Effect of Different Drying Time on Lap Shear Performance and Solid Content of Sago Starch Adhesive onto Corrugated Paper

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Abstract— From this research, different formulation of the sago starch (SS) and polyvinyl alcohol (PVA) blend were analyzed for its drying time effect on lap shear performance. Drying time from 20 min to three hours were varied, in order to achieve optimum solid content and drying time. SS, PVA and additives were formulated at different ratios. Adhesion lap shear strength of each specimen were tested. The recommended drying time found for sago starch and PVA are between 1 hr to 3 hr. Structural changes were also followed using Fourier Transform Infra-Red (FTIR) technique. From the result of shear strength, the formulation of SS and PVA ratio 3:7 have highest strength ~ 4.145 MPa after 3 hours drying time. The strength is compared to formulation SS and PVA ratio 3:2 which have lowest lap shear strength ~ 1.844 MPa. Total solid content of SS and PVA ratio 5:5 is the highest content which is about 25% in contrast with SS to PVA 3:2 ratio which is about 17.38%. Optimum drying time selected to be consistent with fast drying and high solid content and lap shear strength is 40 minutes.

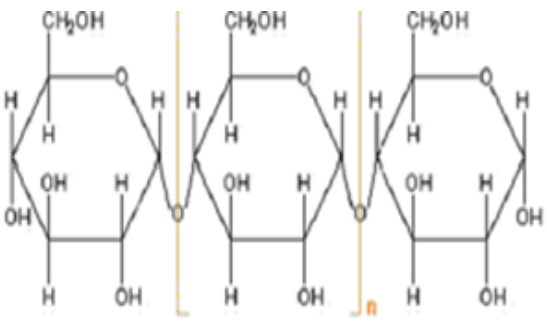
Index Terms— Drying time, FTIR, Lap shear strength, Paper adhesive, Polyvinyl alcohol, Sago starch, Total solid content.

1 Introduction

RECENTLY paper packaging industries in Malaysia imported more than 80% adhesives from China and German which involves millions of ringgits to import the adhesives. Thus, Malaysia has been witnessing a substantial increase in investments for expansion of adhesive facilities by the major global manufactures because of continuously increasing demand for adhesive in the country. These paper packaging are layered with corrugated paper in sandwich manner which is being glued together by using adhesive. Adhesive are substances that are applied to the surface of materials to adhere the corrugated and plain paper together. The adhesive must wet the surface, remain stable and develop strength after it has been applied to the surface. Conventional adhesive made from polyurethane, phenolic and urea formaldehyde had been exploited for paper box packaging industry; they may be harmful as synthetic resins with toxic raw materials are used in their formulations [1].

Nowadays, starch-based adhesive is convenient to use due to low cost and easily available as the starch is a commodity crop produced in surplus. Starch-based adhesive is a renewable polymer and its unique characteristics is versatility for chemical manipulation to use it as a substitute of synthetic polymer. Polyvinyl alcohol (PVA) is used as additive, known as biodegradable polymer. The interaction between starch and polyvinyl alcohol is favorable due to improvement of adhesive's properties. The blends between starch and polyvinyl alcohol would improve blending properties like the tensile strength become higher and the presence of hydroxyl groups tend to form strong hydrogen bonding among molecules[2].According to M. Vishnuvarthanan, additives to enhance the drying properties of adhesives for corrugated boards are polyvinyl alcohol, sodium nitrate and urea, where he found that the drying properties are reduced fastest by half by using polyvinyl alcohol [3].

In this study, sago starch-based adhesive has been modified with several ingredients to obtain excellent properties of adhesive. Sago starches can eliminate the shortcomings of the native starch can be enhanced by modifying the starch as demanded by industry [4]. The fast-drying time of sago starch-based adhesive and high solid content should be improved to avoid paper boxes from deformed. It is important in production to reduce product defects and rejects which caused loss of money. The improvement in starch-based adhesive can produce strong adhesive which has high strength and good adhesion.



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1.1 Sago Starch

Starch is known as polysaccharide, which consists of amylose and amylopectin portion [5]. A biodegradable material that are easily available, renewable, and cheap. Starch from difference sources has varies in structure, distribution of granules, chain length in amylopectin, shape, crystalline structure like crystallinity, polymorphic type, crystal size amylose and lipid content [6] Sago starch is known as 'rumbia' which is isolated from sago palm distributed throughout South East Asia is widely used in sago starch production. The people in rural areas used sago palm as an important resource because it has various uses especially in the production of starch either as sago flour or sago pearl [6]. Rahmah et al had studied sago starch blend with various plasticisers and effect of weathering and soil burial had been studied [7-9] The properties and functions of starches from varies crops is affected by the composition and the structure of starch granules vary considerably between different plants. [10].

1.2 Modified Starch

Modified starch is known as starch derivatives are prepared by physically, enzymatically and chemically to change their properties such as spray starch, cationic starch, yellow dextrin, white dextrin, and oxidized starch. The oxidized starch is the best thickener for application requiring gels of low rigidity to improve adhesion. The modified starches have been characterized as excellent bio-based packaging materials and excellent functional food ingredients. A part of hydroxyl groups in anhydroglucose units are substituted by other acids, ether or ester groups which can form linkage or crosslinks in between the chain. Its lead to the improvement in water resistance of materials and in processibility[10].

1.3 Polyvinyl Alcohol (PVA)

Polyvinyl alcohol (PVA) is suitable to be used as biodegradable packaging materials and PVA created good impact of application innovations based on their application facts. It has to modified with other polymer like starch to enhance their performance and reduce cost due to PVA has poor moisture barrier properties, low biodegradation rate and expensive. However, PVA have high tensile strength, flexibility, high oxygen and aroma barrier properties. Polyvinyl alcohol is suitable for paper adhesive, water soluble packaging film and paper coating due to polyvinyl alcohol has good film forming, emulsifying and adhesive properties. To improve polyvinyl alcohol biodegradable rate and lower the cost, blending polyvinyl alcohol with other cheap renewable polymer like starch is the one of the solution [11] [12].

1.4 Corrugated Paper

Corrugated paper is the second largest application of non-food starches globally[12]. In this application, starch is used as an adhesive between the paper liners. Nowadays, corrugated carton is widely used as container for packaging which is made by shaping hollow-structured corrugated cardboard using raw materials from paper. Corrugated carton that made from paper make it more sensitive to environment moisture. And this affect their compressive strength [13]. Corrugated board is known as orthotropic sandwich structure as shown in figure 2, in which central paper in corrugated has ability to protect their content from mechanical damage because of impacts, vibration, drops and compression loads [14].

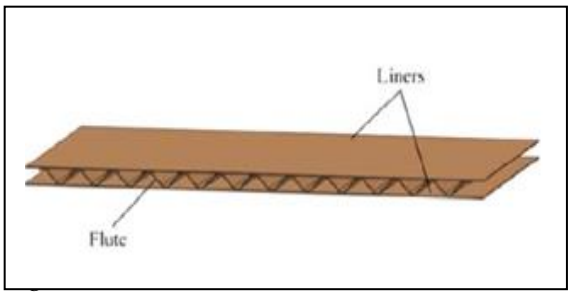
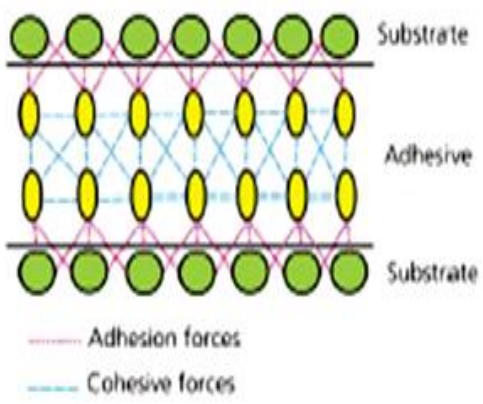


Fig 2 Corrugated paper laminate

In the paper industries, starch-derived adhesive is used as binders and sizing materials. The adhesion of a fluted layer of paper to a flat layer produced corrugated paper; reliable and consistent bond at the highest possible line speeds. The correct rheology is needed to be coated quickly, have sufficient wet tack to hold the flutes and medium together, and penetrate the board for maximum adhesion. Gelling and drying the adhesive at the lowest temperature can maximize line speed and minimize the usage of energy.

1.5 Cohesion Adhesion

Adhesion in figure 3 occurs between two different substances, bonding one material to another. The strength of the bond between the adhesive and the substrate is referred as adhesive strength. It is necessary for wetting to occur between the adhesive and the adherent for adhesion to take place. Wetting is the spreading out of a liquid on a solid surface is achieved when the surface tension of the liquid adhesive is lower than the surface tension of the adherent. The starch adhesive would have a certain adhesion force due to many strongly hydrophilic functional hydroxyl groups in the main chain of the starch molecules [15].



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In the adhesion zone, the adhesive bonded to a substrate often has bonded structure at the interface and two forms of interaction cohesion and adhesion exists.

Cohesion in figure 3 is the internal strength of an adhesive resulting from variety of interactions within the adhesive. In cohesive force, liquids tend to adopt shapes that minimize their surface area. Within the adhesive materials, chemical bonds form due to crosslinking of the polymers within a resin-based material, intermolecular interactions between the adhesive molecules and mechanical bonds and interaction between the molecules in the adhesives. The properties of uncured adhesive affecting these molecular interactions include consistency, flow properties and viscosity of the adhesive [16]. In composite materials, adhesive viscosity is important on the bonding strength, tensile strength and other mechanical properties [15].

2 Methodology and Materials

There are several materials used in this study such as sago starch, PVA, caustic soda, water and crosslinker. These materials are mixed together according to Table 1. First, use the water bath and set the temperature from 60°C to 75°C. Mix the sago starch with water and stir for one minute. Then, PVA was added into the mixture of water and starch. Crosslinker added to increase the viscosity, quicker tack and for better fluid properties. After that, the caustic soda was added into mixture and stir for 5 minutes. Lastly, apply the adhesive to the paper and dry the samples in oven at 60°C. The samples will undergo the lap shear strength and total solid content were analysed.

TABLE 1
FORMULATIONS OF ADHESIVE

Samples	Sago starch (g)	Polyvinyl alcohol (g)	Caustic soda (ml)	Water (ml)	Borax (g)
Samples 1	12	8	10	80	0.3
Samples 2	10	10	10	80	0.3
Samples 3	8	12	10	80	0.3
Samples 4	6	14	10	80	0.3
Samples 5	4	6	10	80	0.3

2.1 Testing

Testing were conducted on petri dish and corrugated paper to determine total solid content and lap shear strength respectively. Fourier Transform Infrared Spectroscopy (FTIR) are also being used to study the interaction between the functional groups in adhesive.

3 Results and Discussion

3.1 Lap Shear Strength

The tests were performed on ASTM D1002. Test strips applied with adhesive were tested. The thickness was measured at three different point of sample and the mean are recorded. Testometric 500 tensile tester were used and crosshead speed at 5.0 mm/minute were used.

Based on Figure 4, formulation 4 of ratio 3:7 showed the highest lap shear strength at 3 hours which is 4.145 MPa. Adhesive found to be higher than this value as it breaks at the tip. Stress at peak for corrugated paper found to range between strength of 1.449 (the lowest) to 4.145 Mpa (the highest).

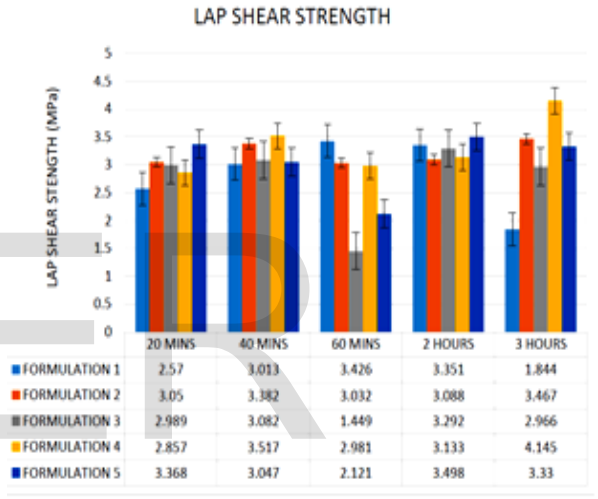


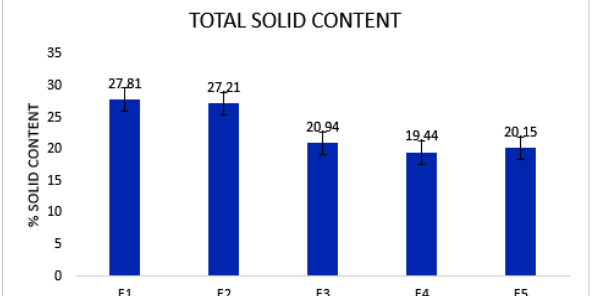
Fig. 4. Graph of lap shear strength versus drying time

3.2 Total Solid Content

3.0 gram of adhesive was weighed in petri dish and put in oven at 60°C for 20 minutes, 40 minutes, 60 minutes, 2 hours and 3 hours. Weight the adhesive and calculate the percentage of solid content as shown in Equation 1.

Solid content % =
[(Wet weight – Dry weight)/ Wet weight] × 100 % (1)

According to Figure 5, after 2 hrs all formulations have achieved about 19-27% of TSC. F4 has highest strength with 19% TSC. This TSC value is rather low. It is contradiction while proved that TSC value not necessary the only factor affecting strength. Ratios of blend and substrate type are more important.



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3.3 Fourier Transform Infrared Spectroscopy (FTIR)

The analysis of FTIR spectroscopy spectra of the blends enabled the hydrogen bond interaction to be identified. Lower wave number results in stronger interaction of hydrogen bond. Bonding of PVOH and starch molecule showed in FTIR having significant absorption at 3500- 3200 cm^{-1}, 1980-1690 cm^{-1}, and series of C-O interlinkage at 1320-1000 cm^{-1}. This showed the present of hydroxyl group still intact upon modification with crosslinker and caustic soda due to presence of aldehyde bond upon heating. The FTIR spectrum in Figure 6 showed similar spectroscopy except at near 2950cm^{-1} which showed the presence of starch in spectrum compared to higher PVA.

TABLE 2
FUNCTIONAL GROUPS OF FTIR

Functional Group	Name of Functional Group	Characteristics Absorptions (cm-1)	F1	F2	F3	F4	F5	Comment
O-H	Alcohol	3500-3200	3287.14	3345.85	3352.13	3360.43	3350.57	O-H bonding of PVA/Starch visibly features with formulation 5 had a highest absorption
C=O	Carbonyl	1760-1690	1639.81	1636.93	1639.52	1640.45	1641.60	C=O bond showed formulation 5 had a very sharp features/absorption
C-O	Acid	1320-1000	1028.16	1030.46	1029.40	1028.83	1108. 0	C-O bond showed formulation 5 had very high transmittance that the absorbed light

4 Conclusions

After 2 hours of drying, all the sample start to achieve 19-27% of solid content. For high strength, formulation 4 can be used with three hours drying time giving lap shear strength of about 4.145 MPa. All lap shear can achieve successful strength of more than 4 MPa as the deformation break occurred at the corrugated paper tip. This showed that, total solid content does not affect the strength of an adhesive. The factor that influence the strength more significantly is the ratio blend of sago starch and PVA.

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