Corrugated Paper Adhesive Strength and Solid Content Using Different Formulation of Starch and Polyvinyl Alcohol (PVOH)

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Abstract— In this research, starch adhesives were prepared using different formulation of sago starch(SS) and PVOH for corrugated paper board. Starch adhesive had long been use for adhesion of paper box but the strength of these boxes are weak and may vary according to type of starch, presence of additives and their solid content. An adhesive is produce by mixing sago starch of various composition with polyvinyl alcohol (PVOH). The adhesive is applied to the paper boxes and the sample was dried at room temperature. Characterizations of the specimen were observed via Fourier Transform Infrared Spectroscopy (FTIR) , Lap Shear Strength and Total Solid Content. From the result, PVOH helps the adhesive to enhance its mechanical properties. Higher content of PVOH formulation had increased the lap shear strength of the adhesive and cohesive strength of SS/ PVOH adhesive is stronger than cohesion strength of corrugated paper. Through starch modification, the mechanical properties and solid content are being control to about 24% and drying time are shorter for higher PVOH content.

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Index Terms Keywords: Corrugated Paper, Adhesive ; Sago starch ; Total Solid content ; FTIR; Lap Shear strength,

1 INTRODUCTION

The world is witnessing a substantial increase in investments for expansion of adhesive facilities by the major global manufactures because of continuously increasing demand for adhesive in various applications. The shifting focus towards bio-based adhesives offer numerous opportunities for the growth of adhesive industries.

Adhesive is an efficient, economical and durable method for assembling materials. Adhesives are applied to the surface of materials to adhere together.[2] The adhesive must wet the surface, remain stable and develop strength after it has been applied to the surface. adhesive harden on adherend to develop structural properties and forming a bond to both surface. adhesive are from polyurethane(PU), phenolic (PF) and urea formaldehyde(UF) had been exploited various adhesive industry for plywood and paper corrugated.[3]. Those adhesives are very harmful to human and environment as they are not biodegradable and for PU etc, they can cause health effects for prolong exposure of the unreacted phenols or isocyanate.

Nowadays, starch-based adhesive is preferred due to low

Nowadays, starch-based adhesive is preferred due to low cost and of sustainable soruce. Starch is a renewable polymer derived from plant crops which can be converted into different applications as food thickener, biodegradable plastics etc [4-6]. Its versatility for chemical manipulation makes it an attractive material for use as substitute for synthetic polymers. Starch has been used as an adhesive in a wide range of products with specified additives to enhance the properties of adhesive.

Polyvinyl alcohol is a 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.[7]

1.1 Corrugated Paper

Corrugated box is made up from the adhesion of a fluted layer of paper to a flat layer and the two layers is usually joined by using adhesive. The corrugated medium is made up from recycled fibre. The single-wall corrugated box is composed from two layers of line board and one layer of fluting made from corrugated medium layeres are glued. Some researchers had investigated the corrugated bonding and its effect on corrugated box performance.[7].According to M.Vishnuvarthanan who had found the additives to enhance the drying properties of adhesives for corrugated boards. He used polyvinyl alcohol, sodium nitrate and urea.

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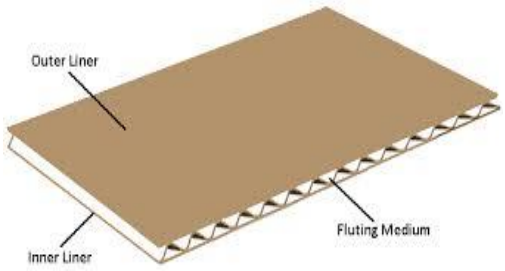

Figure 1: Corrugated board layers

They found the drying properties are reduced fastest by half by using polyvinyl alcohol.[7]. It is important to know the factors to produce a good durable adhesive bond and overcome the wetting problem that cause paper boxes deformation.

Starch-derived adhesives are used in the paper industries.[8] Good strength and stiffness is required to maintain product is properly packed in appropriate paper boxes which do not deform. Starch adhesive properties such as drying time, peel strength can be improved so that quality product with reduced drying time and low defect are realized. Company can increase production with high quality adhesive and contribute to greater profit.

Moreover, the use of biodegradable material such as starch and PVOH are not harmful to the environment and human health. [9] Menwhile, the cost of PVOH and starch can help to reduce the dependence of other materials such as the more expensive urethane type adhesive, which had establisehed use for paper boxes.[10]

The purpose of this study is to overcome the wetting problem of the paper boxes after the drying process. The specific objectives of the research include: determination of the adhesive or shear strength using different formulation of starch and PVOH onto corrughated paper and to optimizethe drying content and drying time of sago starch. The determination of Shear strength and elongation of formulated starch were important to be determined, as the strength of the adhesive can be affected by formulation used. An optimum composition of starch can be chosen later to impart high strength adhesive especially for corrugated paper .

1.1 Sago starch

Sago starch (SS) has been used due to low cost and easy availability compared to starches. In Southeast Asia, sago starch is an important socioeconomic crops. In Malaysia, the plantation of sago starch is dominant in Sarawak and Johor, Malaysia. Sago starch has their own unique characteristic which differ from other starches. The size of sago starch granules ranges from 10 to 50 μm. Sago starch also has a smooth surface and has various gelatinization temperature from 69.5 to 70.2 °C [9] The characteristics of sago and its contents are as tabulated in Table 1[10]. Starches from different sources differ in overall structure through size distribution of the granules, shape, amylose and lipid content, distribution of chain length in amylopectin and crystalline A high amylose content affected the strength , elongation and modulus properties... The content of the linear starch fractions of all the starches were found from the data in the subject literature [11]. The amylose content of sago starch is the highest compared to the others.

TABLE 1 :
APPROXIMATE AMYLOSE AND AMYLOPECTIN CONTENT OF STARCHES.

Starch Type	Amylose content %	Amylopectin content %
Dent Corn	25	75
Waxy Corn	<1	>99
Tapioca	17	83
Potato	20	80
High-amylose Corn	55-70(or higher)	45-30(or lower)
Wheat	25	75
Rice	19	81
Sago++	30-31+	70+

1.2 Polyvinyl alcohol

Polyvinyl alcohol is a water-soluble thermoplastics synthetic resin and has limited application for example as an adhesive. Besides that, it is a non-toxic, odorless and tasteless. Other than that PVOH is fully degradable and dissolve quickly. [12]

2 MATERIALS and METHODOLOGY

The materials used for this research are sago starch, polyvinyl alcohol (PVOH), Borax, Caustic soda (sodium hydroxide) and water. Sago starch was obtained from sago starch manufacturer, Ng Kia Heng Sago Industries in Batu Pahat, Johor, Malaysia. The PVOH grade GOHSENOL is supplied by Nippon Gohsei. And Glycerol,with formula C3H8O3 was supplied by SYTERM ChemAR ® having MW 92.10 g/mol.

The casting method is used in this preparation of starch adhesive..The starch is mixed and stirred with hot water ~80c. After that, PVOH and subsequently borax is added into the conical flask that contains the mixture of water and starch.. Caustic soda is added in the mixture and stirred for 5 minute. The adhesive is applied to the paper and the sample were dried at room temperature. The samples underwent few testing.

TESTs such shear and solid content were determined. ASTM 6882 shear std test with Testomeric 500 tensile tester and

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crosshead speed of 5.000 mm/min were performed. Ranges of the thickness for every sample is 2.610mm to 3.180mm. The width for the sample is 20.00mm.

TABLE 2 FORMULATION OF ADHESIVE FOR SS/PVOH

Sample	Water (ml)	Sago Starch(g)	PVOH (g)	Borax (g)	Caustic soda (ml)
S1	50	12	8	0.3	10
S2	50	10	10	0.3	10
S3	50	8	12	0.3	10
S4	50	6	14	0.3	10

For solid content tests, adesive of about 3.0g were placed in petri dish and put in oven for 6 hours and the oven is set as 60°C. The samples are reweighed and solid content were calculated.

3 RESULTS AND DISCUSSION

3.1 Solid Content

Solid Content of SS /PVOH blend were determined after 24 hours of drying and content constant.

From 1 shows the percentage of solid content of the adhesive. The percentage of dry content for sample of all ranges from 25% to 23% with S1 having greatest solid content which is about 25.41%, and the lowest were for S4 ~ 23.71 %. Based on the result obtained, less amount of starch give the lowest solid content that is S4. Starch can increase the solid content as starch has more insoluble component having less hydroxyl groups and the OH groups are in the complex structure as compared to PVOH which is more linear. The solid content of starch affected the quality of the adhesive. When the value of solid content is obtained, the researcher can easily know the amount needed for starch amount and water dilution needed for producing paper starch adhesive. Accessive water content and not enough drying period can deform the corrugated paper boxes.

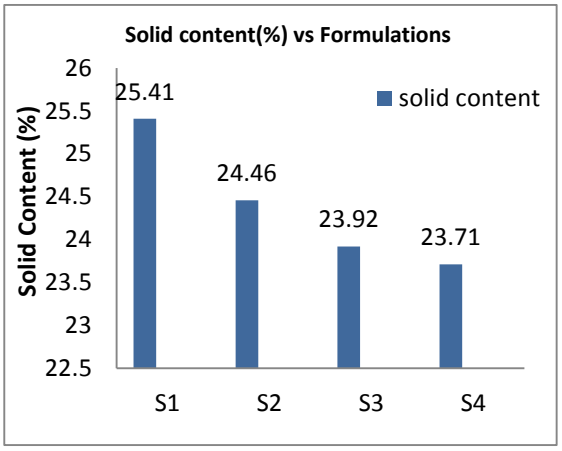

Figure 1 shows the solid content of each formulation.

3.2 Drying time

Drying time is the time taken required for the adhesive to set to the corrugated paper board.

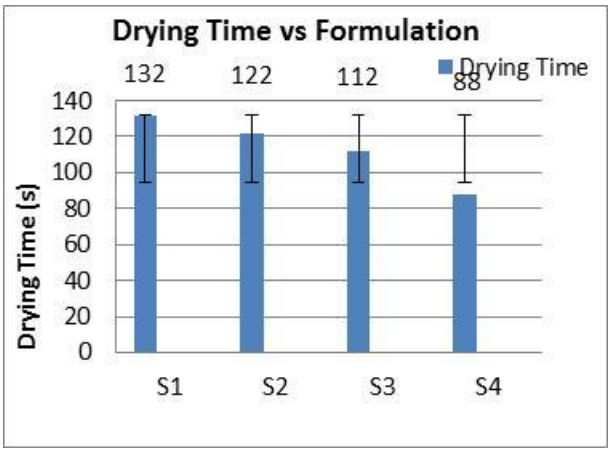

Figure 2 Drying Time vs Various Fromulation of PVOH/SS

Figure 2 shows the result of drying time for every sample from different formulation of starch and PVOH. The sample of S4 has the lowest value of drying time which is 88 seconds. This is followed by S3 which is 112 seconds.. Longest drying time is from S1 which is 132 seconds. Based on the result obtained, the less amount of starch used, the higher the drying time because the starch having more complex structure has more diffuclty in drying in elimation of water molecules through H bonding as compared to PVOH the drying time is high. [13] Upon drying of adhesives, water evaporates; this allow the formation of starch network to take place. During this stage, the proximity of starch chains induced by higher amylose contents could facilitate the formation of the SS/PVOH matrix with more polymer content per area as well [14]

3.3 Shear Strength Test

On corrugated paper sheets, the shear strength were deterimed for different SS /PVOH formulations and found to have Shear Strength and Modulus as below in Figure 3 and 4 respectively.

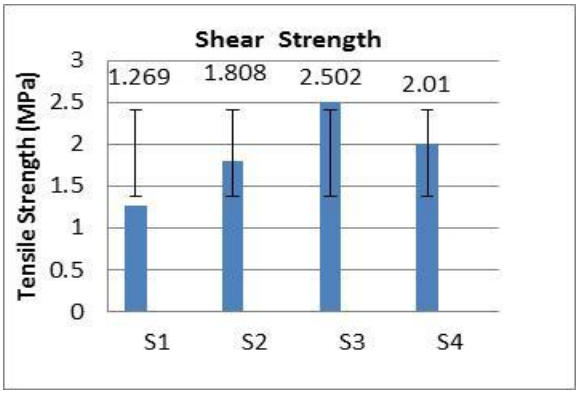

Figure 3. Shear Strength vs Various Formulations of PVOH/SS

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Figures 3 show the result of shear strength (stress at peak) of four samples from different formulation of starch and PVOH. Different formulation affected the shear strength result.. When the maximum stress is high, its means the material is strong. Form the graph, its show that the sample for S3 has the highest strength which is 2.502 MPa compared with other samples. S1 have the lowest shear strength of about 1.269 MPa. In comparison between the highest and lowest tensile strength, it shows that increase in the amount of the starch, had resulted in lower shear strength. An increase of starch may cause more starch gelatinization during applying the adhesive sample to the corrugated board. Higher PVOH content had revealed the greater hydroxyl groups of OH as compared to starch cause higher H bonding and crosslinking which resulted with presence of crosslinker such as borax. The result presented provide an indication of what consitutes a good to medium bond in corrugated board. [13] Well bonded corrugated boards are expected to have high resiliency to out of plane tension, attaining a higher ultimate strength at a larger yield strain.Bonds consisting of ungelatinised starch or poor penetration into paperboards had shown to display less plasticity and strength. Paper surface uniformity is also important as porosity surface roughness, surface wettability promote adhesive penetration into the liner and medium. These factors are also important for good bonding [15] .

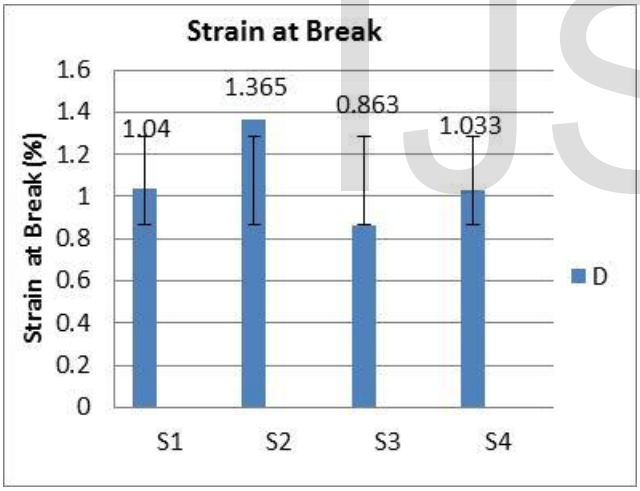

Figure 4 Strain at Break vs Various Formulations of PVOH/SS

Figures 4 show the result of Strain at Strain of four samples from different formulation of starch and PVOH. S2 shows the highest Strain at Break which is 1.365 % followed by S1. S3 had the lowest value of Strain at about 0.863 %. With higher Strain at Break , the make adhesive is more flexible. With S3, the highest shear strength adhesive, the elongation is impaired and has low flexibility. Elasticity and flexibility are related to crytallinity and morphology of the starch blend polymers. The amylose content affects the crystallinity of the starch film, which is often linked to the mechanical properties [16] The increasing crystallinity of amylose and amylopectin in the film increases Young's modulus and tensile strength simultaneously decreasing elongation at break [17]

Starch molecule had contributed to the greater flexibility imparted by the starch chain which has greater mobility upon stretching.

4 CONCLUSION

From the research, the conclusions that can be made are the mechanical properties like tensile strength and modulus is increase as the amount of polyvinyl alcohol increase in the formulation. By increasing the amount of starch content this will contribute to the lower the tensile strength. It may be due to starch composition of high amylase content. The polyvinyl alcohol (PVOH) is added to increase the mechanical properties of starch in many applications that need high mechanical properties. Sample for S3 has the higher shear strength which is 2.502 MPa. Starch is relatively low strength polymer, hence PVOH can strengthen it. So, by blending starch with PVA, the mechanical properties can be improved. The best drying time obtained is 88 seconds. Starch bonding in corrugated single facing arise from increased localised elastic deformation were achieved from adhesive penetration into substrates and where starch full gelatinisation had occurred. Gains in bond strength and corrresponding performance may therefore be optimised through right formulation, solid content and drying time.

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