PVC Polymer Formulation Reinforced with Ground Wheat Straw Filler

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Abstract

Agricultural residues such as wheat straw are low-cost materials which can be milled into millimeter size particles, and used as filler in the manufacture of plastic composite material. In Canada, wheat is a major crop with some 24m tonnes harvested annually. We developed several polyvinyl chloride (PVC) and varying %-wt ground wheat straw biofiller (gWSBF) formulations, and measured their mechanical and short-term (1 day-11 day) weathering properties. Our interest is in rigid PVC based materials, for outdoor applications, ultimately with recycled PVC. A polymer matrix of PVC was used, with 0% - 30%-wt ground wheat straw biofiller of particle size 400 um – 2000 um (90%-tile range), with a mean of 400 um. The formulation was mixed, extruded into pellets, and injection molded into test strips. With increasing %-wt of ground wheat straw from 0% to 30%: Flexural modulus and Tensile Modulus increased (improved); flexural strength, tensile strength, iZod impact (notched) decreased; and Water Absorption (24 h) increased.

Introduction

We seek formulations of PVC and biofiller (for cost reduction) for use in outdoor applications such as decking. The global market volume of PVC is about 36 million metric tonnes (m mt) in 2011. North America produces about 5 m mt (14% of global volume) of PVC annually; only about 1% is recycled (2012) [1]. PVC is widely used for long-life (30y+) construction products: pipes, window frames, etc., this amounts to about 75% of its use [2]. PVC has thousands of formulations for varying applications (rigid vs. flexible, etc.), which makes recycling a challenge due to the wide variety of chemical compositions.

Omtec Inc. manufactures ground Wheat Straw Biofiller (gWSBF) in several grades (average particle lengths) from about 300 um to 1500um. The grade gWSBF-25 is mixed into polypropylene (PP) pellets by about 20%-wt by a plastic compounder, and provided to the Ford Motor Company (”Ford”) for use in the interior storage bins of the Ford Flex utility vehicle assembled in Canada.

Wheat straw is an attractive filler material, as it is an agricultural residue (waste): the excess from the wheat plant when the wheat grain is removed for food, and some centimeters of wheat “stubble”

remains on the ground for fertilizer, weed suppression, and water retention. About 650m mt of wheat are available globally per year (2010), and about two-thirds of that is wheat straw.

Biofillers are often used in polypropylene (PP) and polyvinyl chloride (PVC) plastic composite materials as filling materials, to reduce manufacturing cost: in PP (polypropylene) [3], biofillers are used up to 75% by weight, with a typical particle size of 10 – 60 mesh (2,000 - 180 um). In PVC, biofillers are used up to 60% by weight (typically 20%-60%), and with smaller particle size: 40-120 mesh (425 - 125um.)

Wheat Straw Biofiller

Wheat straw from southwest Ontario, Canada farms (primarily hard winter wheat) was used for the experiments. Round bales of wheat were unwound, fed into a Meadow Mills Hammer Mill #35 (screen size 3/16"), then sieved into 3 fractions using a BM&M Mini Super Screen (24"x72") Sieve with #16 and #35 mesh screens: 1) gWSBF-25 (approx. 400um average particle length), 2) gWSBF-35 (approx. 150um average particle length), and 3) gWSBF-1h. A fourth (4th) fraction – the aerosol dust – is removed as waste with a dust collection system.

Formulations

We started with the wood-PVC formulation from Hajji et al. [4] ("Initial"), and modified it based on locally available chemicals (in small volumes). The formulation for these experiments ("Final") are shown in Table 1:

Table 1. Starting Point Formulation: Wood –PVC formulation from Hajji et al. (2008) [4], and our Final Formulation

Purpose	**Initial (Hajji [4])**	**Final**
Matrix	PVC (K57) Lacovyl SO71	PVC Oxyvinyl 185, K=57
Biofiller	Wood flour, pine; 150-200um; 50%-wt	Ground Wheat Straw; WSBF-25(400um – 2000um); 0%, 10%, 20%, 30%-wt; and WSBF-35 (100um-500um) 20%-wt
Stabilizer	Thermolite T890F	Thermolite T890-S
PVC Heat Stabilizer/ lubricant		Calcium Stearate
Process Aid	Plastistrength 770 & 530 & 320	Plastistrength 770 & 530 & 320
Acrylic impact modifier	Durastrength 320	
External lubricant		Pure Wax
UV Stabilizer		Tinuvin P

Processing

The Injection Molded test strips were produced in five (5) steps:

1. Weigh and mix powders, additives, and biofiller.
2. Hot mix until 32 degrees C (180 degrees F) using a High Intensity Powder Mixer; Gunther Papenmeir KG Mixer, model TGHK8, 3HP.
3. Dehydrate in an oven to reduce moisture to < 1%.
4. Pelletize by extrusion 170 degrees C, 100 rpm using a Co-rotation twin screw extruder; Onyx TEC-2540, screw diameter 25mm L/D 40, 5.5kW motor. See Figure 1 for a picture of the extrudate.
5. Injection mold test strips at 175 degrees C using an Engel ES 80/28 screw diameter 0.866 in, L/D 21, heating 3kW, pump 10HP.) See Figures 2,3,and 4 for pictures of the test strips.

Figure 1. Extrudate 30%-gWSBF-25, ready for cutting into pellets (closeup)

Figure 2. Test Strip produced by Injection Molding (PVC formulation only). Approx. 40g

Figure 3. Test Strip produced by Injection Molding (PVC + gWSBF-25, 20%-wt) . Approx. 40g.

Figure 4. Test Strip produced by Injection Molding (PVC + gWSBF-25, 30%-wt). Approx. 40 g,

Physical and Mechanical Properties

Next, mechanical and weathering properties were measured according to ASTM Test Methods- tabulated in Table 2.

1. Mechanical Properties measurements (ASTM.)
2. Weathering Properties measurements (ASTM).

In addition, we are still performing outdoor Weathering tests; results are not yet available.

Table 2. Mechanical Properties of the PVC and gWSBF Formulations. PVC-only Samples are within expected values quoted in literature [5]. Note 1 – we could not make tests due to low flowability of injection molded test strips.

#	Test Standard	Mechanical Property	Expected Value, 100% PVC [5]	0% WSBF (PVC only)	10% WSBF-25	20% WSBF-25	30% WSBF-25	20% WSBF-35	Units
1	ASTM D790-90	flexural modulus	2000-5500	2540	3260	4110	4950	3580	MPa
2	ASTM D790-90	flexural strength	28-97	85.6	81.8	79.7	75.08	75.08	MPa
3	ASTM D790-90	flexural elongation (strain at yield)		5.20	4.10	2.70	2.80	2.43	%
4	ASTM D638-89	tensile modulus	2400-6900	2370	3060	3790	3630	Note 1	MPa
5	ASTM D638-89	tensile strength	50	50.8	42.9	42.7	40.64	Note 1	MPa
6	ASTM D638-89	tensile elongation	0.15	3.70%	2.66%	1.84%	2.22%	Note 1	%
7	ASTM D256-90	impact strength (izod, notched)	4	59	52	33	30	34.9	J/m
8	ASTM D792	density	1.3-1.7	1.29	1.38	1.38	1.38	1.36	g/cm3

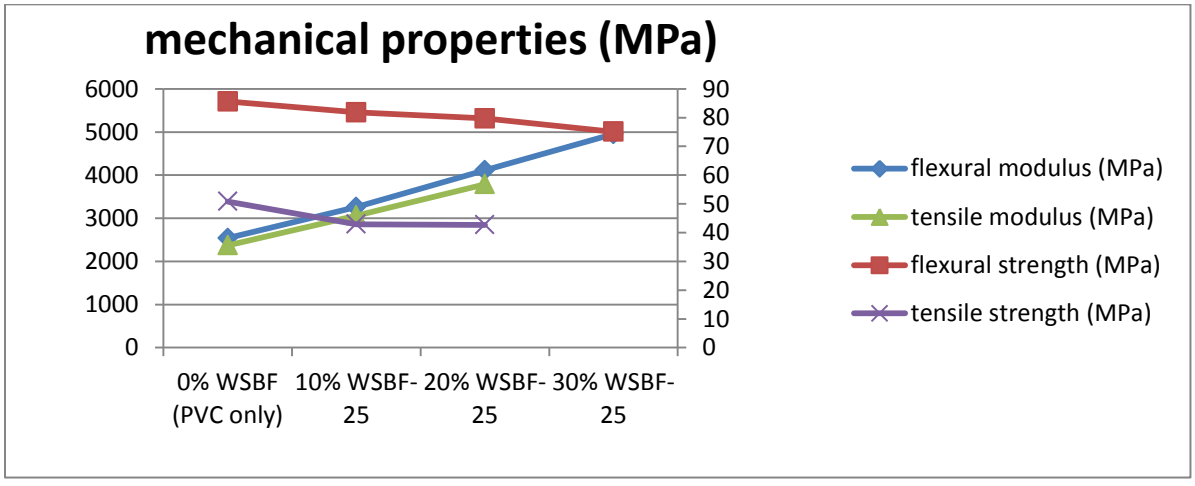

Figure 5. Mechanical Properties of the PVC and 0% - 30%-wt gWSBF-25 Formulations

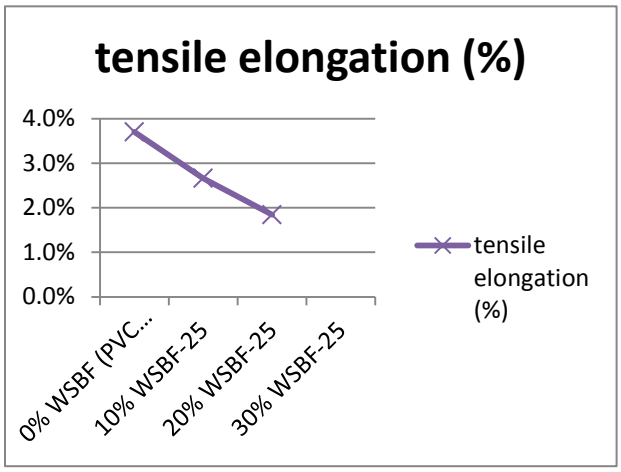

Figure 6. Elongation (%) of PVC and 0% - 30%-wt gWSBF-25

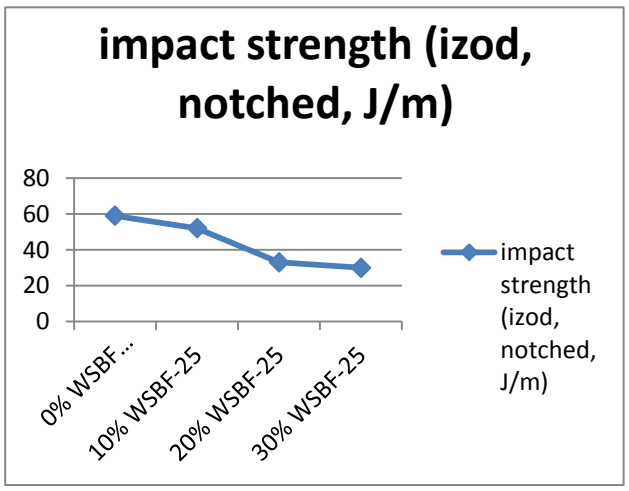

Figure 7. Notched Izod Impact (J/m) of PVC and 0% - 30%-wt gWSBF-25

Weathering Properties

Water Absorption properties are shown in Table 3 and Figure 8.

Table 3. Water Absorption Properties of the PVC and 0% - 30%-wt gWSBF-25 Formulations for 24 h, 4 days, 11 days.

#	Standard	Test Type	Expected Value, 100% PVC [5]	0% WSBF	10% WSBF-25	20% WSBF-25	30% WSBF-25	Units
1	ASTM D570	water absorption, 24 hr	0.1% - 1.5%	0.16%	0.26%	0.39%	0.80%	%
2	ASTM D570	water absorption, 4 day		0.22%	0.42%	0.88%	1.47%	%
3	ASTM D570	water absorption, 11 day		0.28%	0.67%	1.31%	2.27%	%

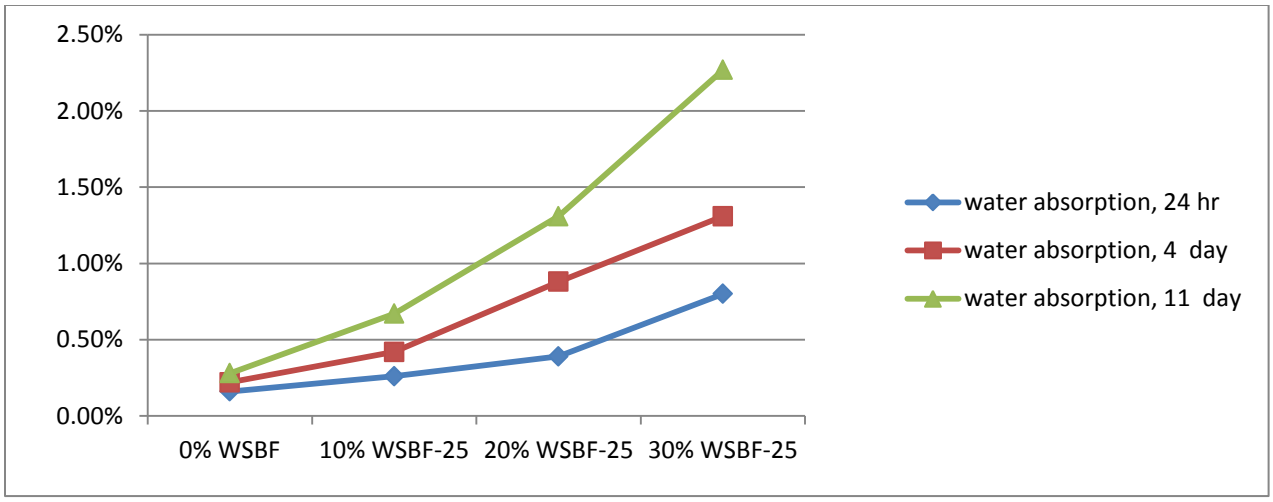

Figure 8. Water Absorption of the PVC and 0% - 30%-wt gWSBF-25 Formulations for 24 h - 11 days.

Conclusions

In our PVC Formulation, as the Wheat Straw (gWSBF) filler load increases from **0%-wt to 30%-wt:**

- Flexural and Tensile Strengths: decrease 10%-20%
- Tensile and Flexural Modulus': increase 55%-95%
- Izod impact (notched): decreases 50%
- Water Absorption: increases 5x – 10x (from 0% to 30% WSBF), but is still less than 2.5% after 11 days

We are continuing with our outdoor weathering tests, to evaluate the changes in mechanical properties over time.

References

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