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Importance of Dynamic Mechanical Analysis to Predict Performance of the Polyvinyl Acetate Wood Adhesives in Summer Season

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Abstract

Conventionally available Polyvinyl acetate (PVAc) wood glues are polyvinyl alcohol (PVA) stabilized, with drawbacks like poor strength at high humidity, poor strength at high temperature and workability at low-temperature. PVAc is non-resistant to high humidity, and if such adhesive bonds are exploited in a highly humid environment, its strength substantially decreases. Sufficiently water-resistant adhesive bonds are achieved by modifying PVAc dispersion with special chemicals like acrylic acid (AA) and N-methylol acrylamide (NMA) as a co-monomer, Silanes, and ethylene modified PVA. The Lewis acids like aluminium chloride and aluminium nitrate are used as cross-linkers. So PVAc adhesives are classified as reactive and non-reactive glue. Application of non-reactive D1 (as per EN 204-205) and reactive D2 and D3 (as per EN 204-205) adhesives for bonding laminate on plywood is a regular practice in the Indian market. In summer time, Crack formation was seen in laminate bonded with reactive D2 and D3 adhesives in regions where the room temperature was above 45˚C. However, if the same laminate substrates were bonded with non-reactive D1, no cracks were seen. To analyse the above phenomenon, we have done Dynamic mechanical analysis of non-reactive D1, reactive D2 and D3 adhesive.

Keywords

Polyvinyl Acetate, Wood, Adhesive, Cracking, Dynamic Mechanical Analysis

1. Introduction

Water soluble polyvinyl alcohol (PVA) is a polymer prepared by partial or complete hydrolysis of polyvinyl acetate (PVAc). It possesses a high crystalline structure due to hydrogen bonding [1]. Physical and chemical properties including water-resistance of PVA depend on the degree of hydrolysis [2] [3] [4]. Polyvinyl acetate (PVAc) emulsion-based adhesives are also called white glues, are thermoplastics polymer, softening when the temperature is increased to a particular level and hardening again when cooled to room temperature. PVAc glues solidify by evaporation or absorption of water by the gluing material or substrate [5]. PVAc glue is used for general wood assembly applications, lamination of plywood, wood thin and thick veneer, and edge bonding as a furniture and carpentry adhesive. In the Indian market, different wood glues are used to bond laminate on commercial plywood and boiling waterproof plywood [6]. Bonded assembly is shown in **Figure 1**.

Crack formation was seen in substrates bonded with reactive D2 and D3 (as per EN 204-205) glues in regions where the temperature was above 45˚C. Cracked assembly is shown in **Figure 2**. However, if the same laminate substrates were bonded with non-reactive D1 (as per EN 204-205) adhesive, no cracks were seen. Here five different PVAc reactive and non-reactive adhesives are taken for Dynamic mechanical analysis and compared against the market findings [4].

Figure 1. Sunmica to plywood bonded assemblies.

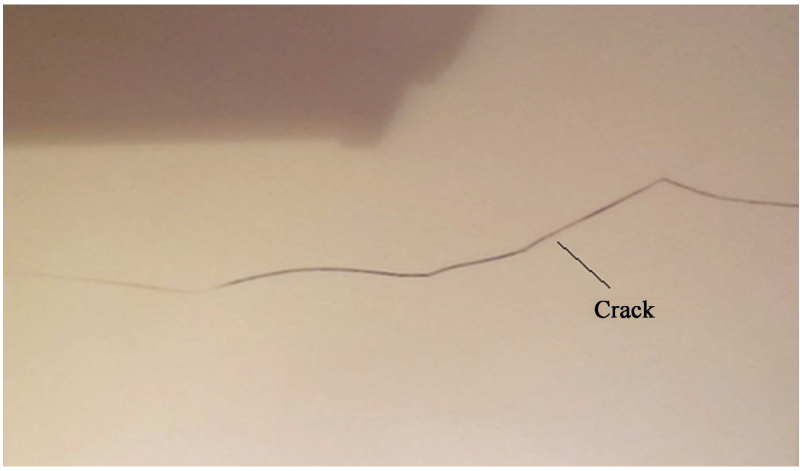

Figure 2. Cracked assembly.

Crosslinking study by DMA analysis

Emulsion polymer films respond to the energy of motion in two ways 1) Elastic response on stress vs. strain relationship curve, which is important for shape recovery; 2) Viscous response on stress vs. strain relationship curve, which is important for dissipating mechanical energy and preventing damage. Viscoelasticity is the property of polymer materials that exhibit viscous and elastic characteristics when deformed. Dynamic mechanical analysis (DMA) is widely used to analyse the viscoelastic characteristics of polymers and is tested as per ASTM D 599296 and SAE Standard J1085 [7]. In DMA, oscillating force is applied to a sample and material's response to that force is analyzed. These responses are expressed in terms of storage modulus (G'), loss modulus (G"), and tan δ (G"/G') as a function of, frequency, temperature or time [8]. The tan delta curve helps to obtain the glass transition temperature (T_g) of the polymer sample. DMA uses a set of samples holding clamps for mechanical testing of polymeric material. The test sample must be molded into a required shape that can work with the selected clamp type. Clamp selections for polymeric samples are based on giving the most suitable motion for specific study types. All DMA clamp configuration features a movable clamp and one or more stationary clamps that are used to mount the sample. The portable part applies the force and displaces the test sample by bending, stretching, shearing or compressing its [9]-[14].

In this paper, we have analyzed polymeric networks with varied crosslinking degrees with the help of DMA analysis and correlate with laminate cracking tendency in summer season. This will be helpful for selection of adhesive at different locality prior to application to avoid the complaint at costumer end. DMA was used to determine the thermomechanical properties of the reactive and non-reactive PVAc wood glues. The curves of the loss tangent and bending storage modulus as a function of temperature were obtained and analyzed.

2. Experimental

Materials

PVAc NR, PVAc R-01, PVAc R-02, PVAc R-03 and PVAc R-04 samples were received from Indian market.

(NR-Non-reactive and R-Reactive)

Sample Preparation

Sample films were prepared by casting them on the Teflon sheet & allowed to be cured at room temperature for 2 days. Prepared films were cut in a definite dimension (Length * Breadth * Width) with the help of a sample cutter prior to the analysis.

3. DMA Characterization

DMA was performed using DMA Q800 from TA Instruments, Mumbai, India. A thin glue film of 200 micron was prepared by applying it on a Polytetrafluoroethylene (PTFE) substrate. The film was kept for physical drying at 30˚C for 24 hrs. The film was removed from the PTFE substrate and placed in the DMA sample holder. The temperature range in DMA test was from −30˚C to 150˚C, with a ramp rate of 5˚C·min^{-1}, frequency 1 Hz and strain 0.1%.

4. Results and Discussions

All the five sample films exhibited the single major transitions above the glassy temperature region: around 40˚C (Tan delta peak) which corresponds to PVAc glass transition through which neat films get softened indicated by almost 4 decades reduction in storage modulus. Overlaid thermogram as shown in Figure 3 of storage modulus curves indicates the highest modulus value for the PVAc R-03 followed by PVAc R-04. PVAc R-01 is the lowest compared to the PVAc NR which comes in the middle.

Compared to PVAc NR, all the four samples exhibit main chain transition (Glass Transition) onset shift to slightly higher temperature indicating better stiffness & elasticity in these films topped by PVAc R-03 followed by PVAc R-04, PVAc R-01 & PVAc R-02 respectively. Storage modulus data at temperature 40˚C (*i.e.*, above room temperature & closer to application temperature) reflects the similar trend with highest modulus value for PVAc R-03 & lowest for the PVAc NR. Rubbery region storage modulus values indicate presence of strong crosslinked network in PVAc R-03 followed by PVAc R-04, PVAc R-01 & PVAc R-02. Loss Modulus curves also indicate the highest modulus value for PVAc R-03 as shown in Figure 4. Tan delta overlay also indicate the shift to higher

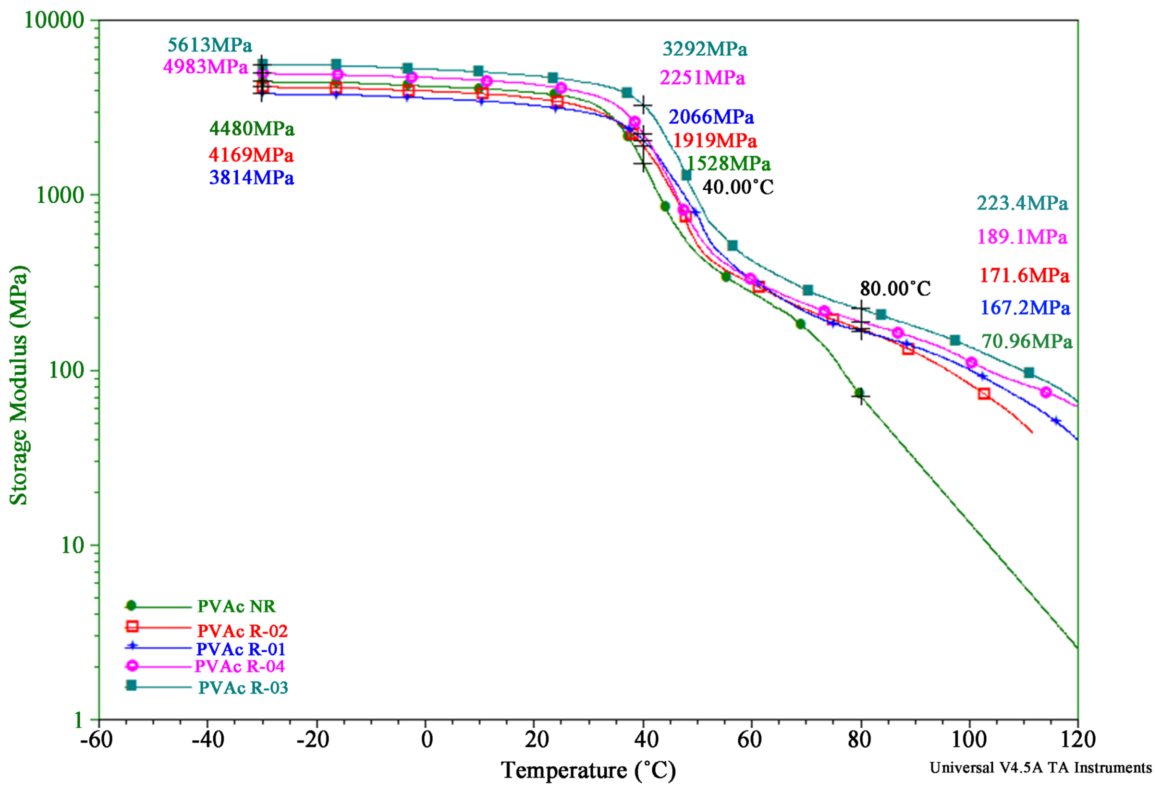

Figure 3. Overlaid thermogram of storage modulus (E') for all the five samples.

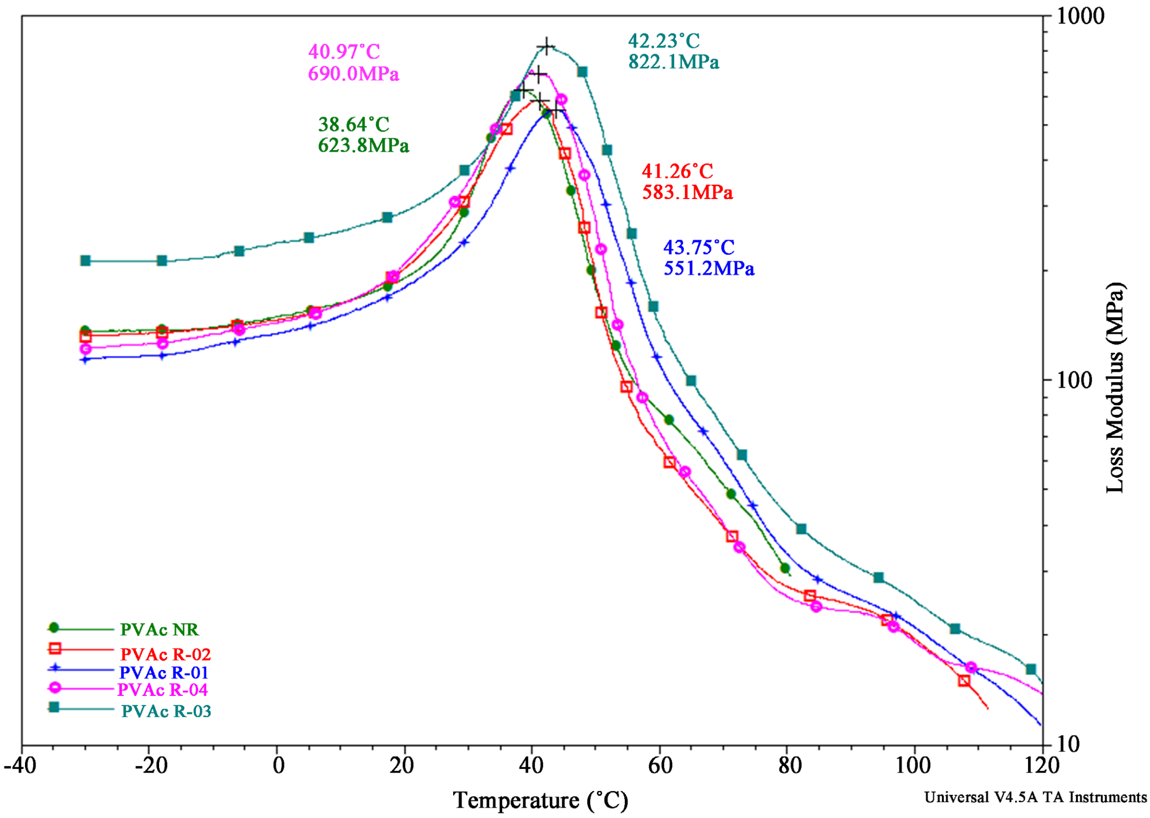

Figure 4. Overlaid thermogram of loss modulus (E") for all five samples.

temperature in PVAc R-03, however the PVAc R-01 sample also indicates the similar shift as that of the PVAc R-03 compared to PVAc NR as shown in Figure 5. PVAc R-02 being the plasticized variant of the PVAc R-01 sample indicate the lowering of the glass transition with tan delta shift to lower temperature. Crosslinked density data are shown in Table 1.

Theoretically at elevated temperatures in a crosslinked system, in plane tensile stresses may get induced in the films which leads to cause the defects like cracking however the surface chemistry of the substrate & thermal expansion mismatch between the film & the substrate can also be the possible causes of the defects which should be considered while analysing the above data for comparing the films. Low-modulus adhesive may readily relieve stress concentration by deformation. When the system is a crosslinking one, at higher temperature the modulus of elasticity increases to a greater extent where the adhesive no longer can effectively release the concentrated stress and may cause defects in the bonded substrates. Storage modulus is the elastic response of the material. It measures the stored energy. Hence if the material has high storage modulus, then there are higher chances of the presence of the concentrated stress.

5. Conclusion

Application of non-reactive D1 and reactive D2 and D3 adhesives for bonding sunmica laminate on plywood is a regular practice in the Indian market. In

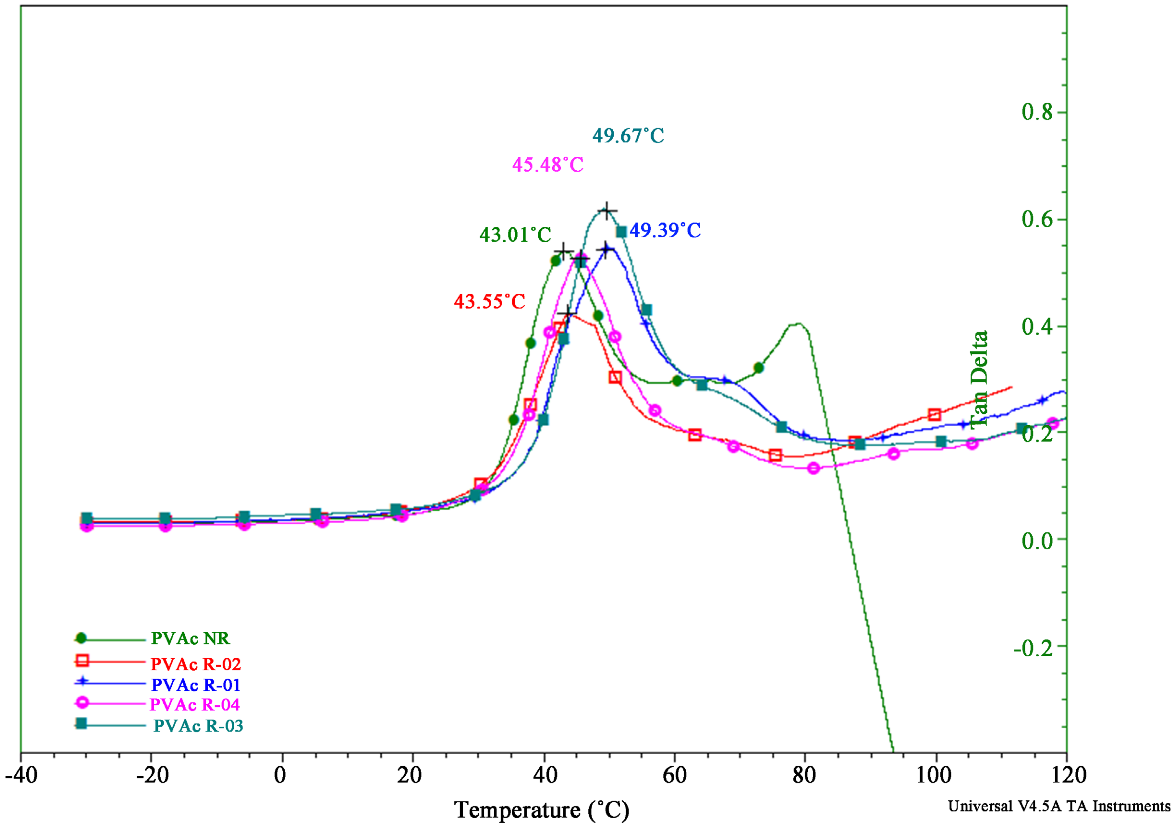

Figure 5. Overlaid thermogram of Tan Delta for all five samples.

Table 1. DMS analysis.

Sample Name	Storage Modulus at glassy region (E' initial) (MPa)	Storage Modulus at 40˚C (MPa)	Storage Modulus at rubbery region (E' rubbery) @ 80˚C (MPa)	Loss Modulus (E") peak (˚C)	Loss Modulus (E") peak max (MPa)	Tan Delta Peak (˚C)	Cross-link Density (10^{-3} mol/cc)
PVAc NR	4480	1528	70.9	38.6	623.8	43.0	08.00
PVAc R-01	3814	2066	167.2	43.7	551.2	49.4	19.00
PVAc R-02	4169	1919	171.6	41.3	583.1	45.3	19.50
PVAc R-03	5613	3292	223.4	42.2	822.1	49.7	25.36
PVAc R-04	4983	2251	189.1	40.9	690.0	45.5	21.50

summer time, Crack formation was seen in laminate bonded with reactive D2 and D3 adhesives in regions where the room temperature was above 45˚C. Low-modulus glues may readily relieve stress concentration by deformation process. When the system is a crosslinking one, at a higher temperature the modulus of elasticity increases to a greater extent where the adhesive no longer can effectively release the concentrated stress and may cause defects in the bonded substrates. Storage modulus is the elastic response of the material. It measures the stored energy. Hence if the material has high storage modulus, then there are higher chances of the presence of the concentrated stress. So, the selection of proper grade of PVAc adhesive in summer season is important to avoid the laminate cracking issues due to thermomechanical properties of glues.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Abbreviations

PVA	Polyvinyl alcohol
PVAc	Polyvinyl acetate
DMA	Dynamic mechanical analysis