

The Effect of Boric Acid on the Adhesive Properties of Polyethylene glycol-Polyvinyl Alcohol Composite

Orlando Ketebu¹, Kotingo Kelvin² and Egai Tariboladei Nimiye³

^{1,3}Department of Chemical Engineering

²Department of Mechanical Engineering

Niger Delta University, Amassoma

Bayelsa State, Nigeria

Abstract: The use of organic solvents such as formaldehydes and its mixtures as conventionally adhesives has been identified as toxic and dangerous to human health because of its ability to cause cancer and affect the environment negatively. The need for an eco-friendly adhesive has been of greater concern. Synthetic polymers such as polyvinyl alcohol (PVA) which are water-soluble polymers with hydroxyl groups can be cross-linked and combined with other natural polymers or synthetic polymers to improve its mechanical properties for use as adhesives. This work looks at combining PVA with another water soluble polymer Polyethylene glycol (PEG) and the composite PVA-PEG cross linked with different concentration of boric acid (BOR) to improve the adhesive and mechanical properties of PVA-PEG adhesives as an alternative for organic adhesive. The experimental result showed that with the addition of 0.5 % and 1% boric acid to form PVA-PEG-BOR adhesive showed an increase in the adhesive properties of PVA-PEG composite from 0%, to 0.5 % and 1%. The XRD diffraction peaks (100) and (200) at 2θ angles 17.89° and 23.48° respectively indicates the formation PVA-PEG composite adhesives. The broadening of the diffraction peaks (100) and (200) in PVA-PEG-BOR (0.5%) and PVA-PEG-BOR (1%) compared to PVA-PEG control shows reduced PVA chains crystallization due to increased plasticization between water and PEG. This in turn favours reduced melting point of PVA and improves its mechanical properties. The Fourier infrared results showed the presence of hydroxyl group stretching at 3200 cm^{-1} , carbon hydrogen stretching (2900 cm^{-1}) and bending frequencies (1300 cm^{-1}) with reduced intensities for PVA-PEG-BOR (1%) followed by PEG-BOR (0.5%) indicating structural changes due to the presence of boric acid. The viscosity of PVA-PEG-BOR composite adhesives increased by the addition of boric acid from 0.5 to 1% and since increase in viscosity is directly proportional to tensile strength; it also means increase in tensile strength and mechanical properties of the adhesive.

Keywords—Adhesive; Polyvinyl alcohol; Polyethylene glycol; Boric acid; Viscosity

1. INTRODUCTION

The binding of materials together for use in various fields such as engineering, education, textile, paper production, food industries, oil and gas industries, chemical and medical sciences has been on the increase because of the need to bring materials together to achieve a goal. This has made researches to look at producing adhesive materials that are eco-friendly with unique benefits such as resistant to corrosive environment, less damage to materials, flexibility, rigidity, and high temperature usage. This unique properties of adhesives has remove the drawbacks faced by the conventional techniques used in binding materials together such as brazing, welding, riveting, soldering and the use of toxic chemicals such as formaldehyde known for causing cancer [1–2] in preparing binders and gums which are harmful to human health. Toxic plasticizers are sometimes used to improve the properties of the adhesive materials which are harmful to human, environment and also difficult to handle [3-4].

The word adhesive simply refers to non-metallic organic substance that can be applied to surfaces and has the ability to bind the surfaces together resisting their separation. The materials to be bounded can be two or more separate materials and the adhesive can be applied on all the materials or selected

portions of the materials before binding. Sometimes words such as gum, glue, cement and paste are often used in place of adhesive for organic materials that binds separate materials together [5].

Adhesives can be grouped as synthetic or natural depending on the type of raw materials used in producing the adhesive. They can also be classified as reactive and non-reactive depending on their reactivity or non-reactivity with materials during the binding process [5].

Adhesive production and use depends on the type of application and this also determines the type of materials that can be used for its production. That is why different types of adhesive are synthesized such as reactive adhesives, drying adhesives and pressure sensitive adhesives.

Adhesives are known to have certain drawbacks depending on the raw material use in synthesizing the adhesive and the application. Constraints such as poor temperature and humidity resistance, long curing time, has made researchers to look at other materials with unique properties such as polymeric materials in synthesizing adhesives. Polymeric materials such as polystyrene, polyethylene glycol, polyvinyl alcohol etc. can be used for adhesive production.

The adhesive properties of these polymeric materials can be improved by treating the materials with good cross-linking agents. Thus, this work looks at the formation of polyethylene glycol and polyvinyl alcohol composite adhesive using boric

acid as the cross-linking agent and how the percent composition of boric acid affects the adhesive properties of the composite. The polyethylene glycol in the composite also acts as plasticizer on polyvinyl alcohol.

Polyethylene glycol (PEG) is a water soluble synthetic polymer that is often used in fields such as medicine, cosmetics, engineering, food, science and in industries. It is a low melting solid primarily made from the polymerization of ethylene oxide. Its application and interaction with water enables for the production of PEG in different molecular weight. It can be used as stabilizers, plasticizers, cleaning agents, drug carriers, binders and as surfactants.

Polyvinyl alcohol (PVA) is a synthetic polymer soluble in water due to its hydroxyl group. It has wide range of applications in field such as medicine, engineering, food, agriculture, cosmetics, textiles etc. It is synthesized through the hydrolysis of polyvinyl acetate in methanol using sodium hydroxide as catalyst. In the reaction, the acetate group in polyvinyl acetate is removed while maintaining the long chain structure of the polymer. The extent of polyvinyl acetate hydrolysis to form PVA also determines the classification of PVA into partially hydrolyzed PVA with 85-89 percentage hydrolysis and fully hydrolyzed PVA with 97-99 percent hydrolysis [6].

PVA are good candidate for the synthesis of adhesives because of its properties and depending on the application, there is need to improve on the mechanical properties of PVA. And one way of improving the properties of PVA as an adhesive is through cross-linking the PVA with a strong cross-linker such as boric acid.

Boric acid (BOR) is a weak monobasic acid and has d-orbitals which enable it to form strong bond with the hydroxyl groups in PVA. This in turn forms complexes that improve the mechanical and adhesion properties of PVA [7].

2. EXPERIMENTATION

2.1 Chemicals

Polyvinyl alcohol ($M_w = 13,000-23,000 \text{ g mol}^{-1}$; 98% hydrolyzed), PEG-4000 with average Molar mass (M) of $3500-4500 \text{ g mol}^{-1}$, Boric acid (97%), Distilled water.

2.2 Equipment

Hot plate, magnetic stirrer, Beakers (100 ml), volumetric flasks (100 ml), weighing balance, centrifuge, syringe, Viscometer, Scanning Electron Microscopy, X-ray Diffractometer, Universal testing machine.

2.3 Synthesis of Polyethylene Glycol-Polyvinyl Alcohol (PEG-PVA) base fluid

15 weight percent of PEG-4000 and 15 weight percent of PVA were prepared by diluting 12.75 grams of PEG and PVA in 85 ml of distilled water with continuous stirring mechanically at 60°C until totally dissolved.

2.4 Formation of Polyethylene Glycol-Polyvinyl Alcohol-Boric acid Matrix (PEG-PVA-BOR) adhesive

The formation of PEG-PVA-BOR) adhesive follows similar method carried out by Ravindra and co researchers [8] with modifications. 85 ml of PEG-PVA base fluid was heated to 95°C with continuous stirring with 0 weight % (control), 0.5 weight % (0.425 grams in 85 ml of PEG-PVA base fluid) and 1 weight % (0.85 grams in 85 ml of PEG-PVA base fluid) of boric acid added respectively and stirred for 2.5 hours for the crosslinking of the polymers. After 2.5 hours the solution was allowed to cool at room temperature to form the PEG-PVA-BOR adhesive.

3 RESULT AND DISCUSSION

Fig. 1 shows the adhesives formed after allowing the samples PVA-PEG control, PVA-PEG-BOR (0.5%) and PVA-PEG-BOR (1%) to cool at room temperature.

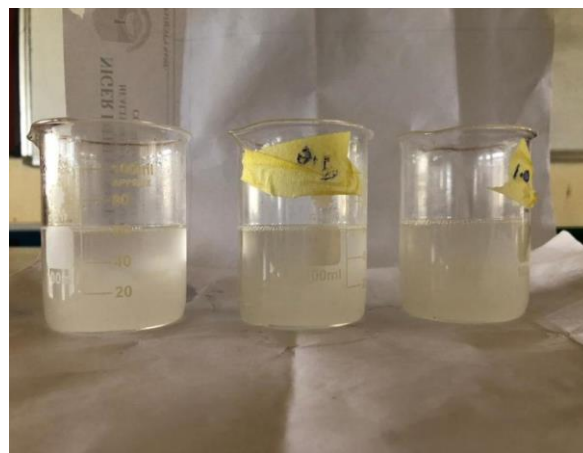


Fig. 1 Formation of adhesive gel for PVA-PEG control, and with 0.5% and 1% boric acid

It can be seen from fig.1 that all the samples are gradually forming gel.

Fig. 2 shows the XRD analysis of PVA-PEG control, PVA-PEG-BOR (0.5%) and PVA-PEG-BOR (1%). In Fig. 2 the appearance of diffraction peaks (100), (200) and (111) at 2θ angles 17.89° , 23.48° and 43° respectively indicates the presence/formation of PVA and PVA-PEG composite adhesives. Fig. 2 also showed the broadening of diffraction peaks (100) and (200) in PVA-PEG-BOR (0.5%) and PVA-PEG-BOR (1%) compared to PVA-PEG control indicating that the crystallization behavior of PVA chains is hindered by the plasticization between water and PEG. This also shows that weakened self-hydrogen bonding between PVA chains by generating the hydrogen bonding with water and PEG molecules. The reduced degree in crystallization favours the melt processing of PVA and thus improving its mechanical properties.

The difference in the intensity of the peaks in Fig. 2 is minimal because equal amount of PEG was added to the PVA-PEG

control, PVA-PEG-BOR (0.5%) and PVA-PEG-BOR (1%) composite.

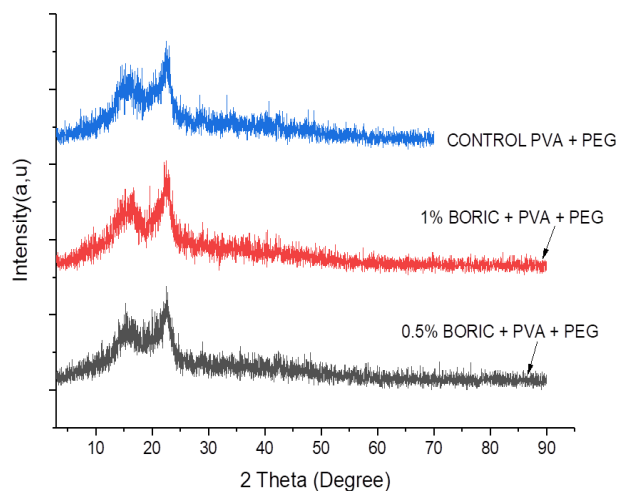


Fig. 2 XRD of PVA-PEG control, PVA-PEG-BOR (0.5%) and PVA-PEG-BOR (1%) composite

Fig. 3, 4 and 5 shows the Fourier Infrared spectrophotometry analysis for the synthesized PVA-PEG control, PVA-PEG-BOR (0.5%) and PVA-PEG-BOR (1%) composite adhesive respectively. The FTIR spectra in Fig. 3, 4 and 5 shows broad band at 3200 cm⁻¹ which indicates the presence of hydroxyl group (-OH) stretching and hydroxyls bonded with hydrogen bond [9-10], resulting from free hydroxyl groups in PVA-PEG composite. There is a reduction in the intensities of the peaks for PVA-PEG-BOR (0.5 %) and PVA-PEG-BOR (1 %) compared to the control indicating change in structures of the composites due to the addition of boric acid. The peak around 2900 cm⁻¹ indicates carbon hydrogen stretching while the peak at 1300 cm⁻¹ indicates bending frequencies. The decrease in intensity of the peaks is more with the PVA-PEG-BOR (1 %) followed by PVA-PEG-BOR (0.5 %) and least with the control. This shows that Boric acid cross-linked better at 1 weight percent in PVA-PEG composite with the good mechanical properties.

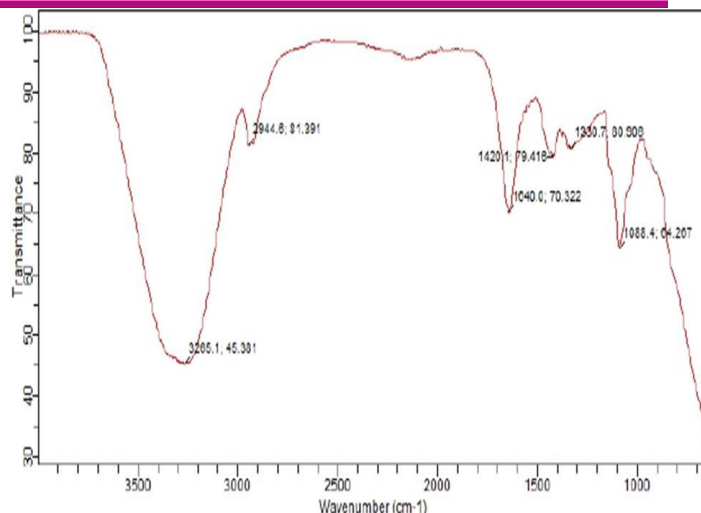


Fig.3 FTIR spectra for PVA-PEG-control

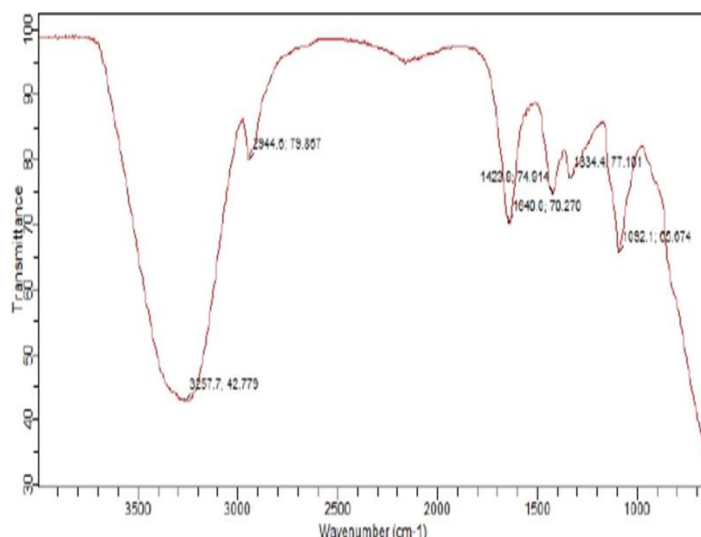


Fig. 4 FTIR spectra for PVA-PEG-BOR (0.5%)

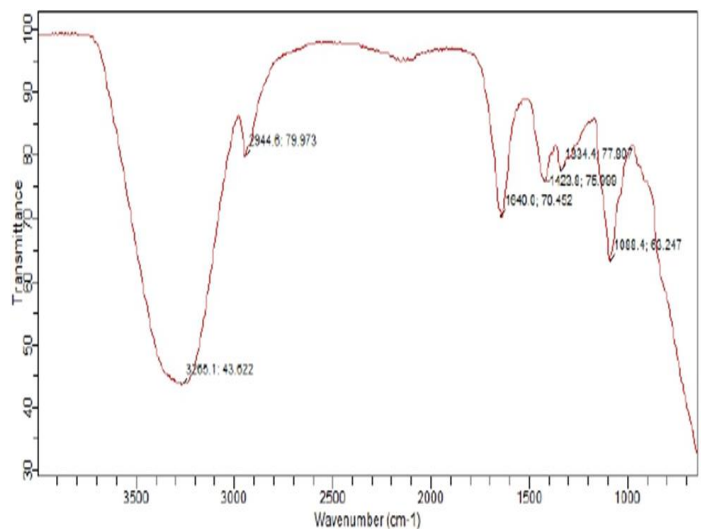


Fig. 5 FTIR spectra for PVA-PEG-BOR (1%)

Table 1 Viscosity of PVA, PVA-PEG control, PVA-PEG-BOR (0.5%) and PVA-PEG-BOR (1%) composite

| Conc. of Boric Acid (%) | Viscosity (Poise) | | | |
|-------------------------|------------------------|-----------------|--------------------|------------------|
| | PVA (Fully hydrolyzed) | PVA-PEG control | PVA-PEG-BOR (0.5%) | PVA-PEG-BOR (1%) |
| 0 | 230 | 330 | - | - |
| 0.5 | - | - | 446 | - |
| 1 | - | - | - | 723 |

With addition of boric acid, the PVA-PEG forms a cross-link with the acid which makes it harder for chains to move within the PVA-PEG composite which in turn increases the viscosity of the PVA-PEG adhesive. From table 1 increasing the percentage of boric acid from 0% to 0.5% and to 1% resulted with increased viscosity from 330 Poise to 446 Poise and 723 Poise compared to hydrolyzed PVA with viscosity 230 Poise. The increased viscosity is due to more entanglement within the PVA-PEG composite as the boric acid concentration increases from 0%, to 0.5% and 1%.

Increase in viscosity is known to be directly proportional to tensile strength. As viscosity increases, the inter-molecular forces within the composite increases which in turn contributes to tensile strength development. This in turn increases the cohesion in the adhesive as chains are brought together and also results in increased molecular weight. Thus the adhesive composite PVA-PEG-BOR (1%) had better tensile strength and increased molecular weight followed by PVA-PEG-BOR (0.5%).

4. CONCLUSION

PVA-PEG composite was formed and the addition of boric acid increased the adhesive properties of PVA-PEG composite from 0%, to 0.5% and 1%. The XRD result showed diffraction peaks (100) and (200) at 2θ angles 17.89° and 23.48° respectively which showed the presence/formation of PVA and PVA-PEG composite adhesives. The XRD also showed broadening of diffraction peaks (100) and (200) in PVA-PEG-BOR (0.5%) and PVA-PEG-BOR (1%) compared to PVA-PEG control indicating reduced PVA chains crystallization due to increased plasticization between water and PEG. The FTIR spectrum also shows the hydroxyl group stretching, carbon hydrogen stretching and bend frequencies for PVA-PEG-BOR adhesives. The results also showed that the viscosity of PVA-PEG composite adhesives increased by the addition of boric acid from 0.5 to 1% and since increase in viscosity is directly proportional to tensile strength; it also means increase in tensile strength and mechanical properties of the PVA-PEG-BOR adhesive.

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