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The Effects of Various Additives on the Processing and Physical Properties of Wood-Filled PVC

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Introduction

In this presentation we will discuss the use of additives such as lubricants, rheology modifiers and dispersion aids in wood-filled PVC composites. It is the goal of this paper to show improvements in flow, surface appearance, process stability and overall processing characteristics of the composite. It is also the goal of the paper to illustrate that these process improvements are conducive to achieving higher filler loading levels without sacrificing processability or surface appearance.

This paper will define the effects of various formulation changes on the following properties:

- Fusion characteristics
- Color (stability)
- Viscosity
- Impact Strength

Background

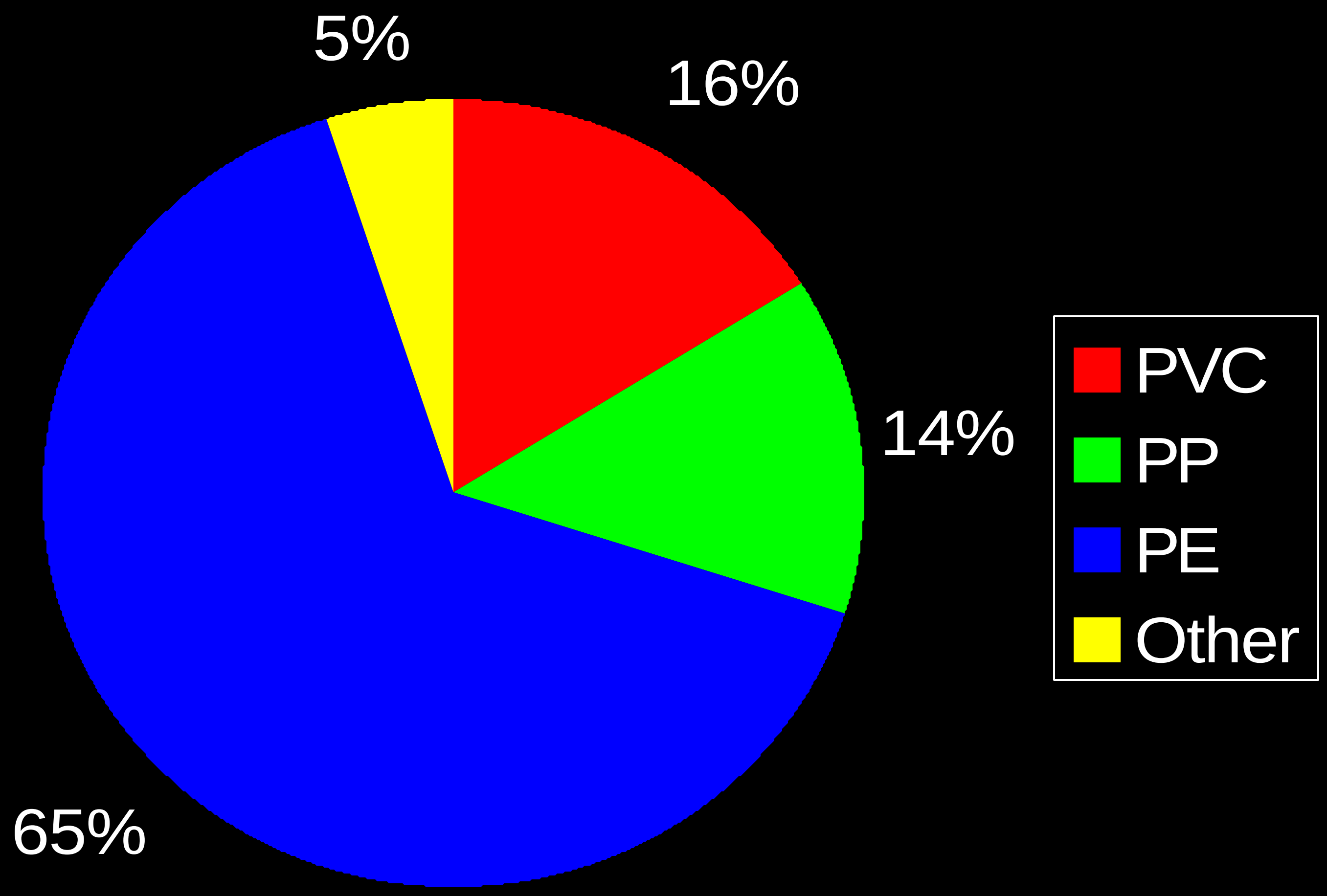
Current industry status:

- Supply driven market (availability of raw materials)
- Starting up the steep slope of the industry growth curve

Wood-plastic composites are gaining credibility as replacements for lumber and other wood products because they:

- Can be more resistant to the effects of moisture and rot
- Resist cracking, splitting, warping, and splintering
- Have better dimensional stability than 100% wood parts
- Are themselves readily recycled and provide an outlet for polymer recyclate and lumberyard scrap
- Can last longer and require less maintenance than wood parts

Polymers Used



Product Limitations

Properties and items that need to be improved include:

- The flexural modulus and tensile strength of the composites are often significantly lower than that of wood
- Composites containing 50% or greater wood fiber can still be adversely affected by moisture and microbial action
- There is a lack of standardization among the various sources of fillers
- There are stability issues with the various flours and fibers during processing
- There are stability and weathering issues with olefin based products
- The ability to assemble the composites by nailing or drilling can be inferior to that of wood

Market Drivers

Market drivers for the building and construction segments include:

- The cost of prime quality lumber and treated lumber continues to soar due to the availability of prime timbered land
- Lumber is in tight supply for construction applications
- The general public has a growing acceptance of wood-plastic composites as an alternative to wood
- The general market is seeking products that require minimal maintenance and attention
- These products are perceived as being environmentally friendly

Barriers to Growth

Several issues are affecting the growth estimates for wood-plastic composites and the ability to succeed in the market:

- Patent infringement (particularly PVC)
- Technology development
- Capital equipment investment
- Distribution/Paths-to-Market
- Availability of lower cost recyclate streams for polymer products

LUBRICANTS

Polymers are made of long chain molecules of varying sizes and distributions. These polymers tend to be:

- Relatively viscous above their melt temperature
- “Sticky” above their melt temperature

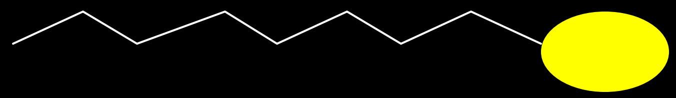
Lubricants serve to decrease the frictional forces found between:

- Polymer : Polymer
- Polymer : Metal
- Polymer : Filler
- Filler : Filler
- Filler : Metal

SURFACTANTS

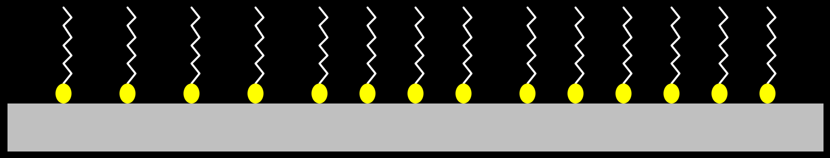
Surfactants = “Surface Active Agents”

Traditional Head-Tail structure:



Tail group is typically soluble in non-polar region (internal).

Head group is typically soluble in polar region or adsorbs to surfaces of polymer, filler or metal. The adsorption is typically via hydrogen bonding. Forms a monolayer with tail group providing lubricating effects.



LUBRICANT CLASSIFICATION

Taken from classical PVC terminology:

- **External = Insoluble**
  - Typically provide lubrication between the polymer and the metal surface of the processing equipment
  - Classic types:

    Polyethylene waxes, Oxidized Polyethylene waxes, Paraffins, Metal Soaps, Esters (high esterification), Amides, Fatty Acids
- **Internal = Semi-Soluble (Plasticizer)**
  - Typically reduce bulk viscosity through partial compatibility with the polymer, thus opening the polymer chain with the lubricant's soluble component while providing intermolecular lubrication with the less soluble portion of the molecule.
  - Classic types:

    Fatty alcohols, Esters (low esterification), EVA Wax, others

REMEMBER!

Most lubricants provide a combination of internal and external effects. It is the balancing of these effects in the formulation that will determine the ultimate and overall effectiveness of the lubricant!

AND

Lubricants will act differently in different polymer compounds due to chemical solubility. The solubilities change relative to polymer chemistry and other additive (Filler!) chemistries!

GENERAL CHEMISTRIES OF LUBRICANTS

- Acid Amides
  - Primary Amides: Erucamide, Oleamide, Stearamide
  - Secondary Amides: EBS, EBO
- Acid Esters
  - PEMS, PEDS, PETS, PEAS, GMS, GMO, Montan Wax, Stearyl Stearate, Distearyl Pthalate
- Fatty Acids
  - Saturated: Lauric (C12), Myristic (C14), Palmitic (C16), ***Stearic (C18)***
  - Unsaturated: Oleic (C18), Erucic
- Hydrocarbon Waxes
  - Polyethylene, Polypropylene, OPE, Paraffin
- Metallic Soaps
  - Calcium, Zinc, Magnesium, Lead, Aluminum, Sodium, Tin, Barium, Cobalt, etc. Stearate

Experimental Program and Evaluation

Objective

The objectives of this program are to:

- Evaluate the affects of various additives with regard to fusion speed, fusion temperature, fusion torque, equilibrium torque and melt stability
- Focus on the lubricant system
- Develop a lubricant that improves flow, surface appearance, process stability
- Optimize additives to increase filler loading levels without sacrificing processability or surface appearance

Formulations/Materials/Suppliers

Material	Level, phr	Grade	Supplier
PVC Resin	100	902FG (K-58)	Geon (Polyone)
Impact Modifier	5-10	Blendex B-131	GE Chemical
		K-400	Rohm & Haas
		Tyrin 3615	DuPont Dow
Process Aid	1	Blendex 869	GE Chemical
		K-120N	Rohm & Haas
		K-175	Rohm & Haas
Titanium Dioxide	1	Ti-Pure 104	DuPont
Calcium Carbonate	3	Omyacarb FT	Omya
Stabilizer	1	Advastab TM-950F	Rohm & Haas
Lubricants	0.65 - 2.5	RL-165	Honeywell
		AC-629A	Honeywell
		SA-0012	Struktol
		Coad 10 CaSt	Norac
Wood Flour	Various	8010 (120 Mesh)	American Wood Fibers
		8020 (120 Mesh)	American Wood Fibers

Program

The data generated is based on compounding in a Brabender PL2000 torque rheometer using the bowl mixer with roller blades at 180°C and 60 rpm. The total mixing time was 6 minutes.

The capillary rheometer testing was performed on a Göettfert Rheometer “Rheotester 1000” at 180°C with a 1 mm diameter die.

The wood flour was dried overnight at 110°C prior to mixing.

Prior to this study a lubrication package was developed that significantly reduced the tendency towards edge tearing in extrusion vs. commonly used combinations of lubricants. This product, Struktol® SA-0012, is also evaluated in this program.

All other additives were recommended from sources within the industry.

Results of Testing

Effects of Impact Modifiers

Base formulation, 0% wood flour, 0.65 phr lubricant

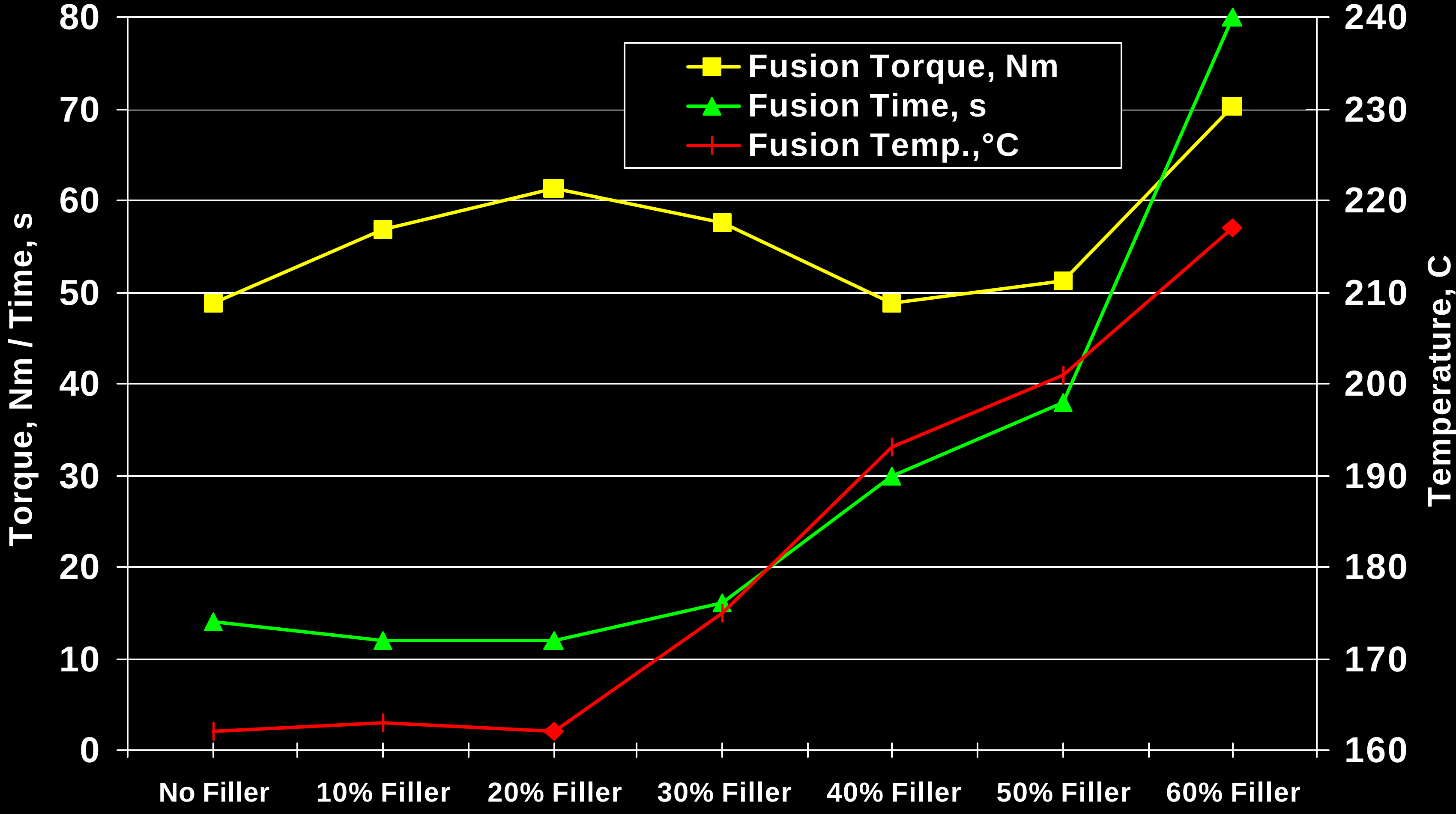
	Level, phr	Fusion Time, s	Fusion Temp.,°C	Fusion Torque, Nm
K-400	10	12	163	47.3
	7.5	16	164	45.3
	5	24	170	40.4
Blendex B-131	10	14	162	48.8
	7.5	20	165	44.0
	5	20	165	41.3
Tyrin 3615	10	14	159	40.8
	7.5	20	164	35.5
	5	22	168	33.7

Effects of Wood Flour Fillers

Base formulation, 5% ABS impact modifier, 1.5 phr SA-0012

	Fusion Time, s	Fusion Temp.,°C	Fusion Torque, Nm
No Filler	14	162	48.8
10% Filler	12	163	56.9
20% Filler	12	162	61.3
30% Filler	16	175	57.6
40% Filler	30	193	48.7
50% Filler	38	201	51.3
60% Filler	396	217	70.3
65% Filler	***No Fusion Occurred***		

Effects of Wood Flour Fillers



Melt Instability and Melt Fracture

Base formulation, 50% wood flour, 1.5 phr lubricant

Capillary rheology testing, 180°C, 1 mm diameter die

	Level, phr	Observations
K-400	10	Instability/Fracture at low shear stress
	7.5	Instability/Fracture at low shear stress
	5	Instability/Fracture at low shear stress
Blendex B-131	10	Instability/Fracture at mid-level shear stress
	7.5	No Instability at high shear stress
	5	No instability at high shear stress
Tyrin 3615	10	Instability/Fracture at high shear stress
	7.5	No Instability at high shear stress
	5	No Instability at high shear stress

Extrusion Problems and Melt Instability

Standard lubricants, 1.5 phr, 50 rpm

Struktol SA-0012, 1.5 phr, 50 rpm

Struktol SA-0012, 1.5 phr, 100 rpm

Effects of Lubricants

Base formulation, 50% wood flour

Standard lubricant is 165 Wax, Calcium Stearate and OPE (1:1:0.25 ratio)

	Level, phr	Fusion Time, s	Fusion Temp.,°C	Fusion Torque, Nm
Std. Lubes	1.5	32	197	49.4
	2.0	64	201	30.5
SA-0012	1.5	28	195	59.3
	2.0	30	195	57.0

Note that even though the fusion torques of the SA-0012 formulations are much higher than the fusion torques of the standard lube formulations, the formulation viscosities (and equilibrium torques) are actually much lower than the standard lube formulations.

Manufacturing Economics

Two primary ways to reduce overall manufacturing costs:

- Reduce raw material costs
- Increase output rates

It is difficult to significantly reduce raw material costs in simple, already low cost formulations. Therefore, focusing on output rates can be the key to dramatically reducing manufacturing costs and increasing margins. This will become much more important as the industry matures, competition increases and market prices erode.

Output Rate vs. Manufacturing Cost

Base formulation, 50% wood flour

Twin screw compounding, 2 MM lbs. Run length

Lube Level	Output Rate, lbs./hr	Raw Material Cost, $/lb.	Total Cost, $/lb.	Total Run Cost, $
1.00 phr	600	0.260	0.383	766,689
1.25 phr	700	0.260	0.374	747,775
1.50 phr	800	0.261	0.367	734,179
1.75 phr	900	0.261	0.361	722,666
2.00 phr	1000	0.261	0.357	714,399

Conclusions

- The SA-0012 can be used to obtain excellent metal release and good overall lubricant processing characteristics in PVC/wood composites. It also did not significantly affect the fusion speed of the formulations tested. When used at an addition level appropriate to the type of impact modifier used and the level of wood filler, it can effectively prevent edge tear and melt fracture.
- Wood flour composites require higher loadings of lubricants to be processed without melt instability. In these formulae, the wood filled compounds required at least 1.5 phr of lubricant versus 0.65 phr in the unfilled compounds to have acceptable processing characteristics.
- The type of impact modifier can have a significant effect upon the processing characteristics of the compound. In this study, the ABS impact modifier gave the best over processing characteristics.
- To successfully process PVC/wood composites, the choice and usage level of the impact modifier and lubricant can significantly affect the process temperature, fusion temperature, fusion time, fusion torque and the melt stability of the compound.