragg's law ($n\lambda = 2d_{hkl}\sin\theta$), where λ is the wavelength for $CuK\alpha$ X-ray source (1.54 Å) and 2θ is the Bragg's angle, does not change with the incorporation of OH groups for any of the lattice planes indicating that the average size of the unit cell is unaffected by the OH groups. That observation supports the conclusion that the alkyl-OH segments are contained in the amorphous phase and not incorporated into the crystalline phase. Calculations of the crystallinity (ϕ_m) of the polymers based on analysis of the area of the crystal and the amorphous peaks were consistent with the DSC results in Table 2.

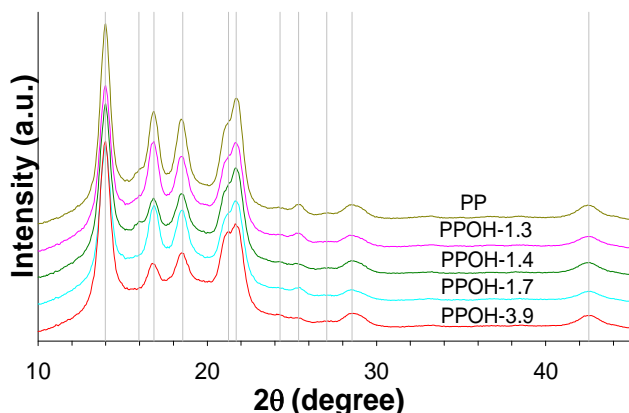


Figure 3. WAXD data on PP and PPOH polymers. The peaks are shifted vertically for clarity.

The SAXS patterns, shown in Fig. 4, reveal a well-defined interference peak because of a quasi-periodic arrangement of PP crystalline domains. For PP, a 2nd peak at a higher scattering vector with a lower intensity is also observed, which could be related to the second order reflection. The ratio of the Bragg's angles of the second and first maxima ($q_1 = 0.43 \text{ nm}^{-1}$, $q_2 = 0.84 \text{ nm}^{-1}$, $\theta_1/\theta_2 \sim 1.95$) deviates only slightly from the ideal value of 2. The absence of a higher diffraction peak for the PPOH copolymers indicates a much lower order of lamellar periodicity compared to PP. The thickness of the crystallite lamellae, i.e., the long-spacing of the PP crystals (L_p) obtained using $L_p = 2\pi/q_{peak}$, where q_{peak} is the scattering wave vector where the intensity peak is observed, decreases with increasing [OH] from 14.1 nm for PP to 12.1 nm for PPOH containing 3.9 mol% OH.

Rheological Characterization

Isothermal SAOS measurements were conducted between (165-280)°C for all the polymers. Fig. 5 shows the master curve for the storage modulus (G') and the loss modulus (G'') at 200°C which were constructed using the principle of time-temperature superposition (TTS). The fact that TTS was followed implies that either these

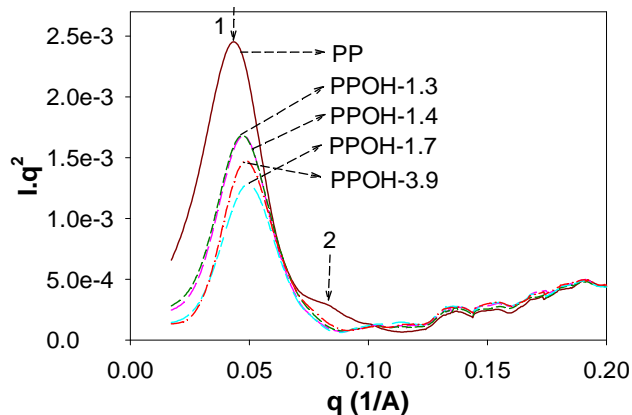


Figure 4. SAXS pattern for PP and PPOH polymers. The intensity data was smoothed and corrected for the parasitic scattering, Lorentz effect and the geometric effect.

measurements did not pick up a separate relaxation contribution from the H-bonded OH groups, or the relaxation times for the H-bonds and the disentanglement motions of the long chains scaled with temperature exactly the same way (which seems more unlikely). It is also observed that the terminal regime corresponding to a Newtonian-like behavior of the polymer chains, where the slopes of G' and G'' vs ω correspond to 1 and 2 respectively, is not reached in the experimental temperature and frequency range for any of the polymers. For PP the slope of G'' vs ω is close to 1, but that of G' vs ω is far off from 2. The terminal slopes are even higher for the PPOH polymers and increase with an increase in [OH] indicating further deviation from the Newtonian behavior. This is a consequence of H-bonding in PPOH copolymers along with contributions from a high PDI.

The moduli results indicate that the melt viscosity and elasticity of the polymers increase with increasing [OH]. For e.g., M_w is higher for PP than for PPOH-1.3 (Table 1). This implies that both G'' and G' should be higher for PP at any given frequency. However, the viscosity of PPOH-1.3 estimated at $\omega = 0.1 \text{ s}^{-1}$ (dynamic viscosity, $\eta' = G''/\omega = 6.74 \times 10^3 \text{ Pa}\cdot\text{s}$) is almost twice than that for PP ($\eta' = 3.5 \times 10^3 \text{ Pa}\cdot\text{s}$). G' taken at the same frequency is again two times higher for PPOH-1.3 than PP. Both the results are a consequence of H-bonding interactions between the OH groups, which act as temporary physical cross-links and suppress the viscous flow.

The SAOS data for PPOH-3.9, shown in Fig. 6, indicates that $G' > G''$ over the entire frequency range studied, which indicates elastic solid behavior. It appears that the H-bonding in that polymer is sufficient to provide a weak gel-like network and viscous flow does not occur. These results are surprising in that one would not expect a

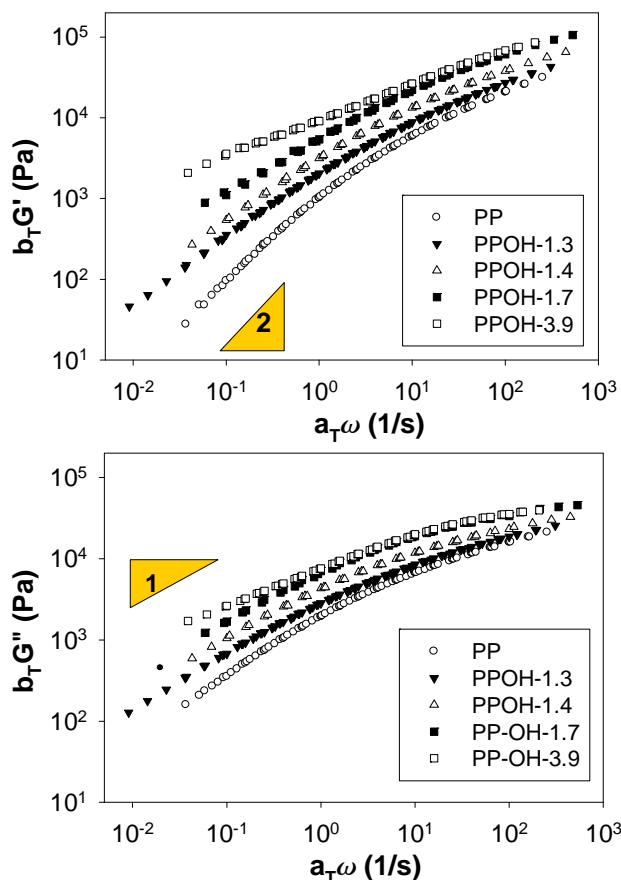


Figure 5. Master curves for the storage modulus (G') and loss modulus (G'') at 200°C for PP and PPOH polymers.

H-bond to persist that strongly at such high temperatures. However, given the incompatibility of polar groups with the hydrocarbon matrix, it may be that the unexpected persistence of the H-bond at 200°C is a consequence of the other result, i.e., dispersion of individual OH groups in the PP continuous phase is more unfavorable.

Conclusions

The incorporation of the hydroxyl-functionalized side chains by copolymerization of affects the base polypropylene structural, thermal and rheological properties. The presence of up to 3.9 mol% OH groups does not change the α -monoclinic crystal structure of the polypropylene, although the average long-spacing in the lamellar structure reduces with an increase in the concentration of OH groups. The reduction of lamella thickness, in turn, results in a decrease in the melting point. Furthermore, the disruption of the ordered packing of PP backbone chain into a lamellar structure by the side-chains reduces the crystallinity by as much as 40%. An interplay between the van der Waals and the H-bonding interaction forces result in an initial decrease followed by an increase in the glass-transition temperature. The H-

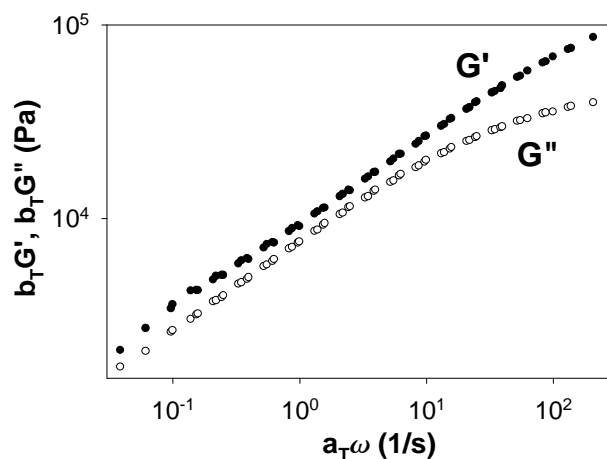


Figure 6. Master curve for the storage modulus (G') and loss modulus (G'') at 200°C for PPOH-3.9.

bonding seems to persist even at a higher temperature of 200°C and enhances the rheological properties of the polymer. The presence of H-bonding increases the melt elasticity as well as the melt strength. For a higher OH concentration of 3.9 mol% the polymer displays a gel-like behavior indicating that the H-bonding interactions results in a weak elastic-like network in the melt state.

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