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Evaluation of latex adhesives containing hydrophobic cores and poly(vinyl acetate) shells: potential to improve poly(vinyl acetate) performance

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Abstract

Various experimental poly(vinyl acetate) (PVAc) latices containing relatively rigid polystyrene (PS) domains were investigated in order to evaluate whether the presence of PS domains improves the performance, especially the creep resistance, of PVAc adhesives. The effects of a range of PS content, PS/PVAc morphologies and core-shell polymerisation approaches were examined by evaluating thin-film mechanical properties and adhesive performance. The results have shown that up to 50% PS (by mass) can be incorporated into a PVAc latex without compromising adhesive strength. Mechanical testing of films indicated the presence of PS maintains film performance at elevated temperature (60°C). Polymers formed using a chain transfer agent during the second stage styrene polymerisation had a concentric core-shell morphology and these performed better than either copolymers having an acorn morphology or a simple blend of PS and PVAc. Incorporation of PS domains into a commercial PVAc adhesive by second-stage polymerisation of styrene did not greatly diminish the performance of the conventional adhesive. While performance advantages acquired by adding PS into PVAc particles were demonstrated during creep testing at high humidity, the presence of PS did not impart any improved resistance to water or to heat, as determined by accelerated exposure water soak testing and shear block testing above 70°C.

Keywords: Poly(vinyl acetate); PVAc adhesive; Creep resistance; Core-shell polymers

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1. Introduction

Poly(vinyl acetate) (PVAc)-based wood adhesives find application in an extensive range of products where the glue may be used in fingerjointing and edge- and face-laminating applications [1]. While PVAc adhesives are convenient to use, have low toxicity and a clear glueline, there are detracting features of this glue which limit its application as an adhesive to non-structural uses only. PVAc adhesives are well known to be susceptible to both moisture and heat, and also tend to creep under load [2,3]. These deficiencies are primarily due to the inherent mechanical properties of the PVAc polymer and plasticisation of PVAc gluelines by moisture [2,3]. The glass transition temperature (T_g, 35°C) of PVAc homopolymer is relatively low [3]. This leads to softening of the PVAc matrix at temperatures above ambient and an associated weakening of glued joints. Similarly, water exposure (soaking or high humidity) has a plasticising effect and will also reduce the strength of any PVAc glueline. Thus PVAc gluelines placed under load are inherently prone to deformation over time and creep, and are therefore unsuitable for use in structural applications. Inappropriate use of PVAc adhesive in such situations invariably results in product failure, of which there are many examples in the commercial arena.

There have been many attempts to overcome, even in part, the deficiencies of PVAc adhesives [2]. Those that have been more successful have tended either to

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incorporate copolymers, e.g. ethylene-vinyl acetate (EVA) [2], or to introduce cross-linking within the PVAc polymer network, either by incorporating appropriate comonomers such as *N*-methylol acrylamide or through the use of isocyanates [3]. The last two approaches necessitate the use of PVAc adhesives as two-component systems, due to the addition of a curing agent prior to glue application. While there are performance advantages over conventional PVAc adhesives, such two-pot formulations require additional preparation and mixing, and do not completely overcome PVAc deficiencies [3]. In fact, no simple, one-component PVAc formulation is commercially available that can offer the potential to overcome all the deficiencies of PVAc adhesives.

One approach to overcome inherent deficiencies of PVAc adhesives may be to design in the required performance, e.g. to improve creep resistance of the PVAc adhesive by enhancing the film's mechanical properties. Incorporation of a hard, relatively high-T_g polymer such as polystyrene (PS) or poly(methyl methacrylate) into the PVAc polymer could emulate the effect of filler materials [5]. This may have the beneficial effect of reinforcing the adhesive glueline against creep and it may also offer some resistance to heat and moisture. By designing the "filler" material within the PVAc adhesive nanoparticles, it is hypothesised that creep performance could be improved while the advantages of a one-pot adhesive system are maintained. In other polymer systems, the use of additive materials to reinforce or modify performance is a common approach, and examples include the use of silica in rubber [6] and the use of PS in EVA formulations [7]. In each case, the purpose of the filler particles is to reinforce the polymer matrix, thereby making it less deformable. In the case of PVAc, the presence of PS in the form of a particle structure should have a similar beneficial effect on glueline creep.

This paper is the fourth in a series investigating the incorporation of PS into PVAc dispersions. The first three papers [8,9,10] were concerned with producing such dispersions. This paper tests the hypothesis outlined above, i.e., it details the mechanical and adhesive performance of PVAc-based adhesives in which PS domains have been incorporated by polymerisation of styrene into PVAc seed emulsions [9,10]. In attempts to overcome inherent incompatibility of vinyl acetate and styrene polymerisation, latices have been prepared by inverse core-shell techniques. Evaluations of adhesive films and glue bonds of PVAc/PS latices were undertaken in order to quantify relationships between PVAc/PS latex microscopic structure and adhesive performance, the outcome being to design in improvements to PVAc-based wood adhesives through the use of this approach.

2. Materials and methods

2.1. PVAc latices

Latices varying in PS content were created by using the same PVAc seed, with the addition of varying amounts of styrene in a second-stage polymerisation to produce PS/PVAc core-shell (CS) type composites, as described previously [10]. These PS/PVAc latices ranged in PS content from 0% to 75% (Table 1). Transmission electron microscopy (TEM) indicated that each composite particle had one PS domain, located at, or very close to, the particle surface [9].

In order to assess the effects of particle morphology on PVAc performance, three PS/PVAc morphologies were investigated: (1) PS/PVAc core-shell made by the conventional route [9]; (2) so-called acorn morphology, as produced by inverse core-shell polymerisation [10]; and (3) a blend of PVAc and PS latices. These different morphologies are indicated by the labels 'CS', 'Acorn', and 'Blend', respectively, and all have the same, overall composition of 50% PS in each PS/PVAc latex (Table 2) and a particle radius of ca. 55 nm [9,10] (the reason for such a small size is that it is impossible to make a CS latex of much larger size by the conventional route [8,9]). In order to compare the performance of structured PS/PVAc particles with that of a simple mixture of the two homopolymers, a blend was created by mixing PVAc and PS latices to have an equal weight

Table 1
Tensile film and adhesive testing results for PVAc latices varying in PS content

PVAc latex % PS	Maximum stress		Adhesive testing			
	25°C (MPa)	60°C (MPa)	Break load (N)	Std. dev. (N)	Wood failure (%)	Std. dev. (%)
0	1.50	0.02	2380	241	69	18
11	1.89	0.03	1572	384	27	31
33	2.41	0.74	1983	177	35	20
49	1.71	1.43	1969	83	52	6
60	0.98	1.14	1821	41	36	14
67	1.40	1.27	1416	80	12	8
75	0.96	1.16	828	75	0	0