Journal of Thermal Analysis and Calorimetry, Vol. 85 (2006) 1, 21–24

THERMAL ANALYSIS OF VINYL SIDING

L. Judovits[*] *and C. C. Crabb*

Arkema Inc., 900 First Avenue, King of Prussia, 19406 PA, USA

Vinyl siding is typically produced by co-extruding a capstock (surface layer) over a PVC substrate formulation. The capstock is often non-PVC, these systems can result in warpage during or after production. In our study we will show that this warpage can result from an interfacial induced stress related to the mismatch between the glass transition of the substrate and the capstock. Additionally, both TMA and TMDSC were used to probe the stress release. Capstock formulations which better match the glass transition of the PVC substrate result in superior performance.

Keywords: *capstock, DSC, glass transition, PVC, vinyl siding*

Introduction

Vinyl siding usually consists of a highly stabilized polyvinyl chloride (PVC) capstock (surface layer) over a differently formulated PVC substrate. Premium formulations increasingly are using alternative capstocks due to improved weatherability, mold resistance, and an expanded color palette [1]. However, alternate capstocks have brought along their own challenges as well since they have different physical properties and processing characteristics than does PVC. One problem noted with alternative capstocks is warpage. This is generally not a problem for PVC capped siding since the thermal and rheological properties of the capstock and substrate are similar. This study will explore the underlying causes of this warpage by comparing two different non-PVC capstocks.

Experimental

Differential scanning calorimetry (DSC) and temperature modulated differential scanning calorimetry (TMDSC) were performed on a TA Instruments Q1000 system in the T4 mode with a refrigerated cooling accessory or TA Instruments 2920 with liquid nitrogen cooling. A nitrogen purge was used for all analyses. For all TMDSC runs, a heating rate of 5°C min^{-1} with an amplitude of ±0.663°C and a period of 50 s was used. For all DSC runs, a rate of 20°C min^{-1} on heating and a 10°C min^{-1} rate on cooling was employed. Thermomechanical analysis (TMA) was performed on a Perkin-Elmer TMA 7 using a heating rate of 5°C min^{-1} with a helium purge and a light force of 10 mN. Analysis was performed on two different real world siding samples and their components.

Results and discussion

ASA (acrylonitrile-styrene-acrylate) is sometimes used as a capstock over PVC. Investigation of a formulation made using this capstock showed extreme warping (Fig. 1). However, such warpage is not noted for an acrylic capstock over PVC. As noted in Fig. 2, the TMA comparisons of the two types of siding result in different expansions upon heating. Reheats of the siding did not show such sudden expansions (Fig. 3 below), instead both the cooling and heating ramps superimpose on each other.

Fig. 1 Extreme warping in an ASA capped vinyl siding sample, sample was exposed at 90°C (194°F) for 10 min

Comparisons to an oven test show similar results that compare to the initial TMA heats. For this test, circles were inscribed on siding samples 9 cm in diameter and heated to various oven temperatures for 10 min. Below is a table summarizing the amount of shrinkage or expansion in the *x* and *y* axis directions. The severe curling noted at 90°C corresponds to the peak (90 to 100°C) noted in the TMA. Similarly if we examine pieces heated in the TMA to 90°C, they show warping.

---

[*] Author for correspondence: larry.judovits@arkemagroup.com

1388–6150/$20.00

Akadémiai Kiadó, Budapest, Hungary
Springer, Dordrecht, The Netherlands

Thus the large increase in height noted in the TMA for the siding sample with an ASA topcoat is due to warping and not to expansion of the material.

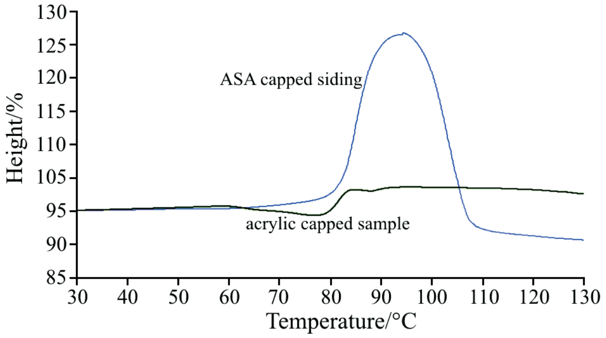

Fig. 2 TMA initial heats of the ASA and acrylic capped siding samples. The runs were heated 5°C min^{-1} with a minimal force of 10 mN

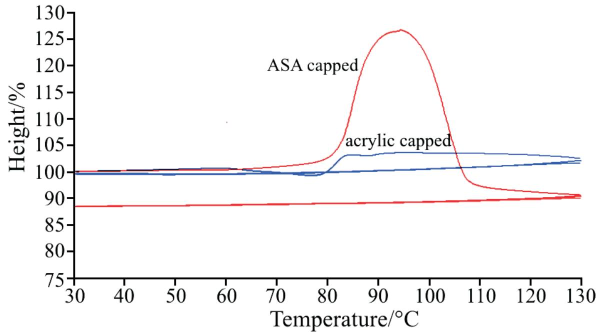

Fig. 3 TMA cycles of siding samples. All runs were cycled 5°C min^{-1} with a minimal force of 10 mN

Comparison of DSC performed on the two siding samples show two glass transitions for the ASA capped siding sample while one glass transition appears evident in the acrylic capped sample (Fig. 4). Although each layer has its separate glass transition, the acrylic sample showed only one transition because both transitions occur over the same temperature range. This was not the case with the ASA material, which showed two transitions. As noted in Fig. 5, the siding curves match the component glass transitions. The PVC transition dominants since it is the major component. This indicates that the physical characteristics of acrylic capped product more closely matches the PVC substrate than does the ASA capstock. More complicated, however, are the initial DSC heats seen in Fig. 6. Both formulations appear to show stress release, particularly the acrylic capped siding. Thus, at first glance, the TMA and the DSC results seem to be contradictory. However, one needs to keep in mind that each technique measures different physical properties. DSC in this case provides an understanding of the process (unfreezing of long range cooperative motion) while TMA monitors the total outcome (dimensional change related to warpage). Moreover, the DSC results are a further indication that the acrylic capped siding can more easily relieve its stress (and not curl) than the ASA capped siding since the glass transitions are a closer match.

A better understanding can be noted in the TMDSC reversing curves (Fig. 7). TMDSC allows one to separate heat flow effects into their reversing and non-reversing constituents. In our case, the glass tran-

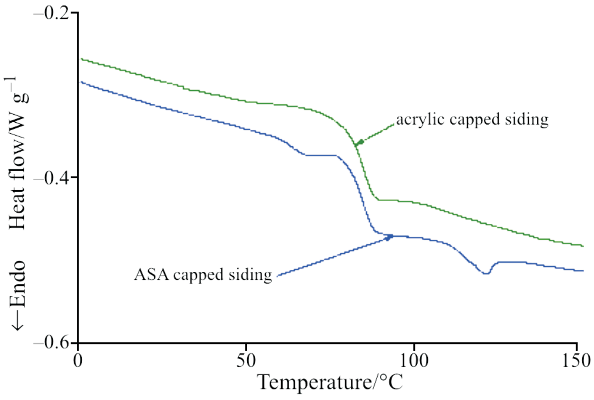

Fig. 4 DSC reheats of siding samples. All runs cooled 10°C min^{-1} through the melt and reheated 20°C min^{-1}

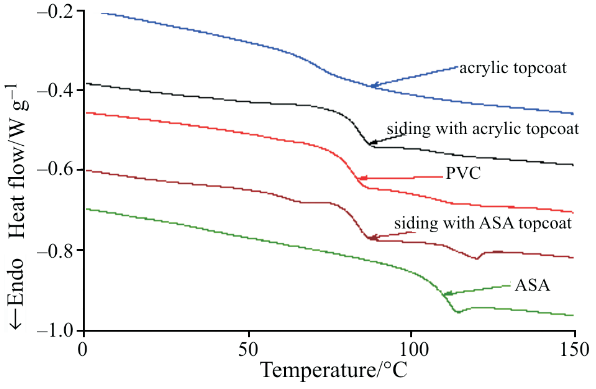

Fig. 5 DSC reheats of siding sample and their components. All runs cooled 10°C min^{-1} through the melt and reheated 20°C min^{-1}

Table 1 Oven testing

Temperature/°C	163	163	130	130	90	90	73	73
Orientation*	M	T	M	T	M	T	M	T
Siding sample				length/%				
ASA topcoat	–15.84	7.37	–9.21	4.84	severe curling		0.14	0.32
Acrylic topcoat	–14.69	3.13	–6.48	2.71	–5.15	1.51	–0.23	0.77

*M=machine, T=transverse

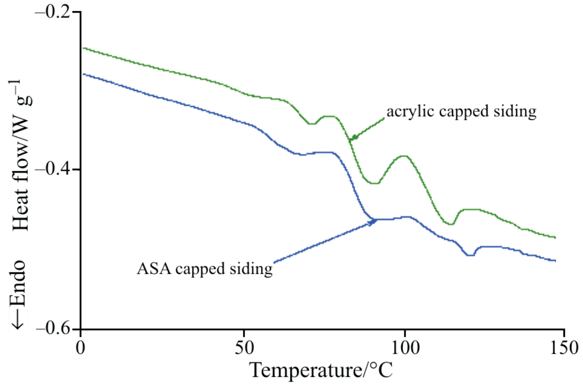

Fig. 6 Initial DSC heats at 20°C min^{-1}. Both formulations appear to show stress release

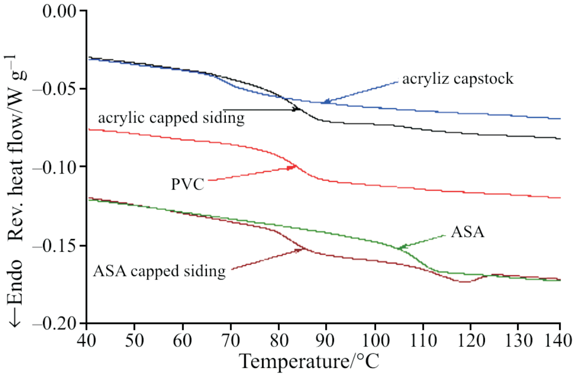

Fig. 7 Reversing heat flow TMDSC curves. All runs were heated 5°C min^{-1} with an amplitude of ±0.663°C and a period of 50 s

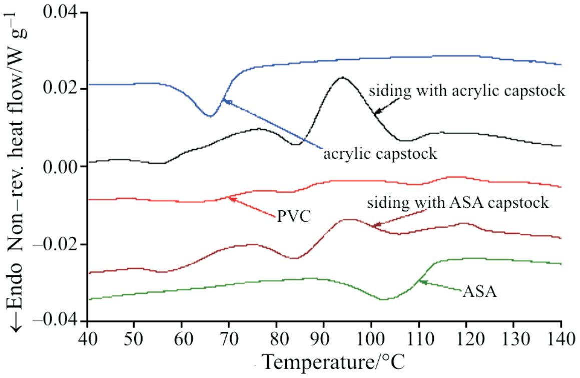

Fig. 8 Non-reversing heat flow of vinyl siding and its components

sition should go into the reversing heat flow while the relaxation effects should go into the non-reversing heat flow. The individual components can now be overlaid with the siding. As mentioned above, two glass transitions are now observed in the ASA capped sample. Of some interest is the large relaxation peak that appears to be associated with the ASA. This can be noted in the DSC trace above and in the TMDSC below of the siding material alone. This relaxation peak does not occur in the reversing curve of the ASA component. Normally, the relaxation peak for a glass transition is separated in the non-reversing heat flow and does not stay in the reversing heat flow. This suggests that this relaxation is probably associated with the interfacial tension between the two layers, once again highlighting stresses introduced by the mismatched glass transition temperatures. If we now note the corresponding non-reversing curves (Fig. 8) we can see various relaxation effects in the siding composite that do not appear to correspond to the capstocks. These effects do seem to match some relaxations observed in the PVC but are more pronounced in the siding. Could this be an indication that the PVC in a siding formulation is under stress?

To further investigate this we performed TMDSC on a PVC formulation that had a variety of thermal histories. This included a control PVC film that had been extruded then heated to 160°C and slowly cooled to relieve stresses, the control film cooled in the DSC 10°C min^{-1} from the melt, the control film stretched at 160°C, and the film stretched at ambient temperature. When stretched at ambient temperature the film necked, however, this was not the case with the high temperature stretch which showed no necking. Generally stress release in the glass transition results in misshaped exotherms [2]. Although there can be other factors that can effect the glass transition such as plastization [3, 4]. The degree of stress release can then be related to the increase in magnitude of the exotherm noted. One can see a trend in the overlay below (Fig. 9) in that the stretched sample shows stress release and can be especially noted for the necked sample, which showed the largest stress release. The largest exotherm noted corresponds to the major exotherm seen in the necked sample.

Consider what happens during the production of vinyl siding: as the coextruded sheet leaves the extruder die, the substrate and capstock are both very hot and at approximately the same temperature. The melt is being pulled and elongated by the first set of pull rolls. Typical elongation in commercial siding is 10–15% in the machine direction. Even though the melt is well above its glass transition temperature, most of this orientation remains in the final product since there is not enough time before vitrification for the sheet to relax. When the melt hits the chilled rolls it begins to cool and then it is quenched when it enters the water bath. As the sheet cools rapidly, it continues to shrink with the alternative capstock shrinking slightly more rapidly than the substrate because of its higher thermal expansion coefficient. This would cause some slight upward curling if the sheet were not being held to shape. What happens next depends on the relative glass transition temperatures of the capstock and substrate. If the capstock has a much higher glass transition than does PVC, it will freeze first. The PVC substrate will then continue to shrink

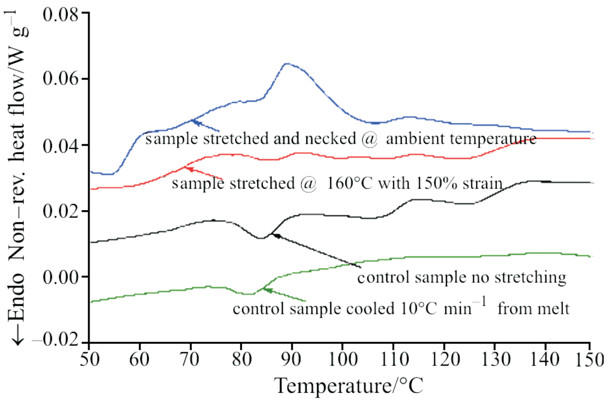

Fig. 9 Non-reversing heat flow of a PVC film subjected to a variety of thermal histories

at a much more rapid rate than the capstock because the thermal expansion coefficient drops substantially when a material is cooled below its glass transition. Again, this disparity in shrinkage rates between the two layers, now much larger, would cause curling if the sheet were not held rigidly to shape. This confinement induces stresses into the siding at the interface (since no delamination is noted). Although some of these stresses relax while the melt is hot enough to flow the remainder are frozen in.

Let us consider two sources of stresses: thermal and mechanical. Thermal stress release relates to the unfreezing of the free volume and the start of free volume production. Mechanical stress release is due to large scale motion in response to an external stress. When both are present after fabrication, usually the induced mechanical stresses are much larger and the mechanical stress release predominates. However, in the case of the siding materials we are probably noting an additional interfacially induced stress. This interfacial induced stress appears to be related to the mismatch between the glass transition of the substrate and the capstock where the lower transition material is unable to relieve stresses induced from thermal contraction (that is, shrinking) as the material is cooled. This stress appears to be as significant as the mechanically induced stress.

Conclusions

In coextrusion of different types of polymers, the potential exists for warpage. This study suggests that the warpage noted in this study appears to be related to when a large mismatch in glass transitions between the capstock and substrate occurs. The mismatch results in different rates of relaxation of the orientational stresses in the capstock and substrate, leading to warping or curling. This phenomenon is minimized or eliminated when the glass transition temperatures of the two layers are the same.

TMDSC was also found to be a useful probe of gauging the mechanically induced stress in PVC when oriented below the glass transition. The non-reversing component showed an increase in a stress release exotherm that could be related to the residual orientation.

References

1 C. C. Crabb and P. Schipper, SPE ANTEC, Annual Technical Conference, 3 (2002) 3352.
2 B. Wunderlich, ‘The Basis of Thermal Analysis’, in Thermal Characterization of Polymeric Materials, 2^{nd} Ed., E. Turi, Ed., Academic Press, 1997.
3 W. B. Xu, Z. F. Zhou, M. L. Ge and W.-P. Pan, J. Therm. Anal. Cal., 78 (2004) 91.
4 M. Benes, V. Placek, G. Matuschek, A. A. Kettrup, K. Györyová, W. D. Emmerich and V. Balek, J. Therm. Anal. Cal., 82 (2005) 761.

DOI: 10.1007/s10973-005-7337-9