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Application of Keratin-Modified Urea-Formaldehyde Resin for Bonding Particleboard

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Abstract: This study was aimed at the application of keratin-modified-urea-formaldehyde (KMUF) resin adhesive for bonding particleboard. The keratin extract was used in developing the urea-formaldehyde resin. The physicochemical properties of the resins which included viscosity, gel time, specific gravity, pH and total solid content of the modified resins were determined. The application of the resin adhesives was done by formulating and forming particle board whose compositions were 80% wood chips, 11% resins and moisture content of approximately 9%.The boards were evaluated for their mechanochemical and water resistance properties. These properties of KMUF boards were compared with that of neat urea-formaldehyde (NUF) board. The results of the characteristics properties of the particleboards showed that KMUF gave improved strengths and better water resistance properties than the NUF board.

Key word: Keratin,application, bonding resin,adhesive, particleboard.

INTRODUCTION

Presently, the major types of adhesives in use today are formaldehyde-condensation petrochemicals. These include urea-formaldehyde (UF), phenol-formaldehyde (PF), melamine-formaldehyde (MF) and resorcinol-formaldehyde (RF) petrochemical adhesives. The above petrochemical adhesives have their own unique properties. Among these petrochemical adhesives, PF possesses the highest mechanochemical strength compared with the rest, but it is the most expensive. On the other hand, UF the least expensive petrochemical adhesive and most versatile in terms of applications has the least mechanochemical strengths. This drawback has drastically limited the applications of UF adhesive only to bonding wood products that will be used in interior non-structural areas. These disadvantages of UF petrochemicals are singularly due to their high susceptibility to thermal and hydrolytic degradation (Myers, G.E., 1985). The use of urea-formaldehyde resin as a major adhesive by the forest product industry is due to a number of advantages, including low cost, ease of use under a wide variety of curing conditions, low cure temperatures, water solubility, resistance to micro-organism and to abrasion, hardness and lack of color, especially of the cured resin. In the past, several attempts have been made by researchers to modify the structure of UF by incorporating some structure-modifiers so as to improve on their thermal and hydrolytic properties. A variety of modifiers have been examined, and have been found to be beneficial for durability (Ebewele, R.O., *et al*., 1991). These included polyamine (Ebewele, R.O., *et al*., 1991) and red onion skin (Edoga, M.O., *et al*., 2001) etc. Meanwhile, these efforts would result in new technique for improving the water repellency of urea-formaldehyde petrochemical adhesive which would subsequently broaden the markets for urea-formaldehyde material as well as poultry feathers. Particleboards are defined as a panel product manufactured from lignocelluloses materials, primarily in form of discrete particles, combined with a synthetic resin or other suitable binder and bonded together under heat and pressure (Maloney, M.T., 1977; Haygreen, G.J and Bowyer, L.J., 1989). Particleboard has been in use since the 1940s, often used in place of the more expensive plywood as sub flooring or instead of natural hard woods in furniture manufacturing. Modern particleboard is now made primarily by combing discarded wood shavings, chips and sawdust with a strong resin and pressing the mixture into serviceable boards and planks. Particleboard are used in furniture and fittings such as tabletops, desktops, doors, shelves boxes, toys, notice board, roofing and flooring etc. However the aim of this study was employ KMUF as a binder for the preparation of particleboard. While the objective was to compare the characteristic properties of boards prepared with KMUF resin to the boards prepared with NUF resin.

MATERIALS AND METHODS

The materials used include among others, keratin, urea, formaldehyde, sodium hydroxide, sodium sulphide, barium hydroxide, ethylalcohol, acetic acid. Some of the equipment used are glass jacketed reactor, oven, bench top density meter, Brookfield viscometer, techne gelation timer, apex hydraulic press, denison machine and Monsanto tensometer. The KMUF and NUF used for this research were prepared according to the methods described by Dim (Dim, P.E., 2009).

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Production of Particleboard:

The furnish or raw material for the particleboards production were selected off cuts, trim, peeler cores, and residues from the Sango Sawmill factory and were mainly mixture of hardwood species. They were reduced in size by a mill and were subsequently screened using a vibrating sieve to 2.00 mm for the core and 1.00 mm for the faces. The furnish was blended with 11 percent by weight of neat base resins (unmodified/modified) and phenol resin on dry solids particle chips weight basis. After blending properly, the furnish was carefully transferred to a board former of dimension 150 mm x 150 mm x 15 mm whose internal surface were covered with polypropylene plastic. The furnish in the board former was 220 g of particle chips in the ratio of 2:1 for core and face, respectively, which was placed carefully on an electrically powered hydraulic press. Prior to this time the press was preheated to ensure even distribution of heat and attainment of the required temperatures of about 120-182 ^{0}C, and the bonding was carried out under pressures of 20-3500 psi for 2-6 minutes ((Maloney, M.T., 1977). The particleboard samples were conditioned at room temperature and atmospheric condition before testing for strengths, water absorption and thickness swelling properties. The entire test was carried out on specimen in accordance with British Standard.

Mechanochemical Properties Evaluation:

Tensile Strength:

The test specimen of 50 mm x 20 mm x thickness, was placed in a machine called Denison model - T42B2. And force was applied until failure of the test specimen, i.e. when there was no further increase in force. The failing force in Newton was recorded for each specimen and the tensile strength was calculated by dividing the failing force in Newton by the cross-sectional area in square meters.

Bending Strength:

The test specimen (25 mm x 27 mm x thickness) was placed in a Monsanto Tensometer and force was applied at a substantial even rate in a direction perpendicular to the length of the test specimen. The failing force in Newton was recorded for each test specimen. The bending strength of each test specimen was calculated by dividing the failing force in Newton by the measured cross-sectional area in square meters.

Compression Strength:

The test specimen (25 mm x 25 mm x thickness) was placed in a suitable machine called Monsanto Tensometer and a compressive force was applied at an even rate in a direction perpendicular to the test specimen. The failing force in Newton was recorded for each test specimen. The compression strength of each test specimen was calculated by dividing the failing force in Newton by the cross-sectional in square meters.

Shear Strength:

Each test specimen was measured to be 20 mm x 20 mm x thickness of the board. The test specimen was placed in a suitable shearing jig, where necessary using metal packing pieces for alignment the force was applied at an even rate. The failing force for each test specimen was recorded. The shear strength in N/m^2 was calculated by dividing the failing force in Newton by the measured across sectional area in square meters.

Water Resistance Properties Evaluation:

Water Absorption:

Each test specimen of 50 mm x 50 mm x thickness was weighed and then immersed in fresh clean water at room temperature of 30 ^{0}C, the water being renewed for each test. The test specimens were separated by at least 13 mm from each other and from the bottom and sides of the container. They were covered by approximately 25 mm of water. At the end of 2 hrs, each test specimen was withdrawn from water, wiped with damp cloth and reweighed to the same degree of accuracy as before. The increase in mass was recorded as a percentage of the initial mass.

Thickness Swell:

The thickness of each test specimen was measured and then immersed in fresh clean water at room temperature of 30 ^{0}C, the water being renewed for each test. The test specimens were separated by at least 13 mm from each other and from the bottom and sides of the container. They were covered by approximately 25 mm of water. At the end of 12 hrs, each test specimen was withdrawn from the water, wiped with a damp cloth and allowed to stand under normal room condition for 2 hrs with its bottom edge on a non-absorbent surface such as a glass sheet. The thickness of each test specimen was re-measured at the same point as before and to the same degree of accuracy, and the increases were recorded. The values obtained, expressed as a percentage of the initial values was reported as the “Swelling value”.

Moisture Content:

The test sample was weighed and dried in an oven at 100 $\pm$ 20^{o}C until approximately constant mass is attained. After drying, the sample was reweighed immediately and recorded. The moisture content, expressed as percentages of the oven dried mass was calculated.

RESULTS AND DISCUSSIONS

The results of physicochemical properties of resins and mechanochemical properties of particleboard samples produced are presented in Table 1.0 and 2.0 below:

Table 1: Property of Modified and Unmodified Resin Samples.

Resin samples	pH at 25^{o}C	Viscosity at 25^{o}C (cp)	TDS at 105^{o}C / 2hrs %	Specific gravity	Gel time at 100^{o}C (Sec)
A (NUF)	8.8	260	62.0	1.45	180
B (KMUF)	9.0	280	63.5	1.34	167
C (KMUF)	8.9	300	66.0	1.29	120
D (KMUF)	9.1	330	69.0	1.25	82

Table 2: Mechanochemical Properties of Particleboard Samples.

Sample Properties	B_1	B_2	B_3	B_4
Bending strength (MPa)	2.48	2.40	2.75	3.20
Tensile strength (MPa)	0.65	0.69	0.95	1.85
Compression strength (MPa)	0.86	0.96	1.14	1.42
Shear strength (MPa)	0.80	0.81	0.90	0.98
Moisture content (%)	8.6	9.2	8.9	9.2
Water absorption (%)	25.0	19.8	14.0	6.8
Thickness swell (%)	5.2	4.8	3.3	1.8

B_1 = Particleboard binded with resin sample A(NUF)
B_2 = Particleboard binded with resin sample B(KMUF)
B_3 = Particleboard binded with resin sample C(KMUF)
B_4 = Particleboard binded with resin sample D(KMUF)

DISCUSSION OF RESULTS

Physicochemical Properties of Resins:

From Table 1.0, it can be seen that the pH of all the resin samples were found to be between the ranges of 8.8–9.1 indicating that the resins are alkaline. It can also be seen that the viscosity at 25^{o}C of the keratin modified resin is higher than the unmodified ones. This may be due to inclusion of keratin in the modified samples. This is in agreement with the fact that the higher the viscosity the better the reactivity of the resin (ATAPEX, 1995).The total solids content of the resin samples as shown in Table 1.0 indicates that the resins have different total solids content, with samples A, B, C, and D having 62.0%, 63.5%, 66.0% and 69.0% respectively. All the values are greater than 45% which is the minimum value and this is recommended by Atapex technical data for timber and plywood. It is also a well known fact that the more the solids content the better the resin (ATAPEX, 1995).Generally the purpose of determining the gel time of a resin for use as adhesive is to ascertain the resins reactivity during hot pressing and storage. Table 1.0 shows that sample A has gel time of 180 seconds, while the modified samples have gel time of 167, 120 and 82 seconds respectively. This implies that sample D of the modified resin has the best reactivity followed by C and lastly sample B. Thus the behaviour of the modified resins showed a great improvement in accordance with Atapex (ATAPEX ,1995).From the same table, the modified resin samples of B, C and D have specific gravities of 1.34, 1.29 and 1.25 respectively while the unmodified sample A has the specific gravity of 1.45. Thus the specific gravity of modified resin is in agreement with the standard, compared to the unmodified resin. Thus keratin inclusion in the resin could potentially lower the resin relative density (specific gravity). This is in accordance with Saheb and Jog (Saheb, D.B and J.P Jog., 1999) that using a natural fiber in such application will definitely benefit from weight reduction since keratin is very light. Because the modified resin is made of about 25%, 50% and 75% keratin, less urea are needed to produce it, according to Durham (Durham, S., 2002), Barnes (Barnes, P., 2002) and Jacobson (Jacobson, L., 2002).

Mechanochemical and Water Resistance Properties of Boards:

The results of mechanochemical and water resistance properties analysis performed on the particle board samples produce are discussed below:

Bending strength:

Bending strength test serve to evaluate the stiffness and stability of the board. It is a characteristic which relates to loading and support spacing where particleboard is used for shelving. From Table 2.0, sample B_4 have the highest bending strength of 3.20 MPa, while sample B_3 is 2.75 MPa, sample B_2 is 2.40 MPa and sample B_1 is 2.48 MPa. The results indicate that the bending strengths of particle board produced with KMUF resin were found to be higher than the NUF resin board. These boards meets the laid down minimum permissible bending strengths for board of different thickness, based on the methods described in (((DIN) 6876: Sheet 3 September, 1967).

Tensile Strength:

Tensile strength test measures the soundness of the interior structure of the board and shows that the board has been properly cured during pressing. As shown in Table 2.0, tensile strengths increase from sample B_1 to B_4.The data also indicates that tensile strength ranged between 0.65MPa to 1.85MPa. The samples B_2, B_3 and B_4 were found to be between 0.69MPa and 1.85MPa, which is greater than sample B_1 (0.65MPa). Therefore, the tensile strength of boards bonded with the modified resins, performed better than the one bonded with neat resin.

Compression Strength:

From Table 2.0, the compression strength of samples B_1, B_2, B_3 and B_4 are 0.86MPa, 0.96MPa, 1.14MPa, and 1.42MPa respectively. As shown in Table 2.0, the modified resin board is 1.42MPa, which compares favourably with strength of phenol-formaldehyde resin bonded board. The result shows that the modified boards performed better than the unmodified board but still inferior to the phenol-formaldehyde board (ATAPEX ,1995).

Shear Strength:

From Table 2.0, the shear strength result shows that sample B_4 has the highest strength value of 0.98MPa, followed by B_3 which has the strength value of 0.90MPa, sample B_2 is 0.81MPa and sample B_1 is 0.80MPa. From this trend it can be seen that there is a significant improvement in the modified resin boards, when compared with that of the unmodified resin board sample.

Conclusions:

KMUF and NUF resins were used as binder in the preparation of particleboard. And the boards were compared based on their mechanochemical properties. The tensile-shear strength and compression-bending strength were higher in particleboards of KMUF compared with that of NUF. The strength values of the boards were found to meet the minimum strength requirements of the Atapex standard. It can be concluded that, the particleboards made with modified resin showed an improved mechanochemical strength qualities and better water resistance performance than the one made with neat resins.,

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