



Synthesis and characterization of xanthan gum stabilized polyvinyl acetate-based wood adhesive

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Abstract

Repercussion of overutilizing the fossil fuels and petrochemicals resulted in global warming and polluted environment. Hence, in the quest for alternative sources of raw materials for developing greener adhesives, renewable and natural polymers like polysaccharides have a huge potential. In particular, the traditional water-based emulsion wood adhesive employs colloid-like polyvinyl alcohol for stabilizing polyvinyl acetate (PVAc) emulsion. Researchers have recently become interested in utilizing xanthan gum, a naturally occurring polymer, in place of stabilizers. Here, the effects of xanthan gum addition as a stabilizer for PVAc homopolymer-based wood adhesives on performance properties were investigated. Emulsion polymerization technique was employed to synthesize xanthan gum stabilized PVAc homopolymer emulsion. Hence, the present work investigates the applicability of xanthan gum added 0.5% and 1% as a colloid for the synthesis of PVAc wood adhesives. Effect of the addition of xanthan gum as a colloid on physical, thermal, and mechanical properties was studied by viscosity, pH, contact angle measurement, differential scanning calorimetry (DSC), and pencil hardness test of films. Emulsions in varying xanthan gum concentrations were prepared, and a universal tensile machine was utilized to measure the shear strength of the PVAc homopolymers applied to wood. As the concentration of xanthan gum increased, the adhesives' viscosity increased. The drastic increase in water resistance with increasing xanthan gum content was confirmed by water contact angle measurement. The use of xanthan gum improved the PVAc films' hardness as well. When compared to a pristine sample, the tensile shear strength with 1 wt% of xanthan increased by 50% after 6 h of bonding in dry environment and by 61% in wet conditions (as per EN 204). The study's overall conclusion highlights the enhanced adhesive performance of xanthan gum stabilized PVAc emulsion-based adhesives.

Keywords Xanthan gum · Polyvinyl acetate · Polyvinyl alcohol · Wood · Adhesive

Introduction

Environmental concerns and the idea of carbon neutrality speed up the development of sustainable technologies, smarter and energy efficient storage devices, and value-added products from sustainable materials [1–9]. Construction and related fields have also focused usage of smarter and sustainable materials as alternative to fossil fuel-based products [10–12]. Petrochemical-based raw materials are used by chemical industries to create value-added products [13–17]. One such instance of a vital component in the wood joinery industry is adhesives [18]. Solvents and synthetic polymers are the key components of synthetic adhesives, having their petrochemical origins [19]. These materials release volatiles, which contaminates environment and are harmful to both human and environment [20, 21]. Therefore, taking into account these constraints, focused research is being done to replace petrochemicals partially or entirely with sustainable materials [22–25]. Water-based wood adhesives, which use water as a solvent rather than volatile organic solvents, are one such development. Polyvinyl acetate (PVAc) emulsion-based adhesives are one of the main candidates in water-based systems [26]. Polyvinyl alcohol (PVA) has traditionally been used in PVAc wood adhesive as a protective colloid [27, 28].

PVAc-based adhesives provide a lot of benefits, including affordability, good adherence to wood substrate, ease of processing with a straightforward mixing method, and great stability [29]. Today, petroleum-based polymers are mostly used to synthesize wood adhesives. There is a desire to use less petroleum-based raw resources and incorporate more bio-based polymers [30–32]. Given the fact that bio-based raw materials are widely available, renewable, non-toxic, and biodegradable [33]. Polysaccharides have been suggested as a potential replacement for PVA in the stabilization of PVAc emulsion [28, 34]. The physical, chemical, and mechanical properties of polysaccharides were modified by the use of grafting, a crucial approach [35, 36]. One of the greatest techniques to enhance the mechanical properties of polysaccharides is to graft polymerization of synthetic polymers onto a polysaccharide's backbone [37]. Apart from starch, which is one of the most reported materials in wood adhesive sector, graft polymerization on similar materials has also huge potential. One such sustainable and naturally occurring polysaccharide material can be xanthan gum (XG).

Xanthan gum is an edible material, which is created by an exopolysaccharide generated by microorganisms through fermentation engineering of carbohydrates [38]. It is widely used as a thickening, suspending agent, emulsifier, and stabilizer and has unique rheological properties, good water solubility, stability to heat, acid, and alkali, as well as good compatibility with various salts [39]. A trisaccharide side chain is linked to alternate D-glucosyl residues in XG, which is composed of 1,4-linked B-D-glucose residues. The backbone of the polymer is similar to that of cellulose. The side chains are β -D-mannose-1,4- β -D-glucuronic acid 1,2- α -D-mannose, where the internal mannose is mostly O-acetylated, and the terminal mannose may be substituted by a 4,6-linked pyruvic acid ketal as shown in Fig. 1 [40]. An anionic polysaccharide, XG has a very high molar mass of above 2000 kg/mol, but it can also be as high as 13,000–50,000 kg/mol. Its

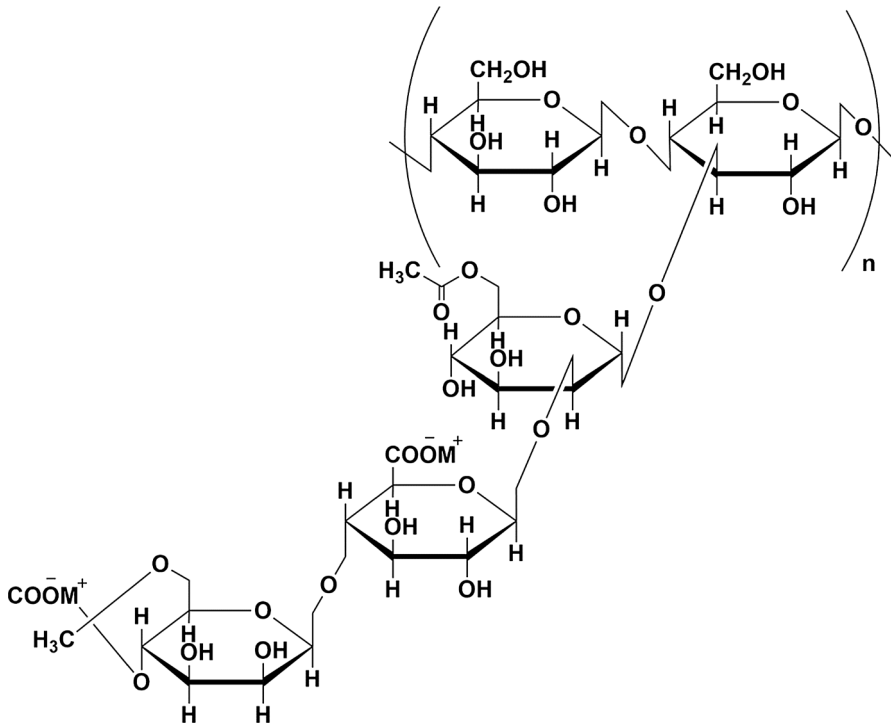


Fig. 1 Chemical structure of xanthan gum

primary chain is made up of glucose units that are separated by mannose and glucuronic acids [39]. Cold and hot water both dissolve XG. Over a wide range of pH values, XG is stable. As a naturally occurring polymer, XG is fully biodegradable according to DIN 38412-L25. In order to achieve the desired thixotropic index and viscosity, XG is used in paints. Other technical uses for XG’s rheological characteristics include printing pastes, colours, texture coatings, and adhesives [41].

A portion of the polyvinyl alcohol in the water-based thixotropic adhesive clear gel is replaced with polyvinylpyrrolidone and XG to give the gel its thixotropic properties. The gel has a thixotropic index that allows the adhesive’s viscosity to break down when a flexible tube or squeeze bottle dispenser is finger-pressed, but it also has a low enough viscosity to make it simple to extrude the gel through an orifice with a diameter of between 0.06 and 0.15 in. To low penetration materials including glass, plastic, and metals, polyvinyl acetate has a strong initial adhesiveness [42]. In addition to acting as a thickening and having pseudoplastic qualities, XG has the effect of making PVAc more adhesiveness. In addition to enhancing the viscosity of water-soluble vinyl acetate derivatives, XG also improves the adhesive strength [43]. The bio-based modified built-in white emulsion and excellent film-forming performance, strong adhesive strength, and

broad application range of the bio-based modified tilde white latex prepared by introducing bio-based raw material of XG, guar gum, and cellulose copolymerized with VAc [28, 30]. High bonding strength, good water resistance, quick drying time, and good creep resistance were all benefits of XG-based carpenter glue [44]. The advantages of the bonded artificial plate using XG as the adhesive include high bonding strength, high water resistance, lack of odd odour, lack of toxicity, lack of annoyance, and lack of formaldehyde pollution caused by common glue.

As XG being a suitable material for water-based adhesives, the current work investigates XG blended PVA as a protective colloid for PVAc emulsion adhesive. As XG has free hydroxy groups, the possibility of grafting vinyl acetate with XG is a workable mechanism. By grafting XG with vinyl acetate, adhesive properties can be further enhanced. The expected grafting of VAc monomer on hydroxyl group of XG is shown in Fig. 2.

XG at different concentrations (0.5 wt% and 1.0 wt%) was incorporated with PVA and synthesized PVAc emulsion. In addition to adhesive performance measurements,

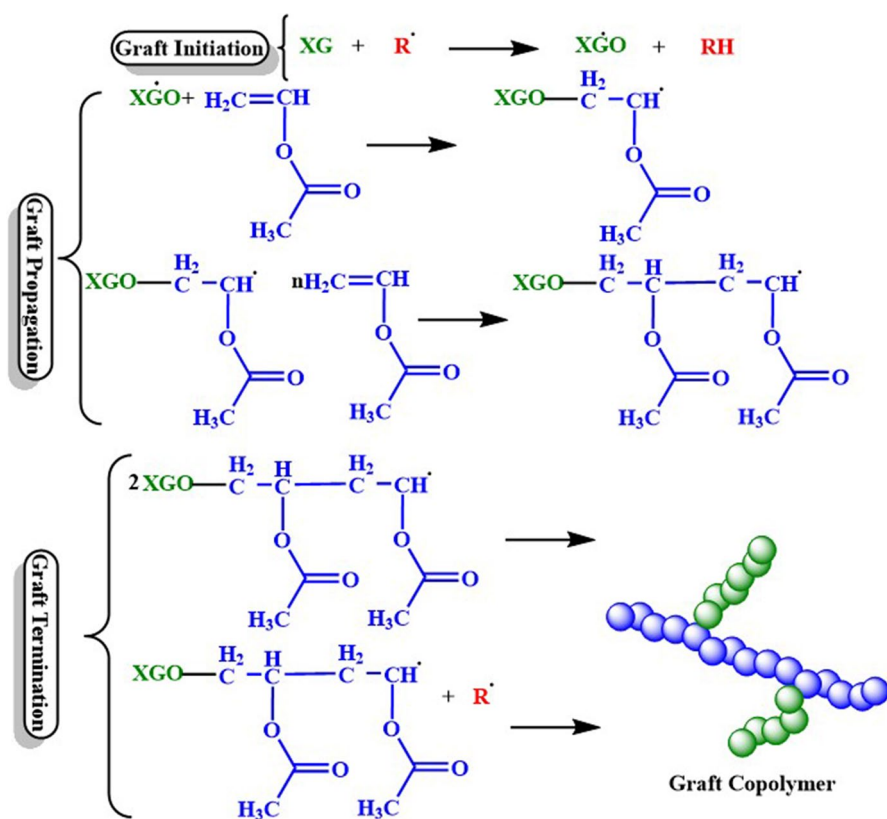


Fig. 2 Grafting of vinyl acetate on xanthan gum (colour figure online)

physical, thermal, and mechanical properties were evaluated. In both dry and wet environments, the XG increased the bonding power of PVAc adhesive. The improvement was evaluated using the shear strength in wet conditions and the percentage of dry wood failure at room temperature. As a result, the study provided a comparison of the effectiveness of PVA stabilized PVAc and XG-PVA stabilized PVAc adhesives. The work presents a XG-PVA stabilized PVAc adhesive with improved physico-chemical, mechano-thermal, and adhesion properties. This work thus opens the way toward the development of an adhesive that is sustainable and environmentally friendly and is based on the colloid XG.

Experimental

Materials

Partially hydrolyzed polyvinyl alcohol (PH PVA) (CAS No. 9002-89-5, % degree of hydrolysis 87–89%, molecular weight 99,000–105,000 g/mol) was obtained from Kuraray Cooperative Limited, India. Vinyl acetate (VAc, CAS No. 108–05-4), sodium lauryl sulphate (SLS, CAS No. 68585-34-2), sodium bicarbonate (SBC, CAS No. 144-55-8), potassium persulphate (PPS, CAS No. 7727-21-1), 2- ethyl hexanol (2 EH, CAS No. 104-76-7) and isothiazolinones preservative (CAS No. 1003-07-2), xanthan gum (pH), and bulk density (untapped 0.3 g/cm³, CAS No. 11138-66-2) were acquired from Sigma-Aldrich. Deionized water (DIW), which was made and tested in the laboratory, was utilized throughout the entire of the experiments.

Preparation method

Preparation of adhesive samples was performed in a similar method reported by Gadhave et al. [28, 45]. Preparation was executed in a flat-bottom glass reactor with a condenser, stirrer, temperature indicator, metric pump, and glass funnel for adding additives. The polymer-based emulsions were synthesized by a semi-continuous emulsion polymerization technique, with thermal energy continuously supplied from a water heating bath. The polymer emulsion recipes are shown in Table 1.

Colloid solution preparation

PVA was first added to a glass reactor with a sealed fat bottom, a stirrer, and a condenser. The complete set was submerged in a bath of water. After adding deionized water, the mixture was continuously stirred at 175 rpm. The final temperature was held at 94–96 °C for 2.5 h after being gradually elevated to that range. Isothiazolinones were then added as a preservative when the solution was cooled to 25 °C.

Table 1 Composition of the emulsions

Components	PVAc Homo Weight (%)	PVAc XG-01 Weight (%)	PVAc XG-02 Weight (%)
Vinyl acetate monomer (VAc)	46.60	46.10	45.60
Xanthan gum	0.00	0.50	1.00
DIW	45.11	45.11	45.11
PH PVA	2.63	2.63	2.63
SBC	0.11	0.11	0.11
SLS	0.01	0.01	0.01
2-Ethyl hexanol	0.01	0.01	0.01
DIW	1.53	1.53	1.53
PSS	0.06	0.06	0.06
DIW	1.20	1.20	1.20
PPS	0.04	0.04	0.04
DIW	2.30	2.30	2.30
Sodium benzoate	0.10	0.10	0.10
DIW	0.15	0.15	0.15
Isothiazolinones preservative	0.15	0.15	0.15
Total	100	100	100

PVA–xanthan gum solution preparation

Calculated amounts of XG and PVA were added to a glass reactor. The mixture was kept stirring continuously at 175 rpm with water as solvent. The temperature gradually increased to 94–96 °C and maintained for 2.5 h. After that, the solution was cooled to 25 °C, and a preservative composed of isothiazolinones was added.

Preparation of PVA stabilized emulsion (PVAc Homo) and PVA and xanthan gum stabilized emulsion (PVAc XG-01 and PVAc XG-02)

Generally, PVA is employed as a emulsion stabilizer in water-based PVAc adhesives [28]. In the present work, for the stabilization of the pristine emulsion, PH PVA solution was used as a protective colloid. Sodium lauryl sulphate was employed as an anionic surfactant. To control foam generation in batch, 2-ethyl hexanol was employed. For the buffer solution, sodium bicarbonate was incorporated. Initiator consists of potassium persulphate solution prepared in deionized water. Vinyl acetate (VAM) monomer was slowly incorporated to perform the polymerization reaction. Up on incorporation of entire monomers, potassium persulphate solution in water was added, and the temperature was maintained at 90 °C for an hour. Isothiazolinone was finally incorporated, which functions as a preservative, after the prepared emulsion was brought to 25 °C. As mentioned earlier, preparation of XG incorporated samples (PVAc XG-01 and PVAc XG-02)

was also prepared in a similar procedure. A blend of PH PVA and XG solution was employed for the preparation of the modified emulsion.

Characterization and testing

Solid content

By heating a sample (about 1 g) in a hot air oven for 120 min at 120 °C, the solids content of the emulsion was determined. In order to reduce error, measurements were made three times. To measure the solid content, the following equation was used,

$$\text{Solid content (\%)} = (W_3 - W_2) / (W_2 - W_1) \times 100\%$$

W_1 = weight of empty weighing pan, W_2 = weight of pan with sample before heating, and W_3 = weight of pan with residue after drying till constant weight.

Viscosity

A Brookfield viscometer RVT was used for calculating the viscosities of the samples. The values were taken at 20 rpm and at a temperature of 30 °C.

pH

pH of the samples was analysed using a digital pH meter, CL 54 + Toshcon Industries, India. To reduce the error, viscosity and pH measurements were taken for 5 times.

Fourier transform infrared spectroscopy (FTIR)

Functional group in hybrid samples was determined by IR spectroscopy analysis using PerkinElmer Spectrum Express 100 spectrometer. ATR-FTIR technique was used for analysis. Sample film was prepared on Teflon sheet and dried at 105 °C for 1 h. Dried film was placed on diamond crystal for scanning. Spectra between 400 and 4000 cm^{-1} were recorded. A background scan was conducted prior to analysis in order to reduce inaccuracy during the reflectance method test.

Differential scanning calorimetry (DSC)

A PerkinElmer instrument Q 100 DSC has been used for estimating the glass transition temperature (T_g) of the samples. During the measurement, an oxygen-free nitrogen stream of 40 mL/min was maintained through the cell. Sample film casted on Teflon was dried at 105 °C for 90 min. About 5-mg film was analysed directly on DSC by

heat–cool–heat method. The DSC analyses were done within a range of -70 – 150 °C at a heating rate of 20 °C min^{-1} .

Drying time on glass plate

Using a film applicator, 200-micron films were casted over a glass plate, and at the same time, stopwatch was started. Time taken for full drying of films are noted at 30 °C.

Pencil hardness test

The pencil hardness test was done using a QHQ-A portable pencil hardness tester, having lead pencils of varying hardness numbers. Using an applicator, 200-micron films were casted over a glass plate. After the films are dried at 28 °C for 1 day, the test was conducted following ASTM D 3363 standard.

Water contact angle measurement

The water contact angle was measured using a Rame-Hart goniometer, Germany, at 28 °C and 60% relative humidity. To measure the contact angle, the samples are cast over glass substrates with an applicator of 100 μm . The test was conducted for 5 times to reduce the error. Contact angle measurement gives an idea of the behaviour of prepared samples with respect to water. Moreover, contact angle measurements can be used to analyse differences in the hydrophobicity of formulations.

Tensile shear strength—wet and dry

Shear strength was evaluated at different intervals in joints prepared by gluing beech specimens in normal climate. Bonded assemblies were tested after keeping them at 23 °C and 60% relative humidity after 6 h, 24 h, and 7 days. In this case, strength was calculated in MPa. Wet strength tests were performed according to condition D3-3 of EN 205 after 7 days in a normal climate, specimens were soaked in water for an additional 24 h and then tested water resistance.

Stability test

For studying the stability of white glue over time period, viscosity was monitored at various time intervals keeping samples at 50 °C in an oven. A Brookfield RVT viscometer was used, and the viscosity was measured at 20 rpm and 30 °C. Viscosity was measured on the 15th day and 30th day after its preparation.

Table 2 Various test results

Sr. No.	Properties	PVAc Homo	PVAc XG-01	PVAc XG-02
1	% Solid	46.4 ± 0.1	46.8 ± 0.1	46.6 ± 0.1
2	Viscosity (Poise)	400 ± 20	1040 ± 20	1230 ± 20
3	pH	4.90 ± 0.4	4.67 ± 0.4	4.50 ± 0.4
4	Drying time on glass plate (% RH—50–55% and Temp—29–31 °C)	40–45 min	30–35	25–30 min
5	Film hardness	HB	H	2H
6	Contact angle (°)	34.9 ± 1.39	64.9 ± 1.39	64.9 ± 1.39
7	Glass transition temperature (°C)	38	39.33	40.28
8	<i>Tensile shear strength (MPa) (dry condition)</i>			
	6 h	2.27 ± 0.4	3.70 ± 0.4	3.40 ± 0.4
	24 h	5.70 ± 0.4	6.10 ± 0.4	6.30 ± 0.4
	7 days	6.20 ± 0.4	6.35 ± 0.4	6.70 ± 0.4
9	Tensile shear strength (MPa) (wet condition) after 24 h	1.27 ± 0.3	1.8 ± 0.3	2.05 ± 0.3

Results and discussion

To consolidate various observations from the characterization and analysis, all the test results are consolidated and tabulated. Table 2 indicates the overall test results regarding the investigation. Discussions regarding each analysis have been detailed in the coming section.

Solid content

By heating a sample (approximately 1 g) for 120 min at 120 °C, the solids content of the emulsion was determined. The solids in each sample are almost the same as shown in Table 2.

Viscosity and pH

The viscosity and pH of the prepared samples are shown in Table 2. The presence of XG in PVAc Homo (PVAc XG-01 and PVAc XG-02) sample enhances the pH and makes the system less acidic in nature as compared to PVAc Homo. Compared to the PVAc Homo, increase in viscosity was observed with increase in the concentration of XG in PVAc Homo. This is due to grafting of VAc monomer on hydroxyl group of XG and hydrogen bonding of unreacted hydroxyls and resulted in huge increased in viscosity as compared to PVAc Homo. Increment in viscosity is a direct indication of successful graft reaction [28].

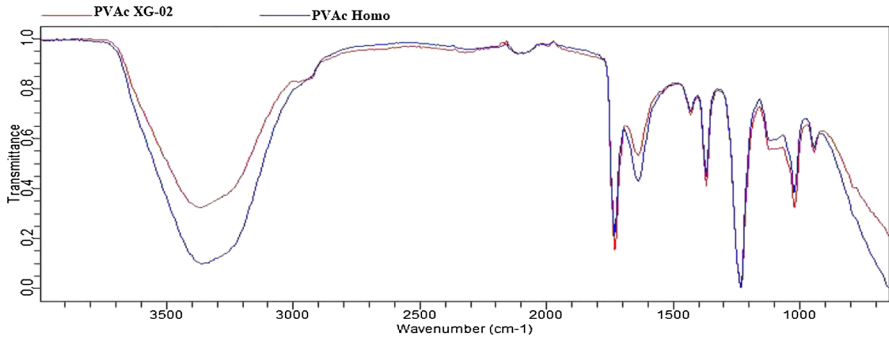


Fig. 3 FTIR spectroscopy results for PVAc Homo and PVAc XG-02 samples

Fourier transform infrared spectroscopy (FTIR)

FTIR was used to confirm the grafting behaviour in XG stabilized PVAc XG-02 against PVA stabilized PVAc Homo, and the results are shown in Fig. 3.

The width and shape of the entire peak for XG stabilized adhesive (PVAc XG-02) were similar to those of PVA stabilized based adhesive (PVAc Homo). However, the grafting reaction and secondary force, i.e., hydrogen bonding contributed to additional structural changes. This can be observed by the shifting of hydroxyl (–OH) peaks in PVAc XG-02 to lower wavenumber as shown in Fig. 3,

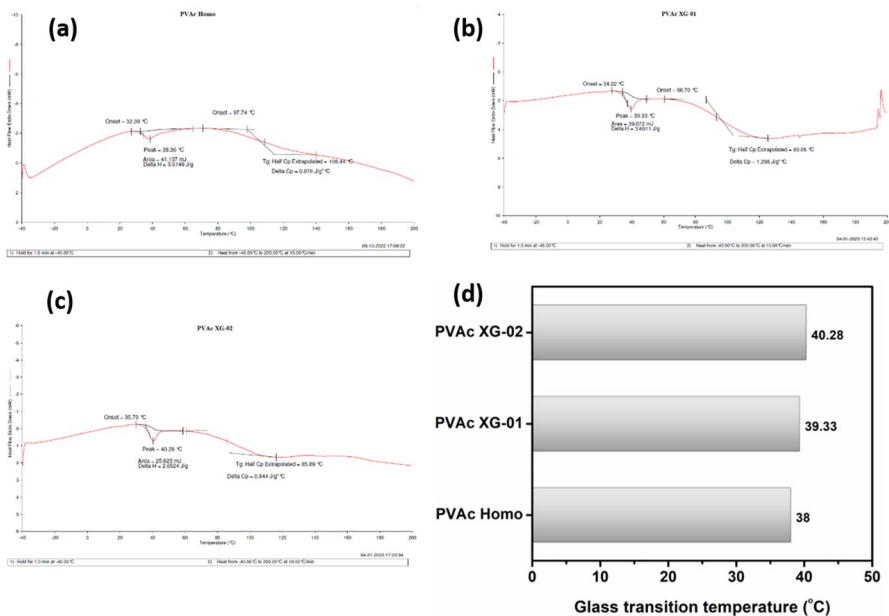


Fig. 4 DSC thermograms for **a** PVAc Homo, **b** PVAc XG-01, **c** PVAc XG-02 samples, and **d** graph showing variation of T_g value with XG content

[46]. The infrared spectrogram of XL S showed that sample exhibited peaks corresponding to the carbonyl group of an ester at 1733 cm^{-1} , indicating that VAc has been grafted with xanthan [37].

Differential scanning calorimetry (DSC)

The DSC curves for PVAc Homo, PVAc XG-01, and PVAc XG-02 films are shown in Fig. 4. As DSC indicates the T_g of polymers, it is essential to identify the thermo-physical transitions which are associated on modifying the polymer [18, 47]. From the results, all the samples were observed to disintegrate at about their T_g , mainly attributed to the decompositions of polymer and homopolymer chains. The presence of free hydroxyl groups of XG in PVAc XG-01 and PVAc XG-02 resulted in high glass transition temperature. This is due to closely packed XG structure, due to the hydrogen-bonded hydroxyl groups of XG and formed secondary bonds. The same is observed from the viscosity analysis. Figure 4d indicates change in T_g values with XG content. Hence corroborating viscosity and DSC analysis, it can be stated that XG incorporation has modified both physical and thermal properties of base polymer, PVAc.

Drying time on glass plate

The drying time test was conducted on glass plate at controlled conditions (% RH—50–55% and Temp—29–31 °C). Drying time for PVAc Homo was more than that of PVAc XG-01 and PVAc XG-02. The high tendency of hydrogen bonding in XG grafted emulsion as compared to PVA stabilized PVAc emulsion due to which water loss from adhesive film get enhanced as shown in Table 2.

Pencil hardness of film

For evaluating mechanical property of film samples, pencil hardness analysis is employed. The test was conducted as per ASTM D 3363 standard which is reported in the previous works [2, 48]. From the results shown in Table 2, increment in hardness value was observed for XG incorporated samples. Hydrogen bonding due to hydroxyl group of XG in the system contributed positively toward hardness in the adhesive film [48]. Moreover, due to grafting of VAc on XG resulted into dense structure, hence from the combined effect of these two factors, the stiff and hard nature of film was more pronounced. Overall, as the slip from sharp pencil due to structural factors increased, hence the PVAc XG-01 and PVAc XG-02 samples showed higher value of pencil hardness. This is in line with the observations deciphered from the viscosity measurement analysis, where XG incorporation positively enhanced viscosity as compared with the PVAc Homo sample.

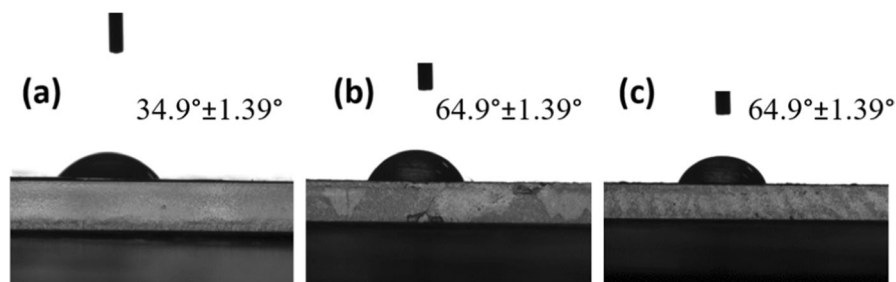


Fig. 5 Water contact angle images for various samples **a** PVAc Homo, **b** PVAc XG-01, and **c** PVAc XG-02

Water contact angle

In general, water contact angle links to the variations in the hydrophobicity in adhesive formulations [18, 19, 49]. Hence, to correlate with the water resistance properties of PVAc XG-01 and PVAc XG-02 with the PVAc Homo, water contact angle measurement was studied. Distilled water is made in contact with the emulsion samples cast over glass slides, and contact angle values were noted. The water contact angle images of the samples are shown in Fig. 5, and the values are labelled in Table 2. It is observed that the contact angle value is higher for PVAc XG-01 and PVAc XG-02 as compared to PVAc Homo. As mentioned, addition of XG with VAc monomer resulted in grafting reaction. As grafting of VAc occurred on the free hydroxyl group of XG resulted in the decrement in the hydrophilic nature of the PVAc Homo sample, increase in the contact angle was observed. It is worth mentioning that the contact angle showed an increment of $\sim 86\%$ when XG was introduced. Overall, XG incorporation enhanced the hydrophobic nature of adhesive sample, indicating less influence of moisture for the modified adhesives.

Tensile shear strength testing—wet and dry conditions

The bonding strength of adhesives was tested on the substrates in dry condition and another set of samples in wet conditions as per EN 204 for water resistance, and the results are shown in Table 2. It is evident from the water contact angle analysis that by the addition of XG in PVAc Homo sample, increment in water resistance was achieved. This can be correlated to the performance property of adhesive samples shown in Table 2. After 24-h immersion in water, PVAc Homo sample showed relatively lower strength as compared to PVAc XG-01 and PVAc XG-02 samples, the results are shown in Fig. 6a. This is due to the effect of XG, which acted as a barrier for water or moisture through adhesive which was validated in contact angle testing. Although XG is a hydrophilic substance, grafting reaction of XG with VAc monomer exhausted free hydroxylic groups, which contributed to better water resistance. It can be seen that with 1 wt% of XG, the tensile shear strength showed increment by $\sim 61\%$ under wet conditions (as per

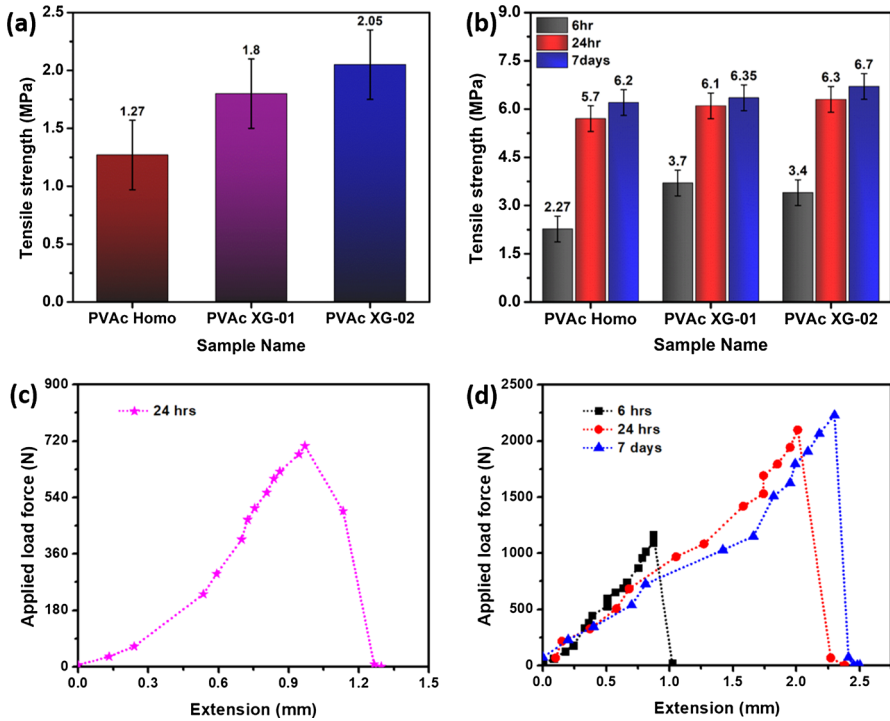


Fig. 6 Tensile shear strength results, **a** test performed in wet conditions for various samples, **b** testing in dry conditions for various samples, and **c**, **d** graph indicating representative curves on force versus extension for PVAc XG-02 samples in wet and dry conditions, respectively (colour figure online)

EN 204) compared to that of pristine sample (PVAc Homo). This initial grab of the modified adhesive under wet conditions is hence advantageous for developing high-performance adhesive.

For the tensile shear strength analysis at dry conditions, the tensile test was conducted at various time intervals after bonding the wood substrates with adhesive samples. Similar to wet conditions, XG addition enhanced tensile shear strength values in dry conditions as well, the results are shown in Fig. 6b. An increment of 50% was observed after 6 h of bonding in dry conditions, for 1 wt% of XG incorporated sample (PVAc XG-02). As observed from the viscosity measurement, introduction of XG enhanced viscosity. Adhesive films showed enhanced hardness as per pencil hardness analysis. Moreover, the hydrophobic nature was more pronounced for XG added samples. Hence, when these observations are correlated with tensile shear strength analysis, grafting reaction of VAc with XG enhanced bonding performance in dry conditions as well. To enable better understanding, for the tensile test, graph indicating a representative curve on force vs. extension for PVAc XG-02 samples in wet and dry conditions is shown in Fig. 6c and d. Overall, XG incorporated sample showed enhancement in performance property over wood specimen by producing faster bonding with quick grab property.

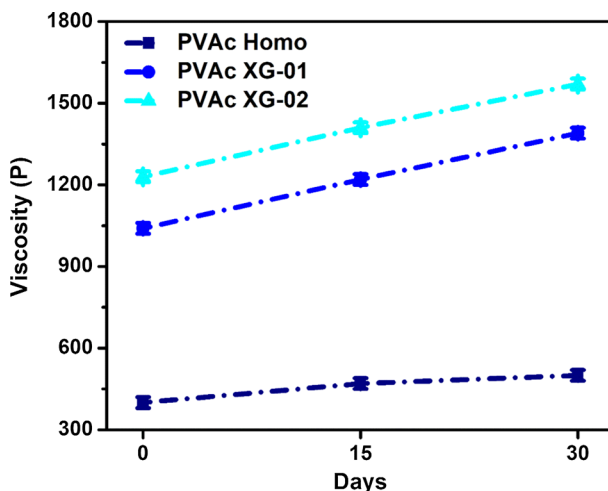


Fig. 7 Time dependency of viscosity stability measurement of all the adhesive samples (colour figure online)

Stability test

In an attempt of incorporating xanthan in PVAc dispersion, the effect of this inclusion on viscosity of the system is very crucial to analyse. To understand the effect, this inclusion may bring into the system, two samples were tested thrice for viscosity at the interval of 15 and 30 days, and the results are shown in Fig. 7. Table 2 clearly demonstrates that the relative increase in viscosity is maximum in PVAc XG-02. It can be attributed to the addition of xanthan in PVAc-based adhesive enhancement in viscosity at 30 °C after 15 days. This is observed due to the hydrogen bonding of unreacted hydroxyl groups of xanthan. Secondary forces resulted in the variation of viscosity during storage of samples at 30 °C. Moreover, the viscosity builds up over time for PVAc XG-01 and PVAc XG-02 samples observed after 30 days at 30 °C due to the formation of the secondary forces.

Conclusions

The addition of renewable ingredients to the current adhesives is essential for accelerating the development of sustainable adhesives. As a result, polysaccharide, which is the most abundant and economical material, was used to develop wood adhesive. XG incorporated PVAc adhesives were prepared by mixing XG at different concentrations 0.5% and 1% during in situ polymerization of PVAc adhesive. The addition of XG to PVAc adhesive improved the viscosity values with enhancement in hardness values of adhesive films. Incorporating XG also improved the water resistance and showed their hydrophobic nature in the modified adhesives. The performance property of the prepared adhesives was analysed by testing the tensile shear

strength of wood joints bonded with these adhesives in at various time intervals and at various conditions. Enhancement in the bonding strength (at both wet and dry conditions) of XG incorporated adhesives on wood substrates was evident from the tensile shear strength values. Overall, by the approach of incorporating XG to the in situ emulsion polymerization of PVAc adhesive showed improvement in physical, mechanical, and performance property of adhesive with enhancement in water resistance as compared to PVAc homopolymer-based adhesive. As a result, this approach could be a useful tool in the continued development of a more environmentally benign and sustainable water-based wood adhesive.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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