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Effects of Thermal Analysis and Drying Time on Green Adhesive Using Agricultural and Plastic Waste Materials as Composites

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Abstract: *The Thermal Analysis and Drying Time characterization of green adhesives using agro and plastic waste materials as composite for domestic and industrial utilizations was carried out. Preparation of adhesive filler (Rice Husk Ash) and formulation of adhesive binders (Polystyrene waste and Arabic gum) were conducted. A synthetic adhesive (Sample A) served as a control. Standard adhesive and samples formulated were labeled A, B, C, D, E, F and G respectively based on varied quantities of fillers and binders. Thermal analysis and drying time of the adhesives were investigated. Thermal stability values which correspond to the curves explained the heating rate, melting point, minimum and maximum heat flow where investigated. The melting point of samples A, B, C, D, E, F and G were 58.88 ^{0} C, 63.40 ^{0} C, 63.36 ^{0} C, 95.04 ^{0} C, 134.32 ^{O} C, 128.68^0 C and 50.96^0 C respectively. The enthalpy change of samples A,B, C, D, E, F and G were 176.72 J/g, 295.37 J/g, 37.12 J/g, 22.10 J/g, 167.49 J/g, 301.97 J/g and 232.64 J/g respectively. The results of the melting points indicate better adhesive that will withstand high temperature of such magnitude. The adhesive samples proved to maintain high bond strength across wide range of temperature. The drying time results revealed that sample A, B, C, D, E, F and G were 122.00s, 64.00s, 108.00s, 102.00s, 128.00s, 87.00s and 116.00s respectively. The higher the drying time the better the bonding strength of the adhesive. Based on the finding of the work, the suitability and workability of the products was investigated and proved to be effective. It is evident that most of the adhesives formulated will compete favourably with the standard in terms of thermal stability, drying time and bond strength. At the end recommendations such as, government should encourage and set-up small-scale industries for the formulation of adhesive from agro and plastic waste materials that can test the feasibility and marketability of the product, thermal analysis and drying time should be use as parameters in the adhesive industry for a qualitative and effective adhesive among others.*

Keywords: ***Adhesive, Expanded polystyrene, Binder, Filler, Thermal stability and Drying time.***

I. Introduction

In the study conducted by Schick (2009), on differential scanning calorimeter (DSC) of semi crystalline polymers stated that, differential scanning calorimeter is an effective analytical tool use to characterize the physical properties of a polymer. It enables determination of melting point, crystallization, mesomorphic transition temperature, enthalpy changes, characterization of glass transition and other effects that show either changes in heat capacity or a latent heat. Characterization of adhesives at room temperature and elevated temperature (Santhosh, 2006) investigated that at a low enough temperature, a polymer is rigid and glassy, while on heating through the glass transition temperature, it becomes relatively flexible and rubbery. If semicrystalline, the next transition stage will be the melting of the crystallines and at higher temperatures, polymers decompose chemically.

Schaible *et al.* (2016) in their study on evaluation of thermoplastic polymers as hot-melt adhesives for mixed-substrate joining reported that thermal behavior is one of the characteristics for hot-melt adhesive. Ohoke and Igwebike-Ossi, (2015) also reported that fillers are generally added in adhesive formulations to provide , increase in thermal and electrical conductivity, increase thermal stability, reduce coefficient of thermal expansion, reduce shrinkage and stress during cure, improve bond strength, improve flow properties, extend pot life and reduce cost. Studies on adhesive joints for low and high temperature utilization was carried out by Marques *et al.* (2015) where resistance and strength of high temperature have always been a major disadvantage of adhesives that exhibit substantial degradation at temperatures considering their polymeric nature, where other structural materials have minutes changes in mechanical properties. Marques *et al.* (2015) also reported the utilization of adhesive in so many industries such as, automobile, aerospace, and electronics and naval. They pointed out these industries manufacture materials that are anticipated to achieve adequately under a large range of environmental provision of which the temperature change. There is a considerable demand for the development of adhesive joints and adhesives able to withstand large temperature slope. Thermal analysis techniques are being widely used for characterization and performance prediction of polymeric materials both in research and quality control. According to Ohoke *et al*. (2015)**,** thermal stability of the adhesives was determined by evaluating the difference in bond strength at room temperature and at lower and higher

temperatures. The ability of an adhesive to maintain high bond strength even across wide variations of temperature is important. This is because the bonded wood will definitely be exposed to fluctuation in environmental conditions, which may affect the coefficient of thermal expansion of the adherends as well as the adhesive. In another development, Schaible *et al.* (2016) stated that, polymers with a high melting enthalpy need more energy for the melting process than polymers with low melting enthalpy and are therefore not ideal as hot-melt adhesives.

In study conducted by Lara *et al*. (2018) reported that mechanical properties of composites are affected by several factors, mainly homogeneity of the material, dispersion and distribution of fillers in the matrix, compatibility between filler and matrix, in addition to specific filler characteristics such as full size of particles and particle distribution. In a studies of Vishuvarthanan and Rajeswari, (2012) on additive for enhancing the drying properties of adhesive for corrugated board explained that drying time is the duration of time recommended for the adhesive to set after it is covered with a substrate. They further stated that the minimum and maximum drying time is 67.00s and 122.00s respectively. Adhesives which are thermoplastic or which are rubber solutions in organic solvents are first applied on the surface of the adherends and the surfaces are exposed to air for long time for drying and volatilization of solvent, before the surfaces are assembled together as reported by Sharshi, (2011) in his study on adhesive drying time in the textbook of engineering chemistry. He further stated that air- drying of adhesive coated surfaces required tackiness which developed to form adhesion and blisters or voids and is avoided by evaporation of the volatile matter before assembling (Sharshi, 2011). This paper reports the effects of thermal analysis and drying time on green adhesive using agricultural and plastic waste materials as composites.

II. Methodology

Collection and Identification of Samples

Waste expanded polystyrenes (EPS) were collected around homes and refuse dumps whereas rice husk was collected at rice milling locations all within Bauchi metropolis. The polystyrene wastes, gum arabic and the rice husks were respectively identified in the Departments of Chemistry and Crop Production of Abubakar Tafawa Balewa University, Bauchi. The Topbond glue was purchased from a vendor in Muda Lawal Market, Bauchi.

Determination of Thermal Properties of Adhesives

The method of Pravin *et al. (*2014) was adopted. A total of seven samples were used for the differential scanning calorimeter (DSC). Two consecutive scans were obtained to minimize the influence of possible residual stresses in the material due to any specific thermal history. A scanning rate of 10^0C/minute for endothermal cycle was used. The glass transition temperature (Tg) and enthalpy of melting (Hm) were determined from the second heating scan, while the enthalpy of crystallization (Hc) was determined from the first cooling scan. The area under the melting or crystallization peak represents the amount of energy required to melt the polymer (Hf) and the amount of energy released during crystallization (Hc), respectively. The peak area calculated is used with the limits of the calculation on the flat portion of the baseline before and after melting or crystallization peak. Peak temperatures were noted as the melting (Tm) and crystallization (Tc) temperature (Pravin *et al.,* 2014).

Determination of Drying Time of Adhesive

The adhesive drying time was investigated using the method adopted by Masumbu *et al*. (2003) with little adjustment. Two pieces of woods were used for the determination and small amount of adhesive was applied on one side of the wood along a line measured 4.0 cm from the shorter edge and away from the longer edges. Direct contact was ensured by moving the roller on top of the bonded woods. A stop clock was started and the drying time was recorded in triplicate.

III. Results

The results of thermal stability consisting of heating rate, melting point, enthalpy change, curve integral and curve category are presented in Table 1 and Figure 1 respectively. The results of drying time of all the adhesive samples are presented in Figure 2.

Table 1: Thermal Stability Values of Heating Rate, Melting Point, Enthalpy Change and Curve Category

Sample	Heating Rate (^{0}C/Min)	Melting Point (^{0}C)	Minimum	Maximum
A	10	58.88	0.89mW at 30.02 ^{0} C	1.28 mW at 299.24 ^{0} C
B	10	63.40	0.60 mW at 35.01 ^{0} C	1.54 Mw at 198.40 ^{0} C
C	10	63.36	1.35 mW at 35.03 ^{0} C	1.65 mW at 93.72 ^{0} C
D	10	95.04	0.43 mW at 35.01 ^{0} C	1.69 mW at 198.41 ^{0} C
E	10	134.32	1.43 mW at 35.01 ^{0} C	1.86 mW at 200.09 ^{0} C
F	10	128.68	0.65 Mw at 30.01 ^{0} C	-0.10 mW at 198.66 ^{0} C
G	10	50.96	0.33 Mw at 30.01 ^{0} C	3.58 Mw at 200.17 ^{0} C

KEY: A =Topbond (Standard), B=AG – RHA, C=EPW- RHA, D=EPW/AG – RHA/$CaCO_3$, E=EPW/AG – RHA, F=PVA/AG – RHA, G=EPW - $CaCO_3$

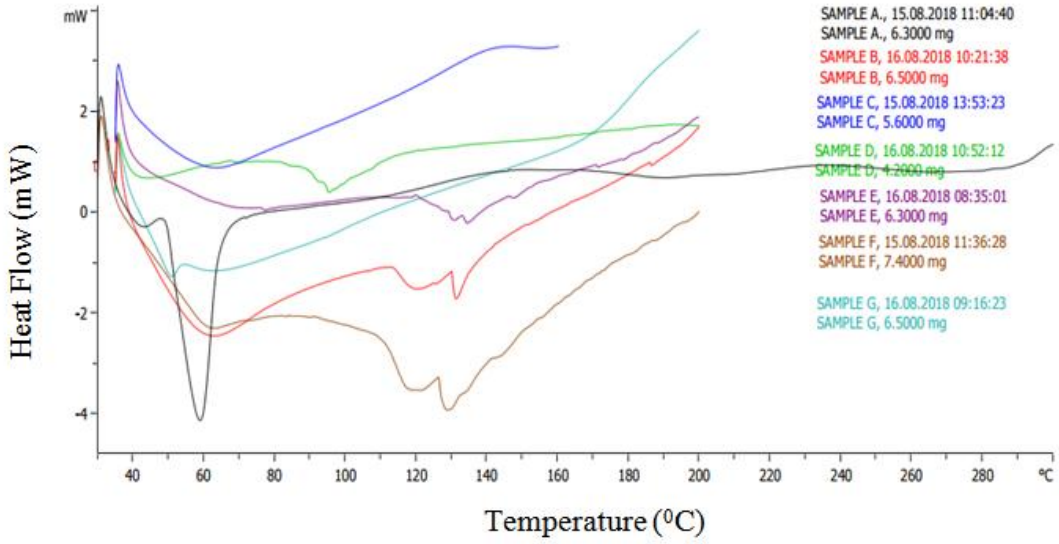

Figure 1: Thermal Stability Curve of Adhesive Samples

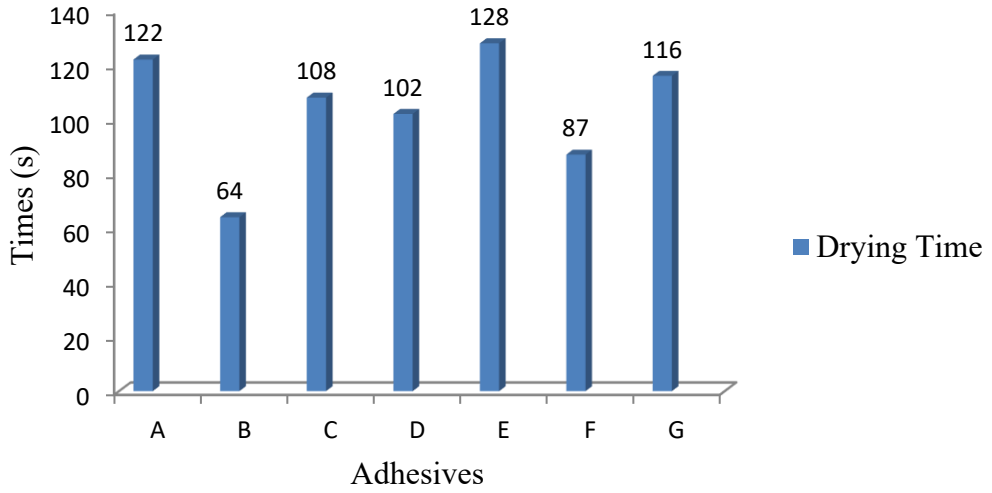

Figure 2: Drying Time of Adhesive Samples

KEY: A =Topbond (Standard), B=AG – RHA, C= EPW- RHA, D=EPW/AG –RHA/$CaCO_3$, E=EPW/AG – RHA, F=PVA/AG – RHA, G =EPW - $CaCO_3$

IV. Discussion

Thermal Stability of the Adhesive Samples

The thermal stability values of heating rate, melting point, enthalpy change and curve category are shown in Table 1. From the peak the first point going down is the glass transition temperature and then a sharp

trough of peak is seen which is the melting point of the sample. The thermal curves which represent thermal properties like glass transition temperature (Tg), heating and cooling curves are shown in Figures 1. These shown a clear endothermic curves where heat absorption took place which resulted to samples heated at the rate of 10 ^{0} C/Min. Endothermic means that more energy is been absorbed. The Maximum and Minimum temperature /heat flow for all the samples including the standard are shown in Appendix II. The melting point of samples A, B, C, D, E, F and G correspond to 58.88^{0}C, 63.40 ^{0}C, 63.36 ^{0}C, 95.04 ^{0}C, 134.32 ^{0}C, 128.68 ^{0}C and 50.96 ^{0}C respectively. Sample E (contain RHA) was recorded with a high melting point which correspond to high thermal stability which is in agreement with the work of Ohoke and Igwebike-Ossi, (2015). The melting point of sample A (Standard) is 58.88 ^{0} C which is less when compared with other formulated samples with the exception of sample G (50.96 ^{0} C). The enthalpy change is the heat consumed per gram of sample which increases in time or temperature. This is an indication of a better adhesive that will withstand high temperature of such magnitude. The heat consumed by the standard and the samples are within the range except sample C and D. The strong intermolecular interaction result in higher melting points of the samples. This is in accordance with the work of Ohoke *et al.* (2015) and Marques *et al.* (2015) who supported that the adhesive stability is related to high bond strength even across wide variation of temperature. It was also in line with the findings of Lara, (2018) who explained that the composites nature of the adhesives are also responsible for maintaining high bond strength across different temperatures.

Drying Time of Adhesive Samples

The graph of drying time of adhesive samples were investigated and presented in Figure 9. The drying time of all the samples revealed that samples A, B, C, D, E, F and G were 122.00 s, 64.00 s, 108.00 s, 102.00 s, 128.00 s, 87.00 s and 116.00 s respectively. Sample E has the highest drying time followed by sample A, G and then C in that order. Sample E, G and C where observed to have the highest values of drying time and this could be due to the high concentration of fillers. The longer the time after application, the wider the difference in bond strength (Ohoke *et al.,* 2015). Drying time is the period of time recommended for the adhesive to set after it is covered with a substrate (Vishnuvarthanan and Rajeswari, 2012). In a research conducted by Akpa (2012), the higher the drying time, the better the bonding strength of the Adhesive. This is in accordance with the finding of this research where samples E and G are among the highest in terms of bond strength and drying time. The results of the present study showed an increase in the shear force and shear strength of sample E and G and also a corresponding increase in drying time which is in accordance with the work of Sharshi (2011) and Akpa, (2012). The thermal stability of the formulated samples and the drying time of this research show effectiveness which could be due to the formulation processes and the nature of the composites. Air-drying for 3-4 seconds advocated by manufacturers is too short to evaporate the solvent. Actually, air-drying for more than ten (10) seconds is recommended by Jeong, (2014) as conducted in the present research. The formulated samples can compete favourably with the standard as observed.

V. Conclusion

The result revealed that the roles of thermal stability and drying time on the adhesive formulation were established. The adhesives formulated may compete favourably with synthetic in terms of thermal stability, drying time and bond strength are essential parameters in the formulation of adhesive. Based on the finding of the work, the suitability and workability of the products was investigated proved to be effective.

VI. Recommendations

The following recommendations were made based on the research findings;

i. The Adhesive Industry should consider the use of Rice Husk Ash (filler), Arabic gum and polystyrene waste (binders) in the formulation of Adhesive.
ii. It is also recommended that further research on adhesive sample for Scanning Electron Microscope (SEM) and formaldehyde emission should be conducted.
iii. The Federal Government should emphasize and recognize the use of environmentally friendly materials in the Adhesive Industry.
iv. Federal Government and Universities should commercialize Adhesive research findings to Adhesive Industries for suitability and applicability to the nation economic development.
v. Government should encourage and set-up small-scale industries for the formulation of adhesive from agro and plastic waste materials that can test the feasibility and marketability of the product.
vi. Thermal analysis and drying time should be use as parameters in the adhesive industry for a qualitative and effective adhesive.

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