RHEOLOGICAL PROPERTIES OF RECYCLED POLYCARBONATE AND ABS MELTS

Ruifeng Liang and Rakesh K. Gupta

Department of Chemical Engineering

West Virginia University

Proc. XIII Int. Congress on Rheology (August 20-25, 2000, Cambridge, UK), Vol.1, pp.216-218

XIII ICR, Cambridge, UK, August 20-25 2000

PLASTICS RECYCLING

- Beverage bottles & milk jugs relatively easy to recycle
- Post-consumer plastics are commingled. Mixed plastics are difficult to use
  - Poor mechanical properties
  - Batch-to-batch composition variations
  - Problems of labels, foam, screws and inserts
- Separation of plastics is critical but costly
- Large collection & transportation costs

POLYMERS FOR ELECTONIC APPLICATIONS

- 150 million pounds of polymer used each year for computer & printer housings etc.
  - More than 50% are PC, ABS, PC/ABS
- Plastics used are relatively expensive
- Products are discarded relatively quickly
- Landfilled as hazardous waste

ISSUES AND APPROACHES

- Numerous types of plastics and presence of contaminants.
  - Negligible resale value
- Plastics separation by chemical type is essential
  - Needed purity level?
- Variations in mw, mwd and chain branching
  - Variations in viscosity & mechanical properties

OBJECTIVE

- To re-use recycled polymers in their original applications via blending with virgin resins
- To increase the recycled content to as much as 50% in any compounded product
- To achieve a minimum of batch-to-batch variation in properties

RHEOLOGICAL CHARACTERIZATION

- Rheometric RMS 800
  - Parallel plates ϕ 25mm, gap 1mm
  - Temperature 250C for PC; 200C for ABS
  - Dynamic modulus (G', G") & complex Viscosity η
  - Shear viscosity η & relaxation modulus G(t)
- Molecular weight & mwd calculation
  - Relaxation spectrum from linear VE data
  - Using Rheometric Scientific software

CHARACTERISTICS OF RECYCLED POLYMERS TESTED

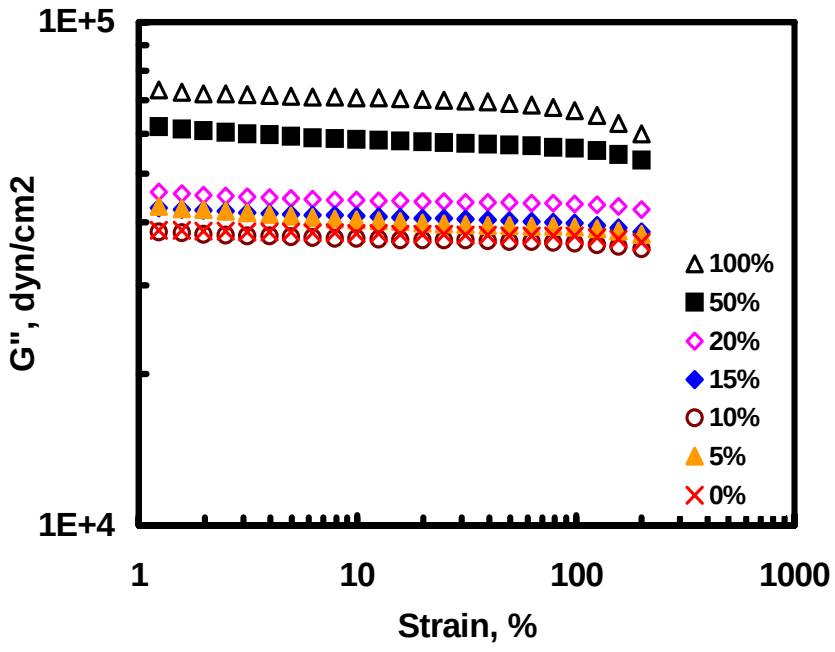
DESIGNATION	PURITY LEVEL	CONTAMINANTS
Recycled PC I R-PC	>99%	No appreciable contamination
Recycled PC II R-528	99%	HIPS 0.016%, PC/ABS 0.03% PMMA 0.05%, PE 0.07%
Recycled PC III R-630	98%	HIPS 0.29%, PC/ABS 0.11%, PMMA 0.25%, PE 0.07%, ABS 0.6%, POM 0.16%
Recycled ABS I R-ABS	99.9%	No appreciable contamination
Recycled ABS II R-594	96%	HIPS 2.4% PPO + Nylon 1.3%
Recycled ABS III R-612	88%	ABS-FR 9.8%, HIPS 1.4% PC/ABS 0.2%
Virgin PC V-PC		(Lexan 101, GE Plastics)
Virgin ABS V-ABS		(Cycolac GPM 5500, GE Plastics)

SAMPLE PREPARATION

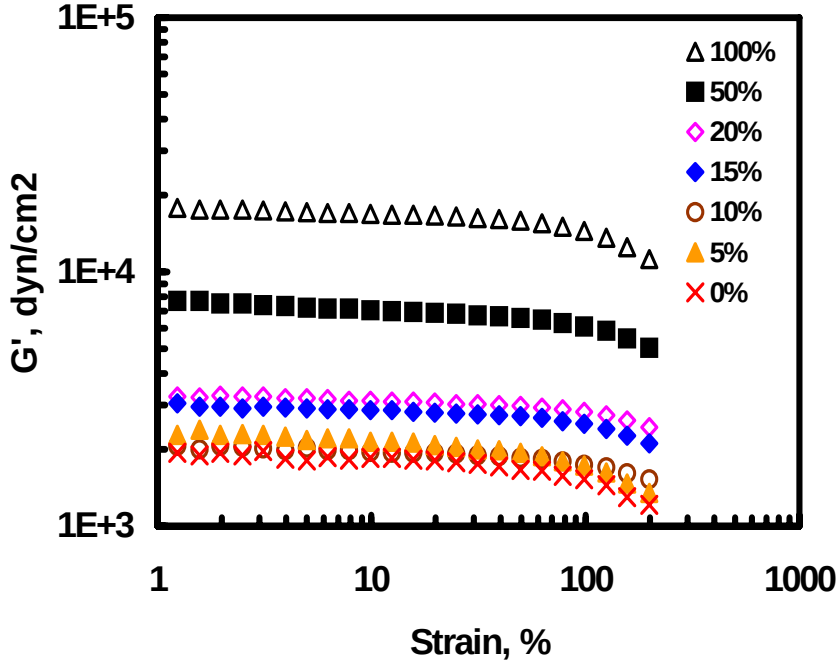
- **Recycled/virgin resin blending ratio**
  - 0, 5, 10, 15, 20, 50, 100 wt% of recycled content for R-PC & R-ABS
  - 0, 15, 100 wt% of recycled content for other purity levels
- **Drying in a vacuum oven at 120C for PC; 90C for ABS**
- **Brabender twin screw extruder**
  - Temp. settings
    - 220C, 265C, 315C, 300C for PC blends
    - 160C, 175C, 190C, 195C for ABS blends
  - Screw speed 30rpm for PC and 20rpm for ABS
- **Pelletizing extrudate into pieces, cooling in water & drying in vacuum oven**
- **Using a heated press to make sheets of thickness 1mm at 200C (PC) /180C (ABS) for testing**

DETERMINATION OF LINEAR VISCOELASTIC STRAIN

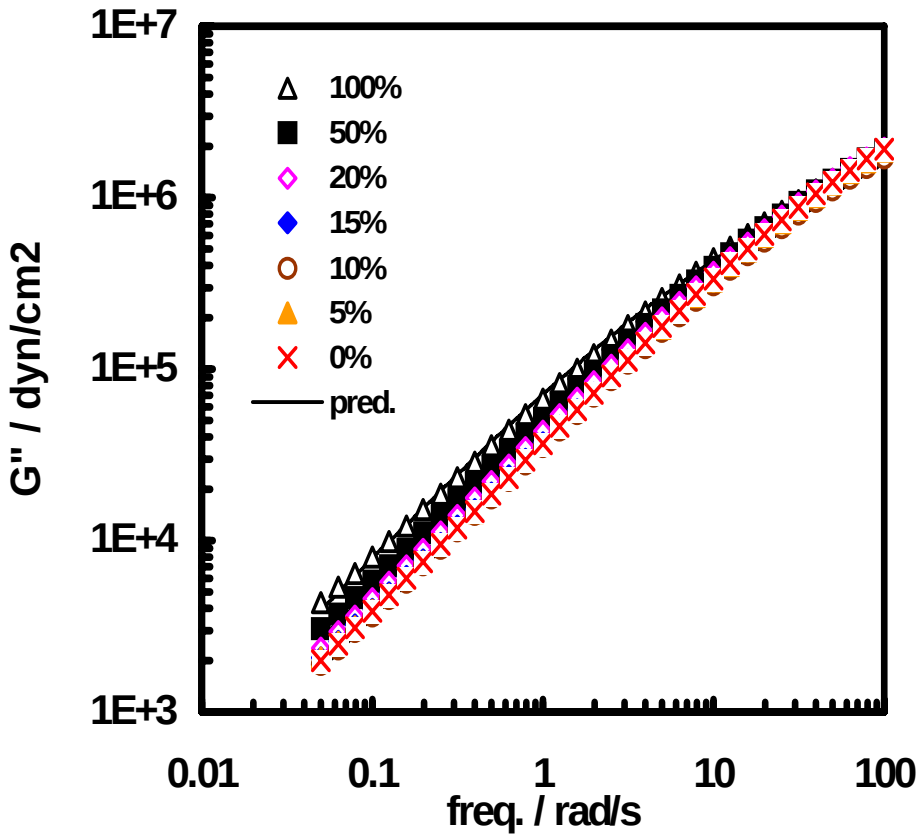
Loss modulus for recycled PC blends (250C, 1rad/s)



Storage modulus for recycled PC blends (250C, 1rad/s)



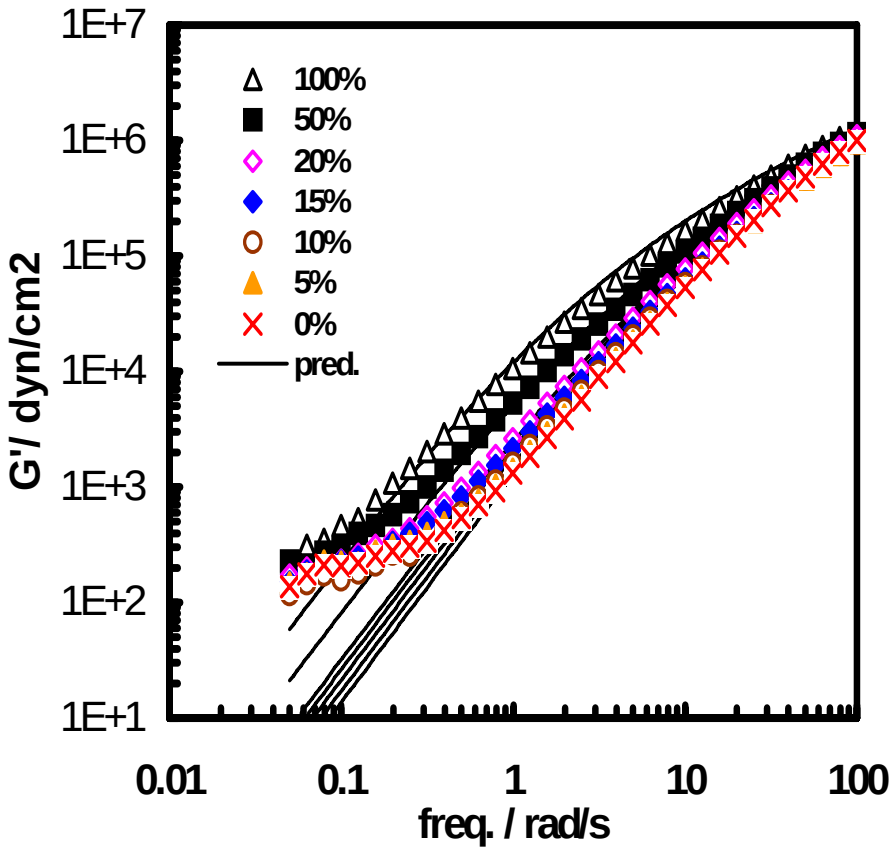
LOSS MODULI OF RECYCLED PC BLENDS



Data for R-PC blends (250C, strain 10%)

- The virgin PC (0%) has lower G" than the recycled PC
- The blends behave in a way between the recycled and virgin PC melts
- The G" of the blends with R- PC content less than 15% are hardly distinguishable from those of virgin PC
- Solid lines represent data predicted using MWD data of 0% and 100% PC samples

STORAGE MODULI OF RECYCLED PC BLENDS

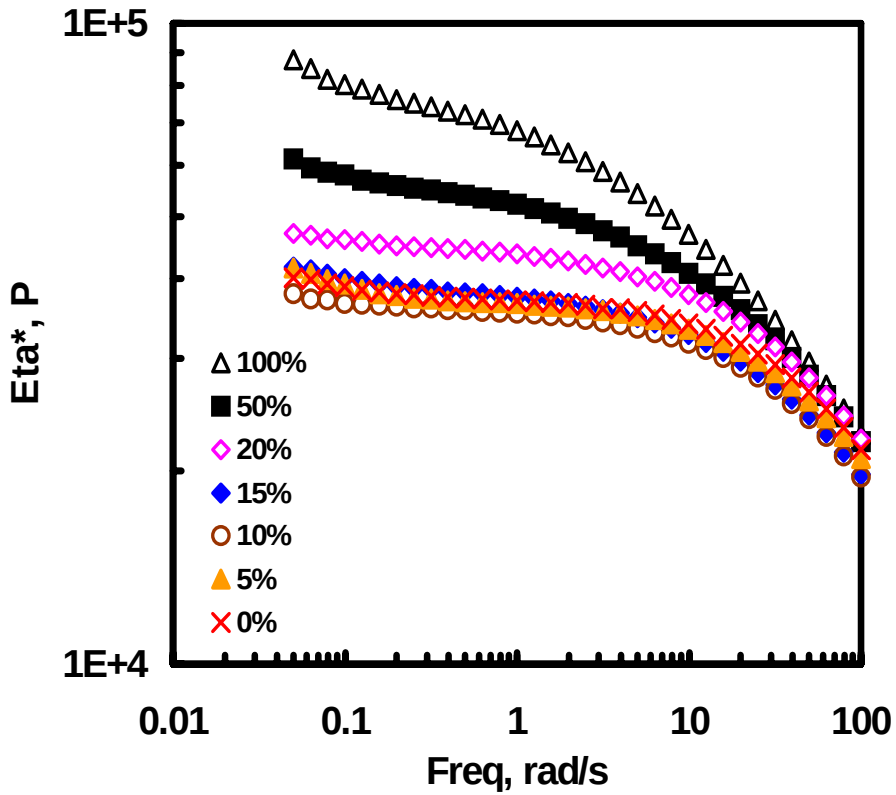


Data for R-PC blends

(250C, strain 10%)

- The blends behave in a way between the recycled and virgin PC melts
- The G' of the blends with R- PC content less than 15% are hardly distinguishable from those of virgin PC
- The G' plateaus appear at low frequencies, more or less, for all the samples
- Solid lines represent data predicted using MWD data of 0% and 100% PC sample

COMPLEX VISCOSITY OF RECYCLED PC BLENDS

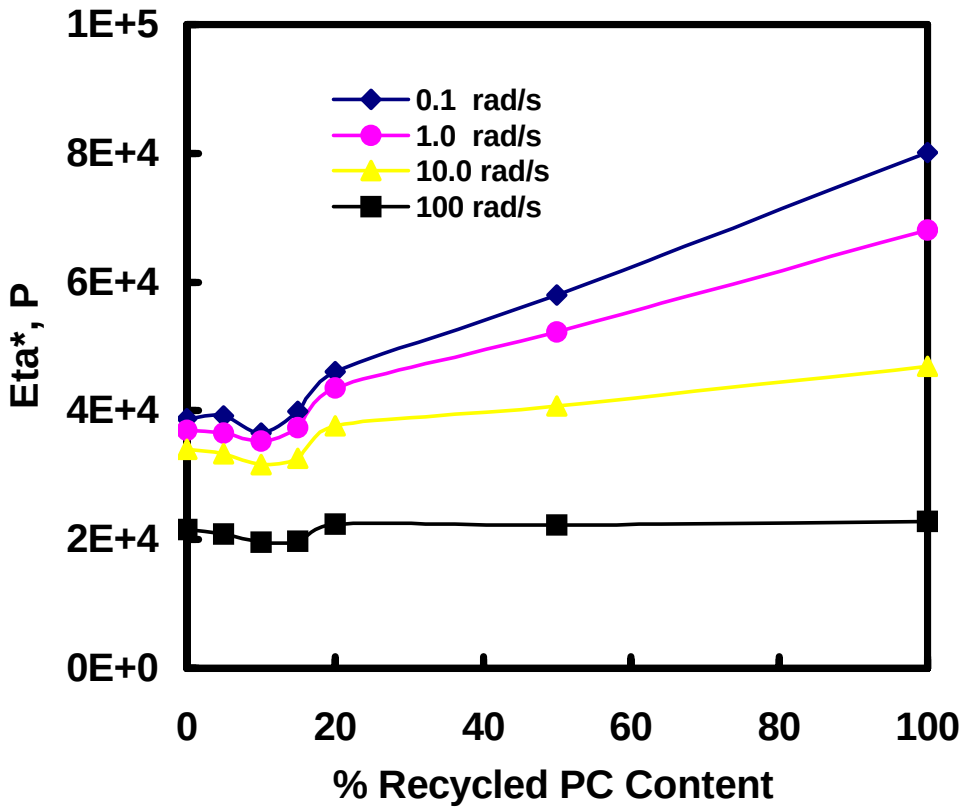


Data for R-PC blends

(250C, strain 10%)

- Recycled PC has a higher viscosity than virgin PC
- The samples with recycled PC content less than 15% have nearly the same properties as that of the virgin resin

COMPLEX VISCOSITY AS A FUNCTION OF RECYCLED PC CONTENT

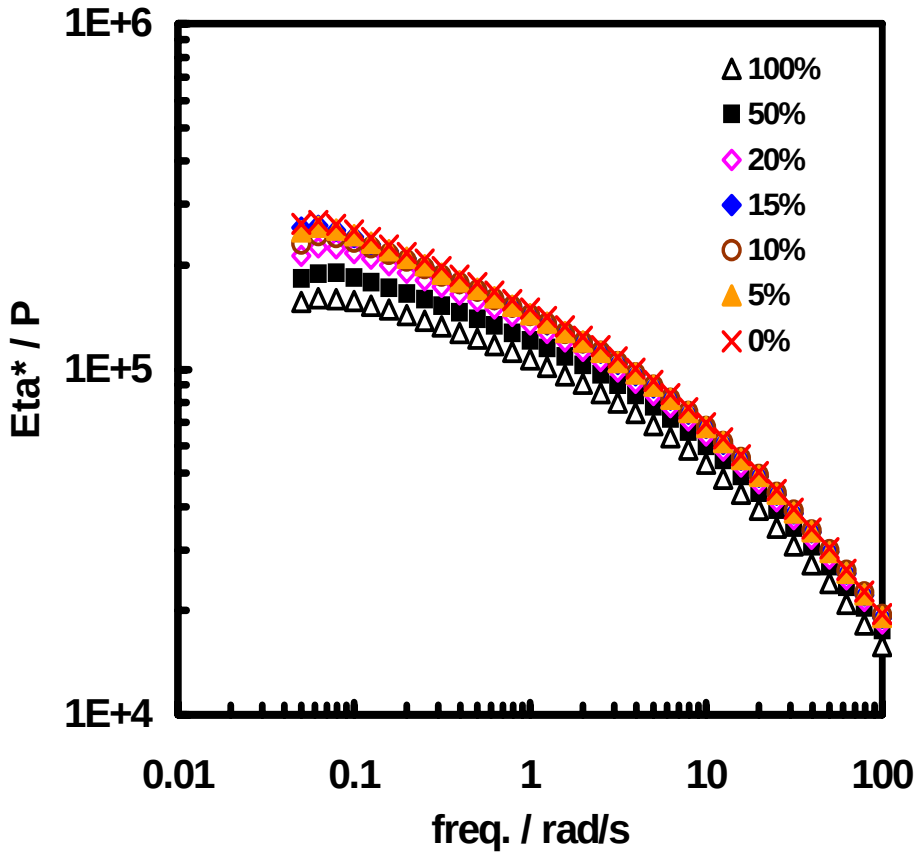


Data for R-PC blends

(250C, strain 10%)

- remains unchanged when recycled PC content is less than 15%
- shows a slight increase when recycled PC content is 20%
- approaches the magnitude of the recycled PC as the recycled PC content further increases

COMPLEX VISCOSITY OF RECYCLED ABS BLENDS



Data for R-ABS blends (200C, strain 10%)

- In contrast to R-PC blends, R-ABS has a weaker viscoelasticity and lower viscosity than virgin ABS
- The samples with R-ABS content less than 15% have nearly the same properties as those of the virgin resin
- '**15% blending rule' -** The minimum virgin content needed to mask the effect of addition of recycled material was about 85%

DOUBLE REPTATION MIXING RULE FOR MWD CALCULATION

For linear flexible polymers

$$G(t) = G_N \left[\int_0^\infty F^{\frac{1}{2}}(M,t) W(M)\, dM \right]^2$$

where

$$F^{\frac{1}{2}}(M,t) = \exp\left\{ \frac{-t}{2\lambda(M)} \right\}$$

$$\lambda(M) = K(T) M^{x}$$

$$K(T) = K(T_0) \exp\left[\frac{E_A}{RT} \right]$$

$G(t)$	Relaxation modulus	$\lambda(M)$	Characteristic relaxation time
$F^{1/2}(M,t)$	Relaxation function	$W(M)$	Weight based MWD
G_N	Plateau modulus	X	Relaxation time exponent
$K(T)$	Front factor dependent on temperature with activation energy E_A		
$K(T_o)$	Front factor at the reference temperature		

MATERIAL PARAMETERS FOR MWD CALCULATION

For Polycarbonate, 250C

1. Relaxation time exponent χ

   χ = 3.40

2. Plateau modulus G_N

   Ellis model data fitting

$$G' = G_N + \frac{c_1}{\omega^{c_2}}$$

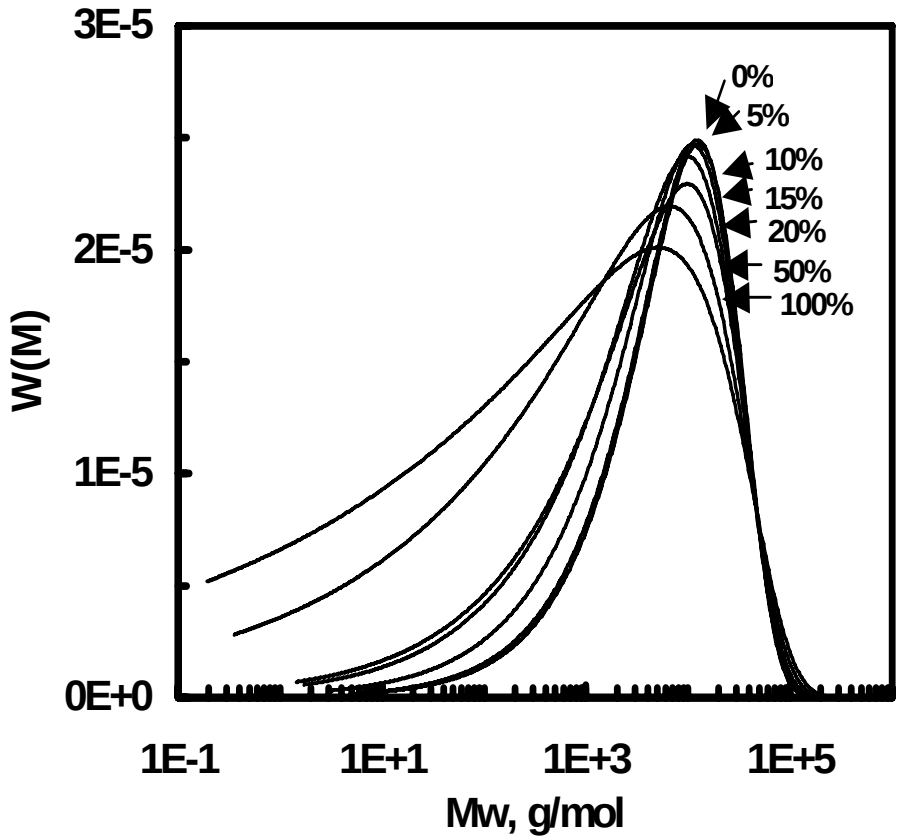
   giving G_N=2.52x10^6 dyn/cm^2

3. Front factor K_λ

   Using χ, G_N and GPC data (Mw=3.0-3.5e4, PI=2.3)

   giving K_λ =3.5x10^{-18}

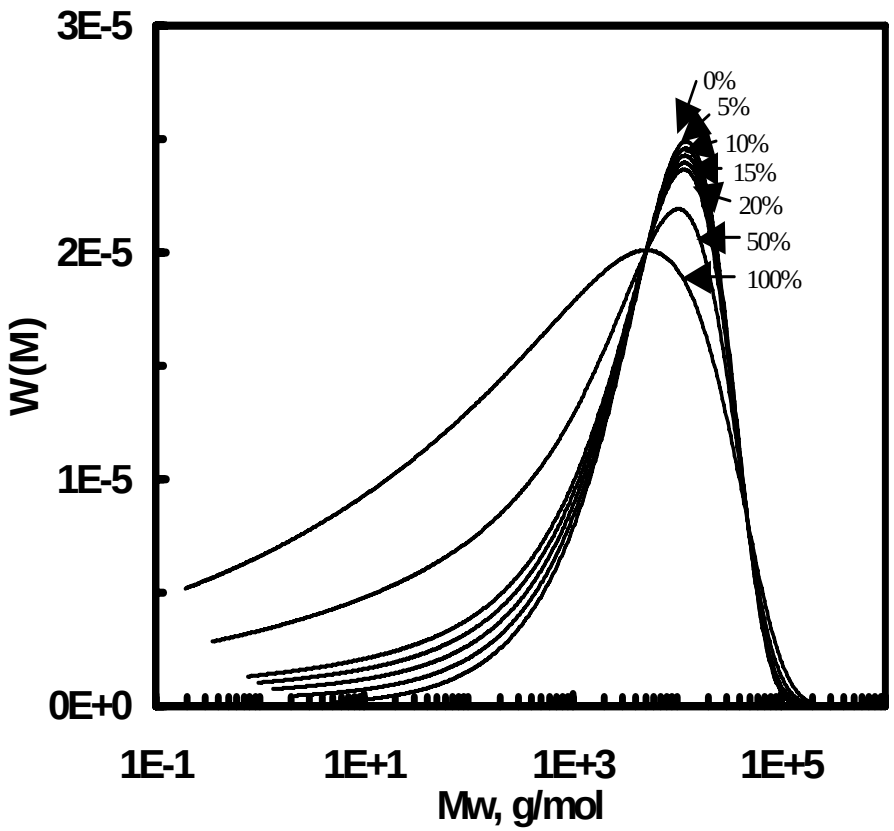
MWD CURVES CALCULATED USING L.V.E. DATA



Weight based MWD curves of recycled PC blends, calculated using experimental linear viscoelasticity data of each sample

- The recycled PC has a higher molecular weight and much wider MWD than the virgin polymer

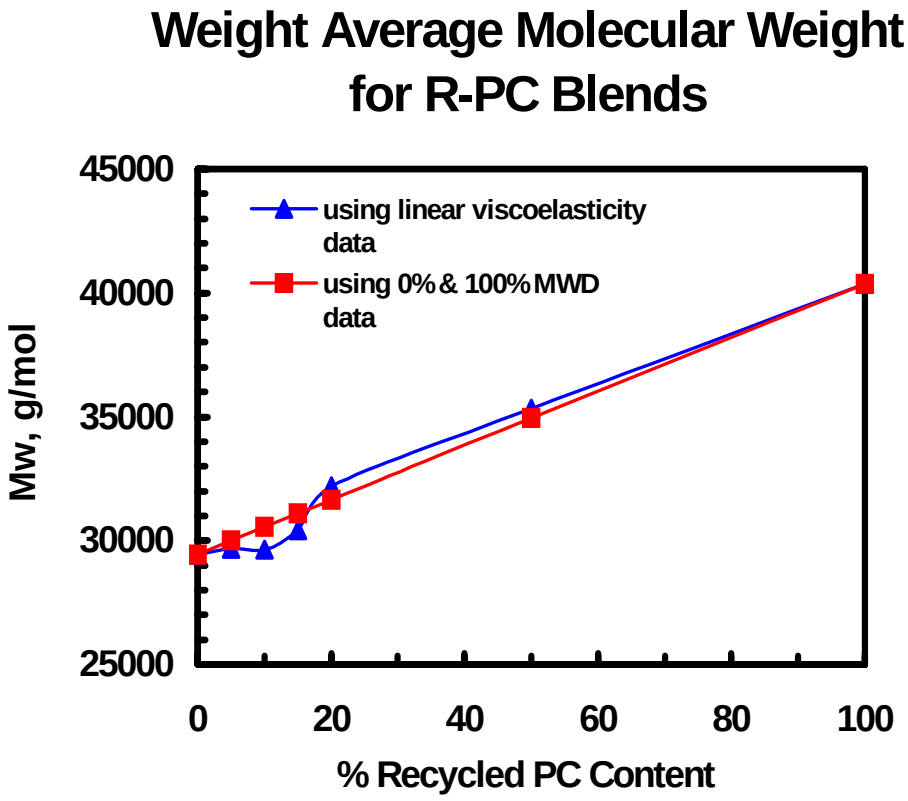
MWD CURVES PREDICTED USING 0% AND 100% SAMPLE MWD DATA

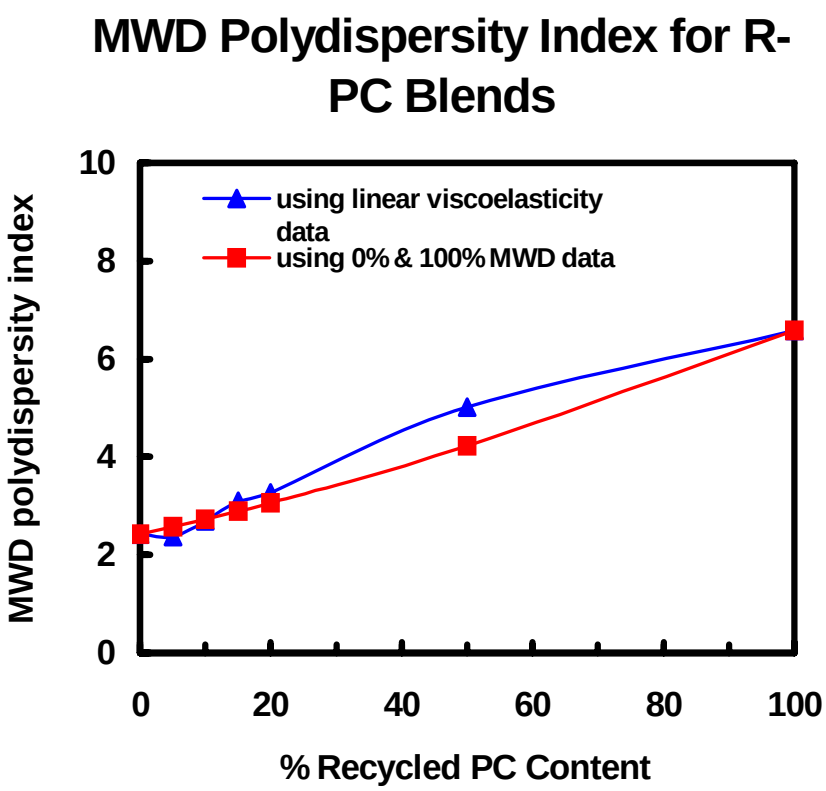


Weight based MWD curves of recycled PC blends, predicted using MWD data of 0% and 100% samples in terms of a simple, linear addition rule

- showing a good agreement with data calculated using exp. linear viscoelasticity data of each sample

WEIGHT AVERAGE MOLECULAR WEIGHT AND POLYDISPERSITY INDEX

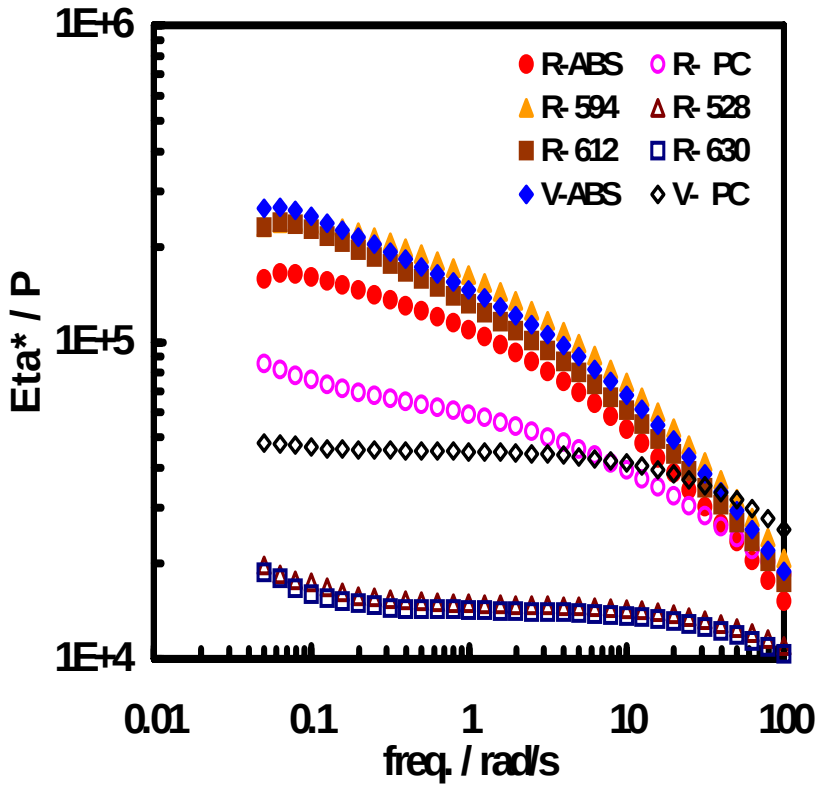




BATCH-TO-BATCH VARIATIONS OF RECYCLED PC & ABS MELTS VISCOSITY

Complex viscosity vs. freq. for three recycled PC and three recycled ABS materials with different purity levels

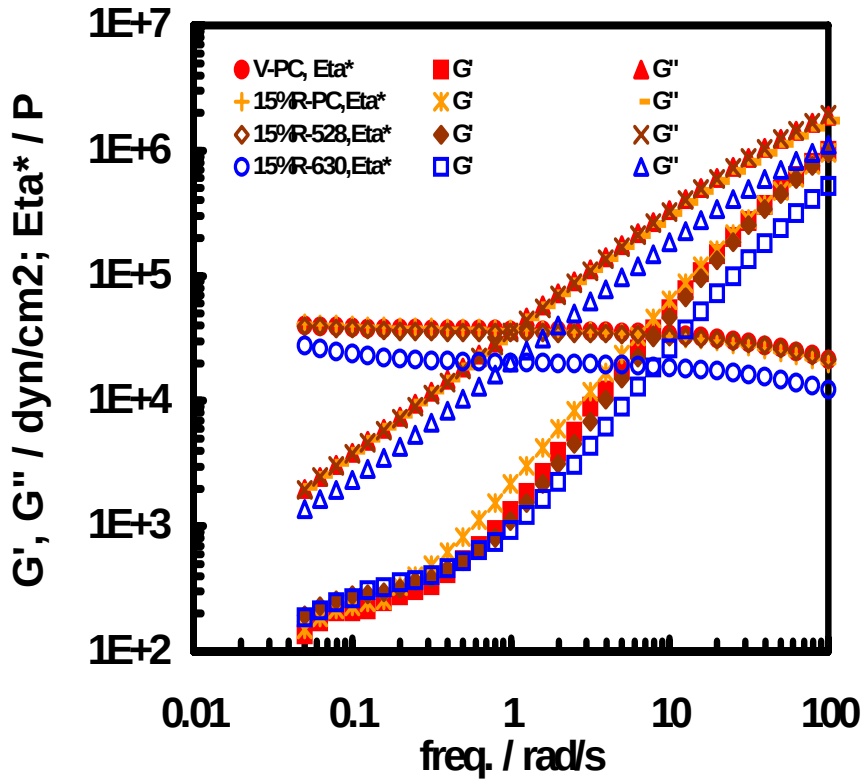
- Material purity and batch-to-batch variations have a large influence on the observed rheology



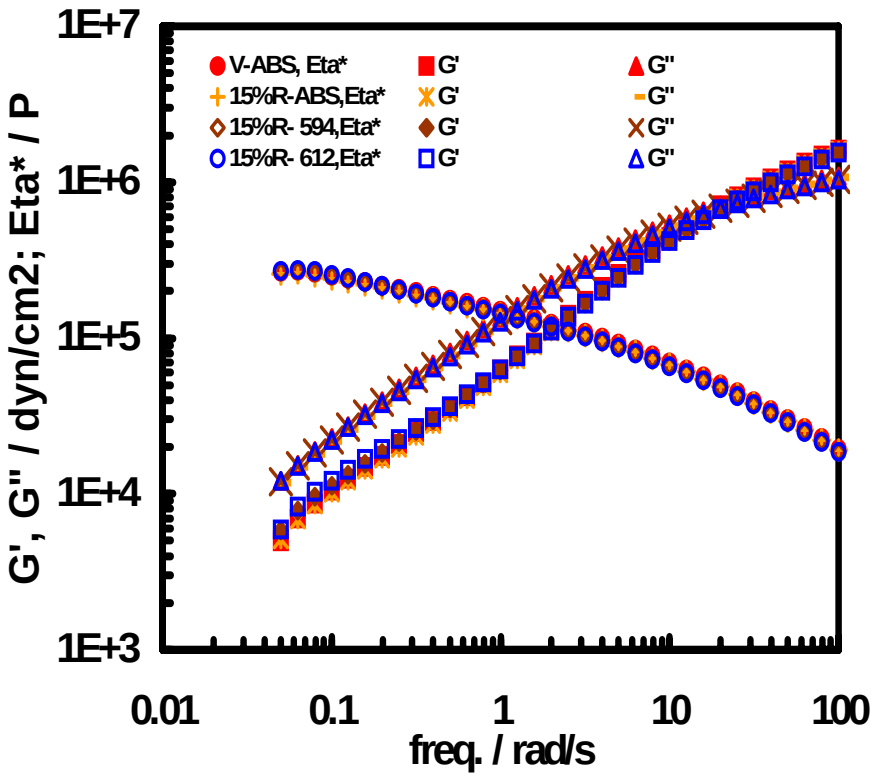
PURITY EFFECT ON DYN. PROPERTIES OF 15% RECYCLED PC BLENDS

Dynamic properties of three 15% recycled PC blends in comparison with virgin PC

- Except R-630PC, the results verify the '15% blending ratio rule'



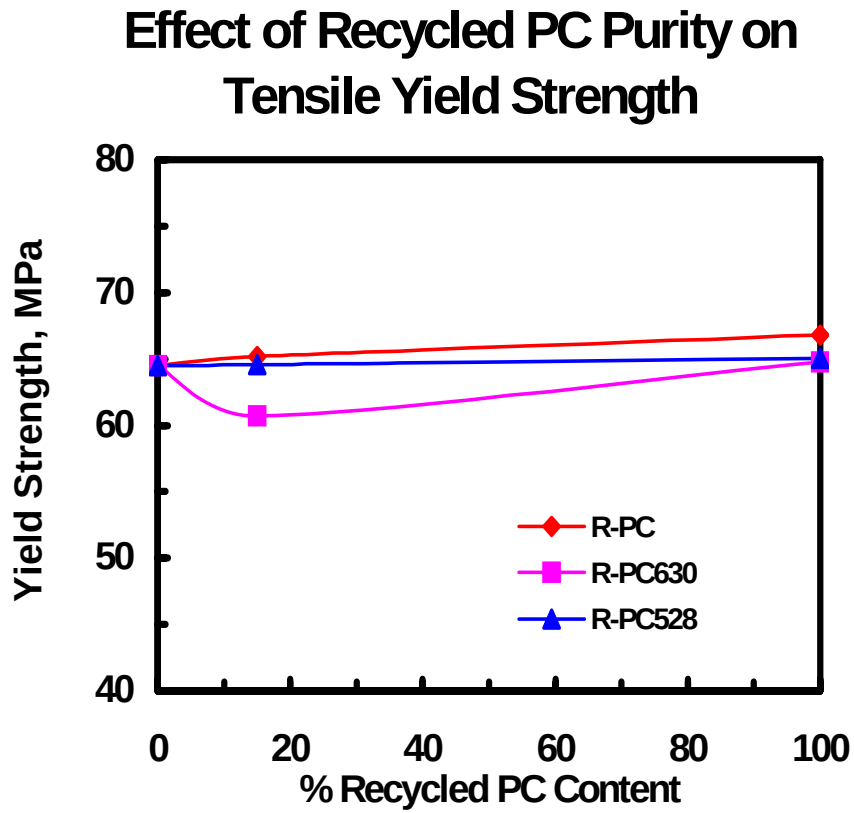
PURITY EFFECT ON DYN. PROPERTIES OF 15% RECYCLED ABS BLENDS

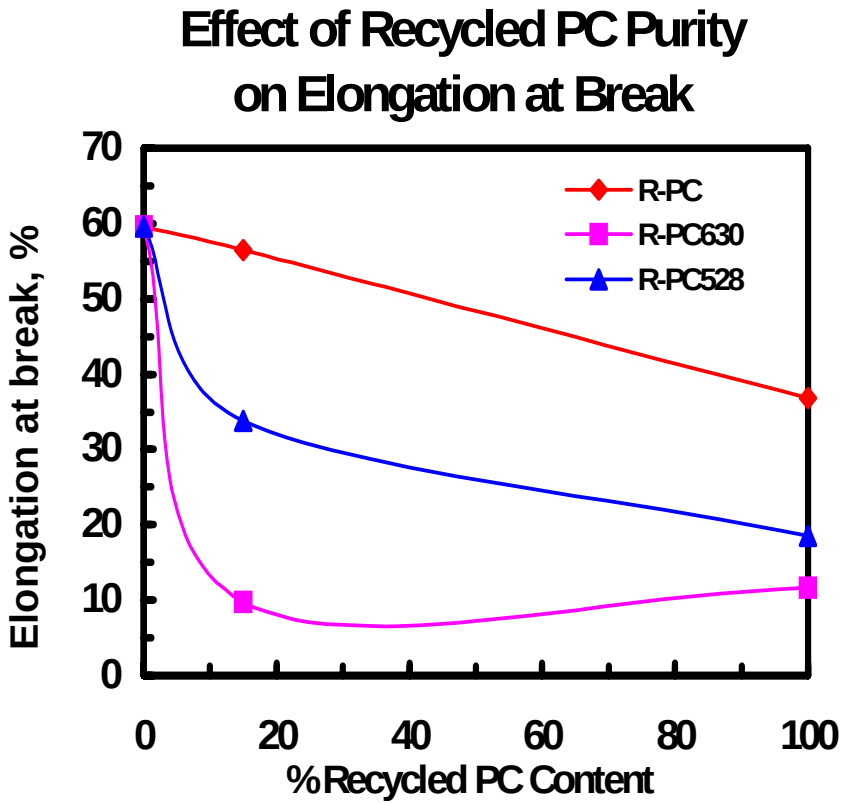


Dynamic properties of three 15% recycled ABS blends are compared with virgin ABS

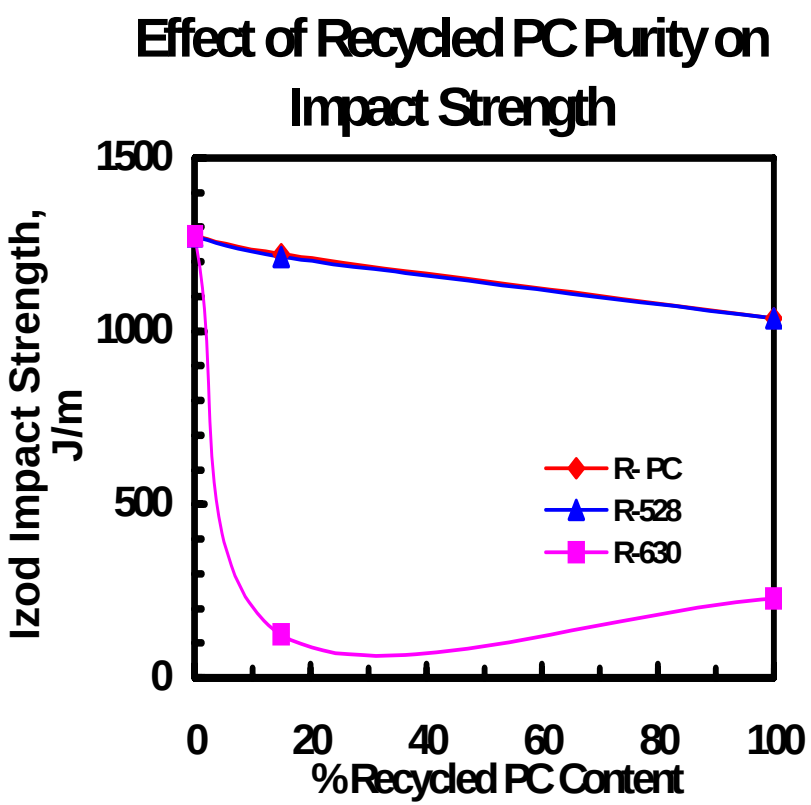
- All three blends have the same values as those of the virgin resin
- These data of different purity levels further verify the '15% blending rule'

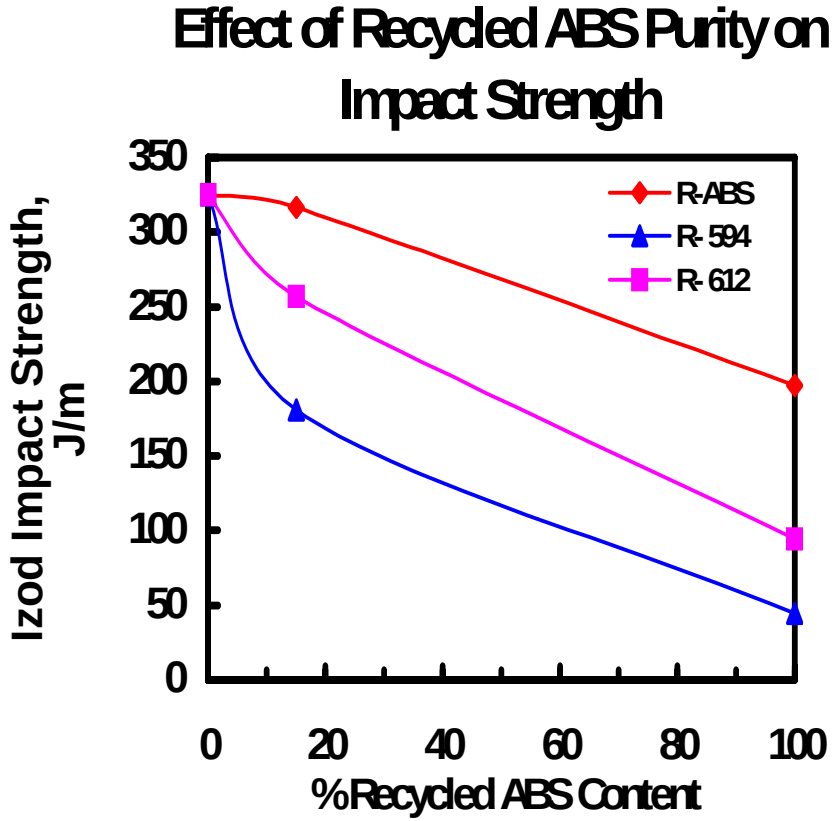
CORRELATION WITH TENSILE PROPERTIES





CORRELATION WITH IZOD IMPACT STRENGTH





CONCLUSIONS

- Recycled PC or ABS melts
  - Linear viscoelastic rheol. behavior
  - Variations from batch-to-batch - Purity level effect
  - Recycled PC has a wider mwd
- Recycled polymer blends with virgin resin
  - The batch-to-batch variations minimized
  - ‘15% blending rule’ for high purity recycled content
- Rheology in simple shear seems less sensitive to impurities than some mech. properties

CURRENT RESEARCH DIRECTION

- Rheological responses under more complex shear deformation and in extensional flow
- Further examine impurity effect & correlate to compatibility of polymers
- Formulate and characterize PC/ABS blends, filled /reinforced blends

ACKNOWLEDGEMENTS

- US Department of Energy
- Teledyne Brown Engineering
- MBA Polymers
- GE Plastics
- Rheometric Scientific