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Performance Tests of Wood Glues on Different Wood Species Used in Wood Workshops: Morogoro Tanzania

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Abstract**—**High tropical forests deforestation for solid wood furniture industry is among of climate change contributing agents. This pressure indirectly is caused by furniture joints failure due to poor gluing technology based on improper use of different glues to different wood species which lead to low quality and weak wood-glue joints. This study was carried in order to run performance tests of wood glues on different wood species used in wood workshops: Morogoro Tanzania whereby three popular wood species of *C. lusitanica, T. glandis* and *E. maidenii* were tested against five glues of Woodfix, Bullbond, Ponal, Fevicol and Coral found in the market. The findings were necessary on developing a guideline for proper glue selection for a particular wood species joining. Random sampling was employed to interview carpenters while conducting a survey on the background of carpenters like their education level and to determine factors that influence their glues choice. Monsanto Tensiometer was used to determine bonding strength of identified wood glues to different wood species in use under British Standard of testing wood shear strength (BS EN 205) procedures. Data obtained from interviewing carpenters were analyzed through Statistical Package of Social Science software (SPSS) to allow the comparison of different data while laboratory data were compiled, related and compared by the use of MS Excel worksheet software as well as Analysis of Variance (ANOVA). Results revealed that among all five wood glues tested in the laboratory to three different wood species, Coral performed much better with the average shear strength 4.18 N/mm^2, 3.23 N/mm^2 and 5.42 N/mm^2 for Cypress, Teak and Eucalyptus respectively. This displays that for a strong joint to be formed to all tree wood species for soft wood and hard wood, Coral has a first priority in use. The developed table of guideline from this research can be useful to carpenters on proper glue selection to a particular wood species so as to meet glue-bond strength. This will secure furniture market as well as reduce pressure to the forests for furniture production because of the strong existing furniture due to their strong joints. Indeed, this can be a good strategy on reducing climate change speed in tropics which result from high deforestation of trees for furniture production.

Keywords**—**Climate change, deforestation, gluing technology, joint failure, wood-glue, wood species.

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I. Introduction

A. Background Information

THE dictionary defines an adhesive/glue as a substance capable of holding materials (adherents) together by surface attachment [1]. Adhesion is the state in which two surfaces are held together by interfacial forces, which may be valence forces, interlocking action, or both while an adherent is a substrate held to another substrate by an adhesive [2].

Wood joining by using adhesive bonding has played an important role in the development and growth of the forest products industry as well as being a key factor in the effective utilization of timber resource from our forests. Adoption of resin technology on wood products manufacturing industry is one of the main changes that have occurred in wood construction in the last 50 years. Resin technology has boosted the improvement of wood industry through forming wood products in a more stabilized structures as well as production of laminated sheet form such as plywood [3].

The largest amounts of adhesives are used to manufacture building materials, such as plywood, structural flake boards, particleboards, fiberboards, structural framing and timbers, architectural doors, windows and frames, factory-laminated wood products, and glass fiber insulation [2]. Mostly, adhesives are used in the industrial construction activities and in other small wood working workshops, even though it can be also used in nonstructural applications as floor coverings, countertops, ceiling and wall tile, trim, and accessories.

Wood glue, as an adhesive, has a property of being able to stick together different wood pieces or wood fibers. The properties of an adhesive need to not only match the needs of the bonded assembly in its end use, but also need to be compatible with the substrate and the bonding process conditions. Generally, for wood bonding, adhesives are of the structural type i.e. they are able to transfer load between adherents. Glue can effectively transfer and distribute stresses, thereby increasing the strength and stiffness of the composite while effective transfer of stress depends on the strength of the links in an imaginary chain of glue-bonded joint [4].

Different types of wood glues exist all over the world with different bonding ability, capacity and strength in relation to the nature, condition and species of the wood pieces to be joined. To form a joint with the best performance, rely much on how well we understand and control the complexity of essential factors that constitute the individual links wood, adhesive, and inter phasing regions between which indeed

determine the strength of the chain formed [2]. Making uniformly strong joints depends primarily upon having the proper correlation of gluing pressure and glue viscosity at the moment pressure is applied on the well prepared wood surfaces [5].

Due to the difference in performance of different wood glues to different wood species, there is variety of wood glues existing in Tanzania. Hence a study on glue performance efficiency is of paramount importance in determining the most appropriate glue for different wood species.

B. Problem Statement and Study Justification

Making uniformly strong joints depends primarily upon having a proper correlation of gluing pressure and glue viscosity at the moment pressure is applied [5]. Vick [2] urged that the performance of the bonded joint depends on how well we understand and control the complexity of factors that constitute the individual links of wood, adhesive, and the interfacing regions between which ultimately determine the strength of the joint. Furthermore, [3] said that glue strength is assessed by measuring the lap shear strength in appropriately designed joints. Schofield [6] did a very good experiment on wood glues. However, his experiment was based on white oak and hard maple which are not grown in Tanzania. Also, the type of glues used in study i.e. polyurethane and epoxy glues are not yet available in the Tanzanian market.

A number of glue types are sold in shops within Morogoro municipal and Tanzania as whole. The problem with most of these glues is that, they are silent on the strength of the glues, shelf and pot and their workability to different wood species. Therefore, it very difficult for carpenters to choose the right glue to use. Due to that reason, this research came out so as to test for wood glue strength to different wood species so as to provide guideline for wood glue selection for different wood species. This testing for the efficiency of different glues was as important as was to discover the truth of shear strength of different glues as are all silent on that. The results obtained and the guideline developed are applicable to increase the awareness of the carpenters hence can lead to the advancement of the quality of wood products, to reduce variation among wood products of the same kind and to prolong its durability; as the proper glue with known shear strength will be used to an appropriate wood species. This will also help wood products from our workshops to be acceptable in international market competition as are of high quality and can tolerate stresses. This will also economize the use of trees resources as this scarce resource is highly depleting, so it need a proper and sustainable utilization of its products. This will rescue more tree felling for furniture production due to strong joints resulted from a nice matching of wood glue with a particular wood species as the result of the details on its shear strength and performance obtained from this research.

C. Objectives

The main objective of this research was to determine the performance of different wood glues to different wood species used in wood workshops in Morogoro municipality, Tanzania. Then, the specific objectives were; to conduct a survey on the background of carpenters dealing directly with furniture processing, to determine factors that influence choice of glues to carpenters with regard to furniture production and the last was to determine the bonding strength of identified wood glues to different wood species in use.

II. Literature Review

A. Glue Concept

Unless they confine their woodworking to knockdown furniture, all woodworkers depend on wood glue on operations. Due to that, there are so many types of glue and masses of competing brands all so as to win the market are proclaiming their superiority [6]. Curing temperature, durability and the origin of the primary components are useful on classifying adhesives even though adhesives can be further put into two classes which are thermoplastic or thermosetting [7].

Natural adhesives are adhesives whose primary composing materials are either plant or animal based materials [7]. These adhesives of natural origin-such as animal, casein, soybean, starch, and blood glues and are still being used to bond wood in some plants and shops, but are being replaced more and more by synthetics. Until nearly the middle of the 20th century, glues based on naturally occurring materials were the principal adhesive bonding agents for wood. The basic ingredients for these generally were byproducts of meat processing (for animal and blood glues), or casein, soybean, and starch [5].

From industrial raw materials that have no natural origin, synthetic adhesives are formulated [7]. In the early 1930's, synthetic resin adhesives began to appear on the woodworking scene; because of their versatility and other advantages, they found widespread use in the woodworking industry. Development of synthetic resin adhesives has facilitated manufacture of many important glued wood products. Among these are laminated bridge timbers, ship keels and frames, and other laminated members for use under severe service; plywood for boats, signs, railroad cars, and other exterior uses; and components for houses and similar structures [5]. Due to its ability to form a strong permanent solid, heat resistant materials, thermosetting adhesives are highly used in heavy duty structural applications to formulate very strong structures. Mainly these are based on solvent solutions of neoprene and are often for installation of hard surface counter-top laminates [8].

Thermoplastic adhesives are basically thermoplastic in nature meaning that they are heated to a sufficient temperature to the extent they will flow and wet the substrates and then set and develop the bulk strength on cooling [9]. So as to soften thermoplastic adhesives, heating without undergoing a chemical change is used and can achieve the kind of strength required for a different use under normal temperature [7].

B. Wood Concept

Wood refers to a type of non-metallic material that needs a separate consideration. Wax, resin, and various products of

oxidation are the common wood contaminants. The peculiar properties of this material make it popular in many applications that call for adhesive bonding in wood. Special procedures in surface preparation are always required due to its physical properties require so as to assure effective bonding [9].

There are actually two major types of wood species used in workshops depending to tree source; these are hardwoods and softwoods responding differently to wood glues. These names can be confusing since some softwood is actually harder than some hardwoods, and conversely some hardwoods are softer than some softwood [10]. A main complication is that different species of woods have different cellular structures, and therefore, adhesives will penetrate them to different degrees. This leads to problems in trying to achieve uniform penetration when bonding different species of wood. For a more porous wood, an adhesive can over-penetrate into the wood and not be on the surface for bonding, while the same adhesive on a less porous wood sits on the surface and may not give significant bonding. Thus, adhesives are formulated for different applications given the type of wood, the type of application, and the application conditions [4]

C. Properties of Wood Species

Wood of different species have various properties which directly and indirectly affect its gluing characteristics during joint formation. Above all the most important is wood's density, but the amount of shrinking and swelling with changes in moisture content is also a very important factor, especially where long term serviceability of glue joints is required [5].

Moisture Content

Moisture content of wood at the time of gluing is important because it affects the quality of the bond and the performance of the glued product in service [5]. Wood-glue joint formation is a chemical reaction which require wood to have the required level of moisture for the reaction to take place thoroughly. For instance, phenol-formaldehyde requires 8-12% of moisture content in wood, in the case of urea-formaldehyde adhesive it is 6-14% wood moister content and for resorcinol adhesive to formulate a strong joint it requires 12-18%. Even though some of the moisture required for joint formation can be gained from the glues themselves, urea-formaldehydes can generate up to 50-60% water while phenol-formaldehydes approximately 35% water by weight [3]. At the beginning, wood must be dried to the level of moisture content appropriate to its service use when joined by using a particular adhesive [9]. Wood has a tendency of shrinking as gives off moisture and swelling as it absorbs moisture in ordinary use. The impacted dimensional changes put stresses on joints in glued products hence for the higher the stresses, the stronger the glue joints must be made to avoid bond failure [5]. The ability of a liquid adhesive to wet a solid substrate determines the compatibility between the adhesive and the substrate [11].

Density and Porosity

Since wood is porous, and different woods have different properties, wood is not an easy material to glue. Because of wood's porosity, it can absorb liquid. Most glues used in the woodworking industry are liquid. Weight of wood is generally expressed either in pounds per cubic foot or as a comparison with the weight of an equal volume of water (specific gravity). Two blocks of wood of equal volume may vary a great deal in weight, even if the blocks are of the same species. In general, strength properties of wood increase with specific gravity in a similar manner [5].

Planed Surface

For strongest joints, wood surfaces should be machined smooth and true with sharp tools, and be essentially free from machine marks, chipped or loosened grain, and other surface irregularities [5]. Surface contamination should either be sanded or planed, or machined away. Air pressure, brushing or vacuuming can be employed to remove debris from such mechanical cleaning operations, otherwise debris can be wiped away with a solvent-moistened cloth. After cleaning the surface, it should be handled as little as possible prior to bonding the particular wood material [9]. The surface preparation has been shown to have a large effect on the quality of a wood surface [12]. One concern is a weak boundary layer, which is a layer between the bulk materials and the true adhesive-adherent interface that is often the weak link and fails cohesively within that layer [13].

D. Glue Mixing and Strength Property

Some adhesives, such as the film types and the straight polyvinyl, are furnished ready for use and hence require no mixing. Others, as the ready-to-use caseins and some powdered urea, need only to be mixed with water, as prescribed by the glue supplier [5].

Adhesive joint strength is the most important engineering property of an adhesive material as the latter is in the realm of engineering mechanics and is required mostly for engineering design purposes [9]. Lap shear strength measurement is useful on assessing glue strength in appropriately designed joints. For instance, cured epoxy adhesive mixes it is generally between 1500 and 2200 psi i.e. 120 - 150 kg/cm^2 depending on the epoxy system employed [3].

E. Glue Spreading

Various methods are used to apply adhesive to joint surfaces when bonding wood, depending largely on the type and amount of glued product and also to some extent on the adhesive. In noticeably higher spread is required with casein glue than with most synthetics [5]. Due to viscous form of most of adhesives it is easily to spread on the wood surface by brush, spatula or roller. So as to obtain the best wood-glue joint results, an adhesive has to be well rubbed on the wood than when poured. This can be much effective once adhesives applied on both surfaces with a thin film on each surface and for many adhesives, the best density of application on bond forming is in order of 200-300 gm^{-2} [7].

F. Assembly Time

This is the interval between spreading the adhesive and the

application of full gluing pressure. If wood surfaces coated with glue are exposed freely to the air, solvent evaporation and changes in adhesive consistency occur much more than if the joint surfaces are in contact. Free exposure of the coated surfaces is called "open assembly;" surfaces in contact, "closed assembly" [5]. Open assembly time as the time adhesive spread areas are exposed to the air before joining the two surfaces coated with adhesive together. Practically this helps on evaporation of solvents hence to enable the adhesive surfaces to begin to cure when joined together. Closed assembly time refer to a time between bringing the spread surfaces together and the application of pressure. The allowable closed assembly time can vary from as short as 5 minutes to as high as 8 hours and sometimes several days depending on the type of adhesive used during joining [7].

G. Joining Pressure

The application of adequate and uniformly distributed pressure to the joint at the proper (required) time is essential in production of consistently high-quality bonded wood-glue joints. Through this, Glue-joint surfaces brought into close contact to enable the adhesive to form a bond between them [5]. This is to overcome natural surface roughness of the wood even though the main reason that pressure is necessary to be applied is to counteract the shrinkage in the glue itself which occurs at the time glue loses moisture as part of its curing process [3]. The amount of pressure needed depends on characteristics of both the wood and adhesive. High density hard wood species like camphor (*Ocotea usambarensis*) require higher pressure than low density soft woods like cypress (*Cupressus lusitanica*) and the pines (*Pinus patula)* [14].

H. Curing Temperature

Curing temperature refers to the degree of heat at which the adhesive dries up to a level where the joint is strong enough for loading after adhesive has been applied and the surfaces firmly bonded together [7]. Most of common wood adhesive can be classified under three groups basing on curing temperature. The first one is high-temperature curing adhesives which cure at temperatures above 90°C and the majority of these adhesives are utilized in composite wood making [14]. The second classes is intermediate temperature curing adhesives which cure at temperatures ranging from 30°C to 90°C and they perform well in construction where timber is exposed to temperatures above room temperatures. The last one is low or room temperature curing adhesives, which cure at temperatures as low as 15°C to 30°C. Most adhesives curing at room temperature are relatively weak in strength [7].

I. Joint Failure

The joints failed in three different ways which are either wood failure or glue failure or the combination of the two depending to what is week at the joint bonding point [6].

(a) Glue failure (b) Wood failure (c) Combination

Fig. 1 Types of joints failure [6]

III. Materials and Methods

A. Description of the Study Area

The study was conducted in Morogoro Municipality, where several wood products processing and utilization are easily found. Morogoro Municipality lies at 500 meters above sea level and rests on the foot of the extensive and undulating 2,138 meters high Uluguru Mountains which form a beautiful backdrop to the Municipal Municipality. It lies within the latitudes of 06°49′20″ South and longitudes of 037°39′55″ East and has an area of 288.35 km² from the whole region which has a total area of 73,039 km² [15]. Morogoro Municipality is mostly a business and agricultural place where people from different corner of Tanzania are found but the native of the land are Waluguru. Carpentry works are among of the business activities which are held in different scales of production in different wards like Sabasaba ward, Ngoto ward and Uwanja-wa-ndege ward. There are single person workshops (small scale), a group of people workshops (medium scale) and industrial workshops (large scale) whereby all of them contribute to the furniture market.

B. Sampling and Data Collection

For conducting a survey on the background of carpenters and the determination of factors that influence their choice of wood-glues was employed where by a list of questions were used to interview carpenters who were selected randomly Also their preference to wood glues was captured by the same approach i.e. using Interview.

For the determination of the bonding strength of identified wood glues to different wood species, seventy five (75) prepared joint samples was arranged for the experiment from three (3) wood species whereby every sampled wood species was tested to five (5) different wood-glue. Replication of five experiments were done for testing shear strength of joints by use of Monsanto Tensiometer. The specimen under test was placed in the shearing tool (shear box) so that the load may be applied to the joint then a continuous motion of the movable head of the Tensiometer at the rate of 0.635 mm/min was applied till the joint broke. Lastly the shear strength of the bond joint was computed and recorded for data analysis. Then, the area failure area in percentage was calculated for every specimen after the joint breakage so as to know how stronger the glue on relation to the wood fibers is after gluing. This was obtained through taking the ratio of the damaged area of the wood to that of the total area of the joint (400 mm^2) then

multiplying to 100%. The found area in percentage calculated were recorded whilst failure area was calculated by;

$$\text{Failure area \%} = \frac{\text{Total damaged area}}{\text{Total area of glue-wood joint}} \times 100\% \quad (1)$$

C. Wood-Glue Joint Strength (Specimens Preparation, Data Collection and Analysis)

The study used samples of hardwood species of, *Eucalyptus maidenii* (Mkaratusi) and *Tectona glandis* (Mtiki). In case of softwood species sample used was *Cupressus lusitanica* (Cypress). These wood samples were collected in several wood workshops in Morogoro Municipality as the representative to most used wood species in wood workshops for the experimental test. Determination of glue-joint strength followed British Standard - BS EN 205 [16] of testing wood shear strength, the standard includes, sample preparations, drying, gluing, assembly, conditioning and testing.

Preparation of Specimen

Samples were prepared according to the instructions under underlying on British Standard (BS EN 205) of testing wood shear strength. In this experiment, 150 specimens were prepared by cross cutting the samples wood into dimensions of 20 mm x 20 mm x 10 mm. The blocks were surfaced prior to gluing with the brush so as to remove any trace of sand before assembling them in pairs so that blocks of approximately the same specific gravity to be glued together. Two pieces of adherents were joined by using the glue samples selected and forming a total of 75 paired joints.

Drying of the Specimen

The specimens under test were dried to moisture content near to twelve percent (12%) based on oven dry weight as required by the BS EN 205 standards. Then, all of the samples were left to air drying till their percentage moisture content reached to approximately 12 % moisture content.

From all of three samples wood species, three specimen of equal dimension of 20 mm X 20 mm X 20 mm from every species were taken then its weight was measured by the use of electronic weigh balance then its weight was recorded. Then all samples were taken to the oven for drying so that we may have a constant weight for discovering its equilibrium moisture content (MC) after another measurement by;

$$\text{MC\%} = \frac{\text{Green weight} - \text{Oven dry weight}}{\text{Oven dry weight}} \times 100\% \quad (2)$$

Glue Preparation and Application

Adhesives were well prepared and applied to the blocks according to the procedure recommended by the manufacturer of the adhesive. This was because different manufacturers have recommended differently ways on how to apply the glue. For instance, the manufacturer of Coral glue has recommended to apply on both sides while Fevicol glue manufacture recommended to apply on a single side. The whole application activity was done using a brush.

Glue Assembly and Pressing

The sample blocks were assembled and cold pressed using a clamp to press the adherent together. Cold pressing was preferred because it uses little pressure and it is inexpensive as available to use. Then wood samples were released from the press for conditioning.

Conditioning of the Samples

After the release from the press, samples were conditioned in order to allow the redistribution of the moisture content and temperature added by the adhesives. For this to be accomplished air conditioning was applied to the bonded assembly for seven days at room temperature before shear testing.

Strength Testing

In order to make a shear testing to the sample specimen; testing methodology for shear strength was adopted from British Standard of testing wood shear strength, BS EN 205 standards. The specimen under test was placed in the shear box so that the load may be applied to the joint. Continuous motion of the movable head of the Tensiometer at the rate of 0.635 mm/min was applied till the joint breaks. Then data were collected and filled in the table of results by indicating the wood species sample joined together under test with the responded area of the joint as well as its shear stress.

Data Collection and Analysis

Data from carpenters' backgrounds were analyzed through Statistical Package of Social Science software (SPSS). Statistical frequency and percentages from this data analysis were useful to easier results discussion as the software allows comparison of different data. Field and laboratory data were compiled, related and compared through MS excel worksheet software as well as Analysis of Variance (ANOVA). Data were usefully to test the significance difference of the performance of glues to different wood species. All collected and analyzed data were useful on recommending the best wood glues to different wood species as have to be applied in wood workshops.

Tensiometer data in kilogram-Force, had to be multiplied to a constant of 9.8066 N as indicated on the calibrated ruler if the Tensiometer machine used. The force obtained in Newton (N) units was then divided to the area of the broken wood glue joint 400 mm^2 so as to get a shear strength (τ) in N/mm^2 of the particular glue to the particular wood species; the same procedures were repeated for every sample joint.

IV. Results and Discussion

A. Research Results

Result from Survey on the Background of the Carpenters.

The background of all carpenters on their education level showed that 50% of the interviewed carpenters were holding primary level of education while 25% of them were secondary level of education holder and the last quota are technical college graduates. This affected much the furniture industry

especially on the glue use just because these who were certificate holder seems to be knowledgeable on the different technical proper uses of glues. Also the background on the working experience of carpenters displayed that those with 0-5 years' experience were 35%, 6-10 years' experience were 30%, 11-15 years' experience were 10%, 16-20 years' experience were 5%, and lastly those with an experience of more than 20 years were 20%. Carpenters with high carpentry experience had high skills on gluing technology hence their furniture joints were strong compared to those with little carpentry experience.

Results on the Factors that Influence Choice of Glues to Carpenters.

The Favorite Wood Glue

There were several difference glue preferences to different carpenters, even though in this survey it seems only three glue types i.e. Coral, Bullbond and Fevicol which found in the market are very much preferred in use compared to the rest which area actually not used due to several reasons.

Fevicol were the mostly preferred wood glue whereby 65% of the sample carpenters interviewed seems to prefer. The main reason was Fevicol shows a very faster result of hardening soon after being applied to the joint. The other reason was the high performance of this wood glue type on joining wet timber as well as green timber during furniture processing. In the case of Coral, 25% of sampled carpenters preferred, by the main reason of this wood glue type always results to a very strong bond hence their good performance in the market. The last was Bullbond whereby 10% of the respondent shown to prefer it mostly just because it is heavy enough to be used as filler in wood cracks and checks in the lumber in their combination with some wood dust (see Fig. 2).

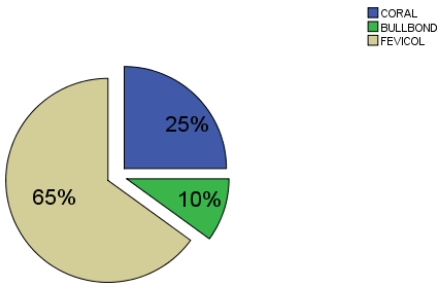

Fig. 2 The mostly preferred glue by carpenters

The rest of glues were not preferred by almost all of the interviewed carpenters due to several reasons but the most one was that; many of wood glues do show high performance in their time of introduction in the market even though as time goes on their performance keep in decreasing as fake glues or with low standard get introduced as the mimic to original one this is like for performance of Ponal glue which shown the best performance in the early 2000's.

The Best Glue Form

The glue forms much preferred by carpenters were light liquid, liquid and heavy liquid. A liquid form of glue which is not too heavy or too light was the mostly preferred form by about 75% of all interviewed carpenters by the reason that it's easy to apply on the wood surface as well as it does not form a large joint line during gluing. The next to preference was a heavy liquid glue like Bullbond glue whereby 15% carpenters liked it; this was because its form support much on wood fillers preparation and has a good performance of filling wood cracks, checks, splits and drilled holes during mechanical wood joining. 10% of the respondent were interested on the light liquid glues by the reason that can more easily applied to the wood surface. Fig. 3 shows the results after glue form preference data analysis.

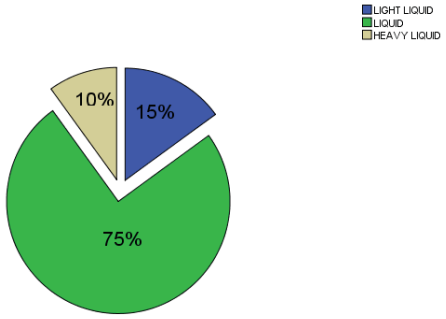

Fig. 3 The mostly preferred glue form to carpenters

Nobody was familiar with other glue forms to be existing; glue forms like powdered glue form and crystal glue form were even not found in the surveyed markets.

The Best Glue Color

Different glue colors were preferred differently by the carpenters on gluing hence showing that glue color has got also an influence on the wood glue choice. Actually it is of small influence compared to glue strength as well as compared to hardening impact of the glue. White colored glues were much preferred by the reason that it is pleasant on looking; and about 60% of the carpenters reached shown to prefer much white glues color like of Bullbond and Coral glues. 40% of the respondent interested much on brown colored glues like Fevicol by the reason that, brown color correlates with to most of wood color hence there is no color interference in the joint. The analyzed data were with the following results.

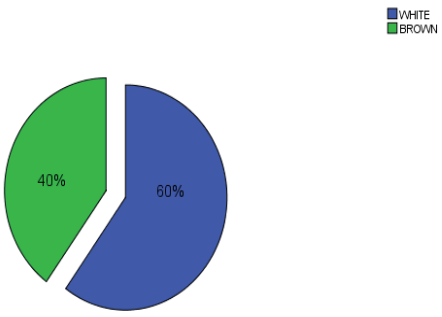

Fig. 4 Percentage distribution of the glue color preference to carpenters

The Cost Influence on Glue Purchases

As it is for other products in the market, wood glues are of different types and they are manufactured by different industries all over the world; due to that, wood glues are of varying price in the market. It was found that, glue cost does not determine carpenters' glue choice (see Fig. 5) since what determined glue to purchase was work piece intended to be produced. Carpenters proposed glues with high price for larger work piece produce to be accomplished while for the small work piece a cheap priced glue was used. And another factor which influenced the glue purchase was the nature of the product to be made as well as how faster it is required to be used by a customer. Also, when there is a need of faster furniture production, Fevicol was mostly preferred as it hardens soon.

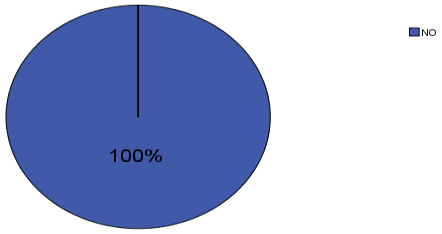

Fig. 5 The influence of glue cost to carpenters use

Different Knowledge on Gluing

For the strong joint to be formed, there is actually a need of having enough knowledge on gluing. This gluing knowledge has a great impact to the performance of different glues during furniture production. Different gluing knowledge like curing time, gluing pressure, assembly time, glue spreading, glue mixing and glue storage were all assessed in this research. Generally, the results showed that carpenters have little knowledge on those staffs but most of them use experiences at work and only few who passed through vocational trainings colleges and other technical schools showed to have knowledge on most of the gluing essentials.

About 95% of the sampled carpenters responded to have knowledge on curing time of the wood-glue joint as well as a knowledge on pressure required for the strong joint to be formed; 60% of the respondents are found to have knowledge on assembly time, 65% had a knowledge on glue spreading techniques for the strong joint to be made. 75% of sampled carpenters found to have knowledge on glue mixing especially during filler materials preparation. Lastly, all respondents had knowledge on glue storage.

B. Results from Specimen Drying

After moisture content measurement, wood samples were found to have an MC of 13.04%, 8.73% and 14.52% for Cypress, Teak and Eucalyptus respectively. Moisture content was nearly the same in the next MC% measurements under oven drying. Moisture content found was still within the limit range recommended for the glue application to the wood i.e. from 5-15% MC. So, the whole sample wood specimens were taken to the Tensiometer for shear strength experiments. Teak wood species was the driest species by the moisture content of 8.73%. Cypress with 13.04% moisture content was moist than Teak but less moist than Eucalyptus which was found to have a moisture content of 14.52%. This then impacted much their ability to firmly stick with glue.

C. Results from Shear Strength Experiment

Based on the shear strength results of each glue to every tree species; the further analysis from average shear strength of every glue joint to every wood species came with the results in as in Table I. Also the results for percentage failure area as averages for every joint were in combination with shear strengths as shown in Table I.

TABLE I
DATA RESULTS WITH AVERAGES OF EVERY GLUE SHEAR STRENGTH (N/MM^2) AND FAILURE AREA (%)

Wood sp.	Wood glues									
	Woodfix		Bullbond		Ponal		Fevicol		Coral	
	Sh	Are	Sh	Are	Sh	Are	Sh	Are	Sh	Are
C. lustanica	3.5	0	2.8	0	2.8	0	2.57	0	4.2	43.9
T. glandis	1.7	0	1.7	0	2.1	0	2.31	0	3.2	0
E. maideii	2.3	0	3.0	0	3.5	0	2.54	0	5.4	0

Sh in the table stands for "Shear" while Are stands for "Area"

The data on shear strength were further analyzed using ANOVA at the 95% confidence level for the statistical significance test of the glue performance to different wood species. The results were as shown in Table II.

TABLE II
ANOVA TABLE

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	3	7.541	2.514	0.818
Column 2	3	7.605	2.535	0.507
Column 3	3	8.414	2.805	0.445
Column 4	3	7.419	2.473	0.020
Column 5	3	12.82	4.276	1.208

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.093	4	1.773	2.957	0.075	3.478
Within Groups	5.995	10	0.599			
Total	13.089	14				

D. The Results Discussion

1) Wood Glues Results Discussion

So, for the all wood species both soft wood and hard wood, Coral has a higher shear strength than the rest with the shear strengths of 4.18 N/mm^2, 3.23 N/mm^2 and 5.42 N/mm^2 for Cypress, Teak and Eucalyptus respectively. Among five wood glues tested in the laboratory to three different wood species, Coral performed much better with the average shear strength of 4.28 N/mm^2 displaying that for a strong joint to be formed to all of the tree wood species for soft wood and hard wood, Coral was the best (see Tables I & II). This might be because its capacity to penetrate through wood pores is higher. Also there is a strong force of attraction between Coral molecules as well as the strong force of attraction to wood molecules as

per specific adhesion theory in gluing technology [4]. Even though only 25% of all assessed carpenters found to prefer Coral; hence, being the second glue in carpenter preference; 65% of all assessed carpenters preferred Fevicol wood glue in their furniture processing due to its faster bonding results (see Fig. 2). However, results from the laboratory experiment showed Fevicol to be the least wood glue in performance during joint forming. Ponal wood glue was the second best glue in joining performance with the average shear strength of 2.80 N/mm^2 as displayed in Tables I and II. This shows that Ponal can be used in gluing activities for hard wood in the absence of Coral glue but not as much good to soft wood as it had shown a weak performance compared to the rest of the glues even though it was better than Fevicol with the difference of 0.25 N/mm^2.

Bullbond and Woodfix glues were the next glues in performance to both softwood and hardwood with the average shear strengths of 2.54 N/mm^2 and 2.51 N/mm^2 respectively. Actually, their performance is just moderate compared to the rest of glues tested, so in the absence of Coral and Ponal, these may be employed to join much of softwood as their performances were higher with softwood species compared to their performance with hardwood species.

The last on performance was found to be Fevicol wood glue with an average shear strength of 2.47 N/mm^2 even though 65% of all assessed carpenters preferred Fevicol wood glue in their furniture processing due to its faster bonding results (see Fig. 2) while the laboratory experiment test revealed Fevicol as the least wood glue in performance. Fevicol performed differently to softwood and hardwood species as for softwood Fevecol performed poorly than any of the glues tested and for hardwood in the case of Eucalyptus wood species, Fevicol also performed poorly but not as Woodfix did. For the case of Teak wood species, its performance was the second best from Coral wood glue. Fevicol wood glue was a bit poor in performance as it develops like a sponge in the glue line which weakens its strength even though it was the best glue to harden very faster after surface joining. Fevicol displayed a good performance to Teak wood species because this wood species was the most dried with the MC of 8.73% hence much moisture from the glue was required to wet the wood first then for joining after hardening. Actually, Fevicol was light liquid compared to the rest four glues that's why it came with a high performance.

Generally, from the ANOVA table results (see Table II) the probability of getting a calculated F value larger than 2.958 by mere chance is 0.075. This is larger than the critical probability 0.05 and hence there is a significant differences of glue performance to different wood species i.e. all glues perform differently to different wood species. Also the F value calculated i.e. 2.958 using the data of all glues tested is smaller than that tabulated 3.478 for the same probability level and degrees of freedom. Hence the performance of all glues to different wood species was statistically non-significant. All of the two ANOVA results indicates that every glue performs differently to different wood species in terms of shear strength of both softwood and hard wood.

2) The Failure Area

The joints failed in three different ways which are wood failure or glue failure or the combination of the two depending to what is week at the joint. Actually, all hardwood wood samples were found to be stronger than the glues used in the test just because they did not show any wood failure after the shear strength test to all glues. This implies that fibers in the wood grain of those hardwood were strongly held together than the adhesive power of holding materials together hence resulting to glue failure [6].

The situation was quite different to softwood under test which resisted to all but one just because Coral lead to some wood damages to Cypress. This situation implies that its wood fibers have weak force holding them together compared to the glue force of joining the two pieces of wood. The result for Coral was combination failure by the percentage average area of wood failure of 42.96% for Coral glue while for the remaining four glues wood fibers resisted.

V. Conclusion and Recommendation

Results of the tests carried out in this study revealed that there is a difference in performance of different wood glue to different wood species hence there is a need for carpenters to be very carefully with glue selection on gluing different wood species of both softwood and hardwood. Coral wood glue performed well among all wood glues tested to wood species; hence, it is clear that Coral wood glue is the best in performance and Fevicol wood glue is the least, so Coral has to be used much than any wood glue while Fevicol have to be less used for the sake of advancing the furniture market. There is an illusion to carpenters on Ponal wood glue performance in gluing. They claim that from carpenters on Ponal wood glue that it has lost its gluing strength, Ponal was still found to have good performance than Fevicol, Woodfix and Bullbond hence it has to be used in the absence of Coral for the better joints.

For the better joining of solid wood pieces in the wood workshops for softwood *C. lusitanica* and hardwood species of *T. glandis* and *E. maidenii,* the research results provided the guideline basing on the most available wood glues in the market. The guideline table starting on the best glue to a particular wood species to the least one is in Table III.

TABLE III
Guideline for Wood-Glue Selection for Different Wood Species

Wood species	Best Glue type	Shear Strength
Cupressus lustanica (Cypress)	Coral	4.18 N/mm^2
	Woodfix	3.50 N/mm^2
	Bullbond	2.88 N/mm^2
	Ponal	2.82 N/mm^2
	Fevicol	2.57 N/mm^2
Tectona glandis (Teak)	Coral	3.23 N/mm^2
	Fevicol	2.31 N/mm^2
	Ponal	2.13 N/mm^2
	Woodfix	1.73 N/mm^2
	Bullbond	1.72 N/mm^2
Eucalyptus maidenii (Eucalyptus)	Coral	5.42 N/mm^2
	Ponal	3.46 N/mm^2
	Bullbond	3.01 N/mm^2
	Fevicol	2.54 N/mm^2
	Woodfix	2.31 N/mm^2

For the furniture market to be of a great importance and profit to both carpenters and nation, we would like to recommend that; carpenters have to use the developed guideline, Table III, on glue selection so as to meet glue-bond strength requirements for every particular species. This is useful on securing and stabilizing furniture market and reducing human pressure to forests for furniture production as the strong existing furniture due to their strong joints.

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