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# EFFECTS OF KAOLIN CLAY ON THE BOND QUALITY OF COCONUT COIR DUST TANNIN-FORMALDEHYDE BASED WOOD ADHESIVES

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**Abstract:** The effects of Kaolin clay extender on coconut coir dust tannin-formaldehyde based adhesives, using plywood as bonded substrate, were investigated. Results show the practical adhesion (shear strength) and wood failure values are highest at the critical pigment volume concentration of each glue system; and that both the shear strength and wood failure increased with increasing pigmentation. Optimum levels were observed at 10-14% pigment volume concentration. The best overall performance was obtained with the resorcinol modified coconut coir dust tannin-formaldehyde resin based adhesives.

**Key words:** Adhesive bond, coir dust tannin, kaolin clay, plywood, tannin-formaldehyde resins.

## INTRODUCTION

Extenders or fillers of different types have been used in adhesive formulations. The proportions of such extenders depend on the purpose for which the adhesive is intended, the nature of the extenders and the resin used in the formulation. However, the primary objective for the addition of extenders is to reduce the cost of the formulations. Suitable extenders for adhesive formulations include kaolin clay, whiting, barytes, coconut shell flour and wood flour. Much work has been done on clay minerals of different countries from the point of view of their industrial applications.[1,2] Nigerian clay minerals on the other hand have been studied mainly from the point of view of mineralogical content and composition, and very little work has been done on their use as extenders in coatings.[3] The present work was carried out to determine the effects of an indigenous kaolin clay as an extender, at different pigmentation levels, on the adhesion (bond strength) of adhesives formulated with it, using coconut coir dust tannin-formaldehyde resins. Other properties such as wood failure and glue pot life were also assessed.

## METHODS AND MATERIALS

*Kaolin clay extender:* The raw clay was obtained from a hand dug pit at Ezinachi - Okigwe, Nigeria. The raw clay samples were wet refined, sieved and calcined at 850°C for 1h. It had a specific gravity 1.96; oil absorption 54.3; surface area 7.13; pH(aqueous slurry) 6.2 and was identified as kaolinite clay.[3]

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*Extraction of tannin:* The coconut coir dust tannin extract was obtained according to the method described by Odozi *et al.*[4] One gram of sun-dried coconut coir dust was added to 75ml distilled water and placed in a water-bath at 40°C for 3h. The mixture was then filtered to remove suspended particles. The solid extract was obtained from the extract solution by evaporating the solvent using a rotor evaporator.

*Preparation of tannin - formaldehyde resins:* Four different resins were prepared according to the methods described by Odozi and Agiri.[5] Phenol, resorcinol and cashewnut shell liquid (CNSL) were, in turn, used to modify the tannin - formaldehyde resins. The molar ratios of the various components used are shown in Table 1.

**Table 1: Molar ratios of the resin components.**

| Resin | Molar ratios | | | | |
|---|---|---|---|---|---|
| No. | Tannin extract | Formaldehyde | Phenol | Resorcinol | CNSL |
| 1 | 2.0 | 0.8 | | | |
| 2 | 1.0 | 0.8 | 1.0 | | |
| 3 | 1.0 | 0.8 | | 1.0 | |
| 4 | 1.0 | 0.8 | | | 1.0 |

*Resin 1 - Tannin / formaldehyde:* A mixture of 2.0 moles coconut coir dust tannin extract (based on the molecular weight of flavonol), 0.8 mole formaldehyde solution (37%w/v), 40ml methanol and 0.8ml anti-foaming agent was prepared at ambient temperature. The mixture was refluxed for 30 min. To this mixture was added 25ml 25%w/v NaOH solution, refluxed for 2h, and then cooled and stored.

*Resin 2 - Tannin / formaldehyde / phenol:* A mixture of 1.0 mole coconut coir dust tannin extract, 0.8 mole formaldehyde solution (37% w/v), 40ml methanol and 0.8ml of anti-foaming agent was prepared at ambient temperature. The mixture was refluxed for 30min. Then 1.0 mole phenol and 40ml 25% w/v NaOH solution were added, refluxed for 2h, cooled and stored.

*Resin 3 - Tannin / formaldehyde / Resorcinol:* Resin 3 was prepared using the same procedure as for resin 2 but replacing the phenol with resorcinol.

*Resin 4 - Tannin / formaldehyde / CNSL:* In preparing resin 4, 1.0 mole coconut coir dust tannin extract, 0.8 mole formaldehyde and 1.0 mole cashewnut shell liquid (CNSL) were used. Other chemicals added were the same as for resin 2.

*Glue Formulation*: A series of glues with pigment volume concentration (PVC) varying from 0 to 20% were prepared using the tannin - formaldehyde resins with the calcined kaolin clay, paraformaldehyde (96%), coconut shell flour and water as may be necessary to adjust viscosity. Glues 1, 2, 3 and 4 were prepared using resins 1, 2, 3 and 4 respectively. A typical formulation is shown in Table 2.

**Table 2: A typical glue formulation.**

| Formulation Components | Parts by weight |
|---|---|
| Tannin - formaldehyde resin | 100 |
| Kaolin clay (calcined) | variable |
| Coconut shell flour | 4 |
| Paraformaldehyde | 8 |

*Preparation of Plywood:* Three plywood panels of thickness 1.2mm, 4.0mm, 1.2mm respectively were prepared for each glue/kaolin clay concentration using sapele veneers (6% moisture content). The veneers were then glued at ambient temperature by brush application and hot pressed at 110$^0$C for a press time of 5min.

*Evaluation of adhesive bond quality in plywood:* To determine the ultimate strength of the various adhesives, shear specimens were tested to failure using Mosanto - Tensometer type W. Thereafter, the separated surfaces of the specimen sheared areas were immediately examined and percent wood failure (proportion of wood fibre remaining at break point) assessed. For each sample, five readings were taken and the average value reported. Bonded specimens were boiled at 70$^0$C for 3h and thereafter examined for delamination.

## RESULTS AND DISCUSSION

The effect of clay pigmentation on the practical adhesion (shear strength) of the glue systems based on coconut coir dust tannin - formaldehyde resins containing varying amounts of the calcined kaolin clay extender are shown in Table 3. The proportion of wood fibre remaining at break (percent wood failure) is shown in Table 4. Glue systems formulated with PVC greater than 20% were too thick for any practical applications.

*Effect of clay pigmentation on adhesion (bond quality):* It can be seen from the results in Table 3 that as PVC increases, the practical adhesion (shear strength) value increases up to a certain level of pigmentation, and then decreases. This observation occurred with all the glue systems studied, even though the optimum PVC values were different in each case. The pigmentation level corresponding

to the highest practical adhesion value can be considered to be the critical pigment volume concentration (CPVC) of the particular glue/clay extender system.[6] The practical adhesion value at the CPVC can be seen (Table 3) to be highest for glue 3 at 10% PVC, followed by glue 4 at 12% PVC, glue 2 at 14% PVC and glue 1 at 14% PVC. On adhesion, the best performance was observed with resorcinol modified coconut coir dust tannin - formaldehyde resin based glue (resin 3).

**Table 3: Effect of clay pigmentation on shear strength.**

| Pigment Vol. Conc. % | Shear strength x $10^4$ ($N/m^2$) | | | |
|---|---|---|---|---|
| | Glue 1 | Glue 2 | Glue 3 | Glue 4 |
| 0 | 14.7 | 15.7 | 19.6 | 16.2 |
| 2 | 15.7 | 17.7 | 24.6 | 17.2 |
| 4 | 19.6 | 18.6 | 27.0 | 19.6 |
| 6 | 21.6 | 19.6 | 29.4 | 24.6 |
| 8 | 22.5 | 21.6 | 34.3 | 27.0 |
| 10 | 23.5 | 22.5 | 36.8 | 29.4 |
| 12 | 24.6 | 24.0 | 35.3 | 31.9 |
| 14 | 25.9 | 27.0 | 27.9 | 25.9 |
| 16 | 24.0 | 24.0 | 18.6 | 22.5 |
| 18 | 22.5 | 18.1 | 13.7 | 17.2 |
| 20 | 18.6 | 12.3 | 9.8 | 14.7 |

*Effect of Clay pigmentation on percent wood failure:* Wood failure of wood substrate assesses the bond quality of sheared specimen at failure or break. As shown in Table 4, percent wood failure increases as the pigment volume concentration is increased up to a maximum around 10-14% PVC. Any further addition of clay decreases the percent wood failure from the observed maximum value. As observed in the case of shear strength, the highest level of wood failure occurred at 10% PVC for glue 3, at 12% PVC for glue 4, at 14% PVC for glue 2 and 14% PVC for glue 1. These values correspond to the CPVC point of the clay extender/glue system. The decrease in percent wood failure beyond the CPVC may be attributed to insufficient resin in the system to coat the clay particles. This introduces voids into the system and increases particle-to-particle interactions when compared to particle - to - resin interactions that existed below the CPVC point of each glue system. It was noticed that plywood samples glued with these adhesives failed predominantly in the glueline when subjected to the boil test.

**Table 4: Effect of clay pigmentation on percent wood failure.**

| Pigment Vol. Conc. (%) | Wood failure (%) | | | |
|---|---|---|---|---|
| | Glue 1 | Glue 2 | Glue 3 | Glue 4 |
| 0 | 30 | 41 | 44 | 53 |
| 2 | 36 | 45 | 56 | 60 |
| 4 | 40 | 52 | 67 | 65 |
| 6 | 48 | 55 | 70 | 68 |
| 8 | 55 | 58 | 86 | 70 |
| 10 | 60 | 65 | 94 | 84 |
| 12 | 66 | 70 | 76 | 78 |
| 14 | 70 | 75 | 64 | 72 |
| 16 | 52 | 63 | 58 | 63 |
| 18 | 38 | 48 | 52 | 51 |
| 20 | 25 | 28 | 45 | 40 |

It is clear that tannin - formaldehyde adhesives can be pigmented with kaolin clay extender, and satisfactory bond quality obtained in the PVC range of 10 - 14%. Taking into consideration the overall properties of the glues, it could be concluded that the resorcinol modified coconut coir dust tannin - formaldehyde resin based glue gave the best performance.

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