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The Performance of Dovetail Halving Joint in Leg-and- Rail Construction Using Chrysophyllum Albidum Case Study: The Working Chair

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Abstract
The need to improve upon the quality, reliability, strength and durability of wooden chairs require that more attention be paid to the optimal strength and rigidity of the chair joints. This study was set out to assess the performance of dovetail halving joint in leg-and-rail construction. In the study, mortise and tenon joint and dovetail halving joint were compared. The joints were constructed with Chrysophyllum albidum wood and tenon/tail lengths of 38 mm and 50 mm were used. The width of the tenon and the moisture content of the wood used were kept constant at 55 mm and 12% respectively. Twenty-four chairs were constructed using the lengths of tenons or tails as indicated. The strength of the chairs was tested using ANSI/BIFMA Standards. The results of the test were analysed using tables, bar chart, graphs, percentages and analysis of variance (ANOVA). The ANOVA revealed that at 5% significant level, the type of joint had significant effect on the strength of the working chair. The tables, bar charts and percentages also showed that dovetail halving jointed chairs had greater strength than mortise and tenon jointed chairs. Based on the results of the tests, it is recommended that for greater strength of the chair, dovetail halving joint with a tail-length of 50 mm should be used in its construction.
Keywords: *strength of a chair, working chair, chair joint, dovetail halving,length of tenon,*

Introduction

Throughout history, wood has been used to manufacture many products for use by man and even with the influx of other materials like plastics and metals; wood continues to play an important role in the manufacturing industry. According to[1], two of humanity's basic needs are shelter and furniture and these are mostly made from wood. In Ghana before the arrival of the Europeans, furniture making or carpentry was a family vocation and parents taught their children rudiments of carpentry from generation to generation[2]. [3] cited Hung who buttressed the assertion of[2] that there are three methods for learning traditional woodworking in Taiwan: (1) government craftsmen, whose skills are passed on by scholars who have adequate knowledge in woodworking; (2) skilled woodworkers, with basic knowledge who are recruited by government craftsmen, and (3) private woodworkers, who passed down their skills to family members and apprentices. However, with the inception of Western Education in 1529, particularly technical education from 1850 to 1900, courses like carpentry, woodwork, cabinetwork and other vocations were taught in schools in Ghana[4]. The introduction of Western Education changed the situation and people learnt trades or vocations without necessarily being the children of master craftsmen.[1] again made a point that furniture making today is both a science and an art. To him, the science relates to production decisions, that is, proper application of materials, tools and processes while the artistic and creative talents of the furniture maker are seen in the curves, precise joints, suitable colouring and finishing of a product. In furniture design, the joints to use should be the most important decision to take in the designing process. The members forming the structure though may be strong to carry the forces imposed upon them; the joints should not be too weak to cause failure in the structure. One may not be far from right to say that most structural failures in furniture are as a result of weak joints that are used in their construction. Therefore, joints used in the construction of certain furniture pieces should be well designed to take care of the imposed loads when in service[5].

Furniture made in the past lasted for a lifetime and handed down from generation to generation because the craftsmen took into consideration during manufacture quality, durability and beauty as the basic characteristics of production[6]. One would have expected a change in the quality of production of furniture with the introduction of Western Education bearing in mind that furniture making is a science as well as art. On the contrary, this type of Education has only produced many small-scale furniture producers dotted all over the country with little or no theoretical background about the furniture they produce. One of such chairs produced by these furniture makers is the working chair. Chairs have been known and used throughout history but were not commonly used by most people until fairly recently[7]. As people developed interest in chairs, furniture makers elevated the low stools which they used into chairs with distinct styles. The styles were associated with how the legs were joined to the seat, the shape and construction of the seat[8]. The working chair may be one of the most used chairs all over the world since it is found in the homes, offices and schools. The secretary in the office sits between 25-38 hours a week working and therefore needs a comfortable chair to perform efficiently. Students may sit even longer than the secretary and will need comfortable chairs for maximum concentration[8]. Most of these chairs in schools and offices are broken down as a result of the failure of the joint between the back leg and the seat rail. The failure of this joint has economic and social implications especially in the developing world since the school authorities or management of companies have to replace the chairs at a cost. Education of children is regarded as a key to economic progress even though it is expensive no matter the nation or region that is practicing it. This is because financial resources available for education all over the world are limited[9]. It is based on this that the working chair has to be strong and rigid. Again, most consumers are moving away from working chairs made of wood to those made of plastics or metals due to durability. The chair is constructed with framing joints like dowel and mortise and tenon, the most used joints by woodworkers [10].[11][10][12][13] reported that the mortise and tenon joint is the most used joint in frame work because it can resist racking and twisting forces effectively. They argued that the wide surface area of the tenon enables the forces to be distributed across a maximum number of wood fibres. However, when this type of joint is used to construct chairs, the joints especially those between the back leg and the seat rail fail within a short time due to the stress it is subjected during sitting process. According to[14], people exert undue pressure on the chairs they sit on through various activities such as rocking and dragging thereby causing the glued joints to fail. The fact is that mortise and tenon joint used in leg-and-rail constructions though can resist racking and twisting forces, they do not resist wood movement, a situation where the tenon in the mortise will shrink or swell to break the glue line, a major problem with mortise and tenon joint[10][11]. To be able to solve this problem, an idea to use dovetail halving joint in the construction of the working chair instead of mortise and tenon joint was developed based on[15] assertion that dovetailed construction works were adopted in Medieval Woodworking to avoid wood movement. Previous studies have not compared the strength of mortise and tenon joint to that of dovetail halving joint in the working chair construction. Again, how the length of the tenon or tail affects the strength of the joints has not been investigated. This study sought to compare the strengths of two joints (dovetail and mortise and tenon) to find out which of them would be stronger and also to establish the length of tenon or tail that would give adequate strength to the joints. Apart from the stress that the chair is subjected, other factors likely to affect its strength and durability include moisture content of the wood; the kind of adhesive used in bonding the joints; the type of wood used - hard or soft; low, medium or high density; the pressure applied during clamping and the length of time that the applied pressure was maintained[8][1][16]. The need to improve upon the quality, reliability, strength and durability of wooden chairs require that more attention be paid to the optimal strength and rigidity of the joints of the chair. For the working chair to serve the purpose for which it was designed there was the need to examine the various factors that reinforce the strength of joints especially the one between the back leg and the seat rail which almost always fail before other joints in the chair. It was against this background that the following factors which are likely to affect the strength of the working chair joints were researched into. The factors include(1) the joints used in the chair construction and (2) the length of tenons or tails of the joints.

Objectives of the study

The purpose of this study therefore was to analyse the performance of two joints – square mortise-and-tenon, and dovetail halving in the designing and construction of a working chair. To achieve this objective, the following specific objectives were considered.

- To determine the most suitable joint- square mortise & tenon / dovetail halving- for constructing the working chair
- To determine whether length of tenons or tails give more strength to the joints of the working chair

A critical look at the problem at stake (the failure of the joint between the back leg and the seat rail) required a very comprehensive study. It was necessary therefore to have a guide, points of reference or relevant hypotheses to help arrive at a decisive but precise conclusion for the entire project. The following hypotheses were used to guide the research.

Hypothesis I

- The type of joint (dovetail halving or mortise-and-tenon) to be used in the construction of the working chair will not affect the strength of the chair.

Hypothesis II

- Differences in the length of tenons or tails to be used in the construction will not affect the strength of the working chair.

Literature Review

Joints

Joint making is sometimes regarded as a measure of the furniture maker's skills. In every design however, it is important to make a good choice. of the joints to use since the various types of joints are used for specific purposes. Mortise and tenon and dovetail halving joints are all framing joints and that if the mortise and tenon joint is used in chair framing, then dovetail halving joint could equally be used for chair framing[17]. Many writers and researchers including[10][7][16][11] agreed that mortise and tenon joint is one of the oldest methods for jointing wood at right angles and even now, it continues to be a superior choice because the large surface area of the joint spreads the loads and stresses that the joint is subjected to across a maximum amount of wood fibre. It provides a large side - grain to side - grain gluing surface. Some research works[10][11] have been done on mortise and tenon joint to look at its strength and durability properties.[11][13] worked on improving the strength and durability of mortise and tenon joint. The results of some of the research works showed that rectangular mortise and tenon joint is stronger than round mortise and tenon joint.[13] concluded that rectangular mortise and tenon joint is 15% stronger than round mortise and tenon joint.[18] stated in an article entitled “Mortise and Tenon Joints for Timber” that;

“The strength of the mortise and tenon joint makes it ideal for use in framing and general-purpose furniture works. For really strong joint, the tenon must be a tight fit into the mortise.″

[19] found mortise and tenon join to be about 4 times stronger than dowel joint and this is explained that mortise and tenon joint has more bonding surface than dowel joint).

The mortise and tenon joint consists of a finger or tenon, cut on one member and fitted into a socket or mortise of a corresponding dimension in the other member (Figure 1).

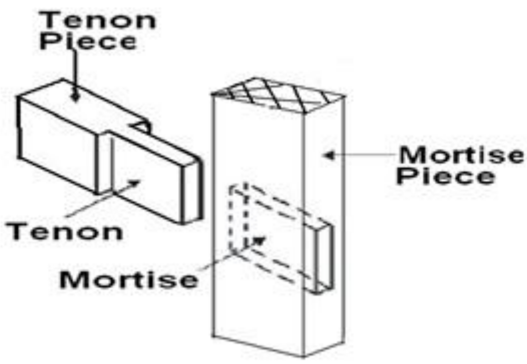


Figure 1: Mortise and Tenon Joint

There are many types of mortise and tenon joints and as a result, it is referred to as a versatile joint thereby making it very popular in furniture construction. The types are rectangular tenon with rectangular mortise, round tenon with round mortise, round tenon with rectangular mortise and loose- tenon joint. In Ghana, most furniture pieces are built from mortise and tenon joints due to the fact that the joint is strong and that it is easy to construct as it has been alluded to earlier by some researchers. The mortise and tenon joint also has a large gluing area which makes it the good choice when it comes to table and chair construction. It is also used where exceptional strength and wearing qualities are needed[20]. According to[16], the strength of the joint depends on the following factors, the length of the tenon, the thickness of the tenon, tenon width and the depth of the mortise.[21] also observed that the width and length of tenon of mortise and tenon joint give the joint good resistance to lateral and twisting forces. This means that the proportion of the mortise and its corresponding length of the tenon are important to the strength of the joint. The form of the joint is largely determined by the section of the tenoned member[16]. However,[12] stated that when the tenon is too long, it is subjected to undue pressure as a result of wood movement and when the tenon is too short the joint will fail because of the small glue area it will have. He then recommended a mortise that will go half way into the leg. The dream of every engineer is to design or produce a joint that will be very strong to solve human problems.

Rectangular mortise and tenon was used for the study instead of the round mortise and tenon because there is enough evidence that rectangular mortise and tenon joint is 15% stronger than round mortise and tenon joint in chair construction [13][11]. These researchers however agreed that mortise and tenon joints cannot resist wood movement, hence the failure of most structures joined with mortise and tenon joints.

Dovetail joints on the other hand are the embodiment of woodworking joints because they express what wood joints are all about. The interlocking, wedge-shaped nature of the tails or pins demonstrates clearly that the joints would hold together even if there is no glue. It is argued that a lot of halving joints are available to be used for different designs and that dovetail halving joint is used where great strength is required, however, its construction is much more difficult than other types of halving joints[22]. Dovetail joint is an extremely strong and attractive joint that are used for the construction of boxes, chests, quality furniture and cabinet drawers[23].

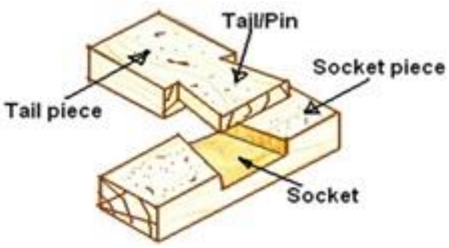


Figure 2: Dovetail Halving Joint

The inherent strength obtained from the joint's tails or pins resists the pulling forces applied to the joint[16][20]. Dovetail joints are made in different ways. They include through dovetail, lap dovetail, double lap dovetail, secrete mitre and dovetail halving. Halving joints are those that are cut in components of equal thickness. Half the thickness of each component is cut away so that when the remaining parts are brought together, a thickness equal to that of one member is formed [8]. Halving joints are relatively easy to cut and are used in frame construction[20]. Dovetail halving joint is similar to "T" halving except that it is a lock-type[1]. The dovetail halving joint can resist pulling forces better[16]. What is more is that, dovetail joints are strong and interlocking joints that are used in furniture construction[8]. In Medieval woodworking, dovetail construction was adopted to avoid wood movement which is a problem in mortise and tenon joints[15].

Wood movement is a major problem in mortise and tenon joints. This joint however is used in working chair construction. Most researchers are looking for alternative joints that will solve the problem of wood movement in mortise and tenon joints.[15] assertion that dovetailed construction works was adopted in Medieval Woodworking to avoid wood movement was used as the framework for the study where dovetail halving joints were used in the construction of the working chair in addition to mortise and tenon joints. This was to compare the strengths of the two joints.

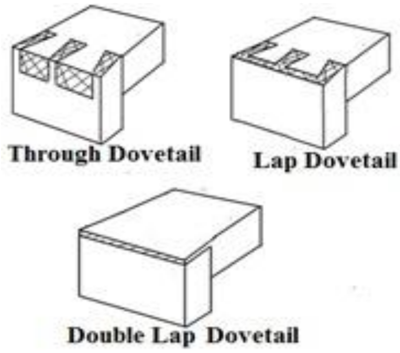
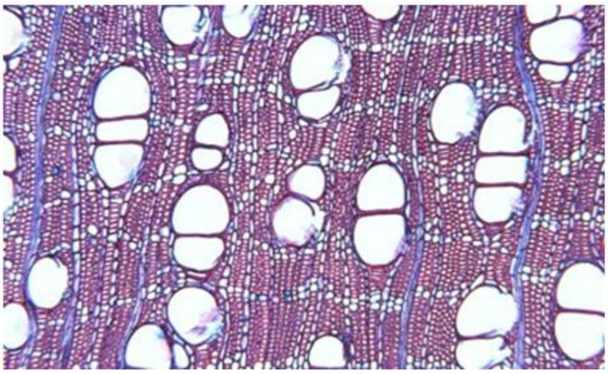


Figure 3: Types of Dovetail Joints

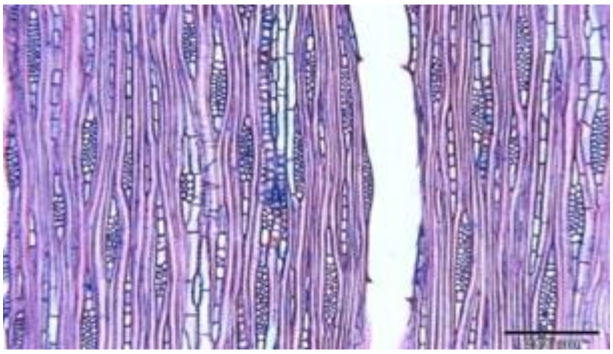
Chrysophyllum albidum, (Star Apple) the timber species that was used in the study is a tropical timber that grows well in all forest types and its distribution span from Sierra Leone to Guinea Bissau in West Africa extending to Kenya and Uganda in East Africa and Sudan in North Africa [24][25][26].[27] however included Central Africa in the distribution. In Ghana, *Chrysophyllum albidum* is known as *Asanfuna* and it is mostly found in the semi-deciduous forests[27]. The wood is grey-brown to white in colour with little or no distinction between the heartwood and sapwood. It is a medium to heavy density wood of about 700kgm^{-3} at 12% m. c.[28]. The felling diameter as recommended by the Forest Services Division of Ghana is 70 cm. The tree grows to between 25 and 36 metres in height and around 2.3 metres in girth. The species has been classified by International Union for Conservation of Nature and Natural Resources[29] as a lower risk near threatened. The wood is very hard and has fine texture. The species takes finishes and glues easily, it has good fastening ability including nailing and screwing. Even though the species is considered a non-durable wood, it is used for interior joinery, frames, light structural works, beams, joists, flooring, steps and stairs, furniture, turnery, veneer, and handles of tools because of its toughness[24][28][27]. However, its blunting effect on cutting tools is severe. The macroscopic features of *Chrysophyllum albidum* indicated that growth ring boundaries of the species are either absent or indistinct. This may be due to the continuous growth throughout the growing season in the tropics[16]. It is a diffuse-porous with inter-vessel pits alternating. The diffuse-porous nature of the wood may be the reason for it being less difficult to finish[16]. Its vessel-ray pits have distinct borders and the size and shape are similar to inter-vessel pits throughout the ray cell. There are 5 to 20 vessels per square millimeter. The wood has got simple fibres with minutely bordered pits. Some of the fibres are thin-walled while others are thick-walled. The axial parenchyma cells of the species are indistinct to the naked eye, diffuse, reticulate and are in very narrow regular bands or lines up to three cells wide. The parenchyma cells are smaller than fibre tissue bands. The proportion of fibre tissue is low.

The ray parenchyma cells in the wood are narrow but uniform and the cell walls are disjunctive. Unfortunately, the species contains prismatic crystals that are found in the chambers of ray and axial parenchyma cells. The crystals have been identified to be sand. The severity of the wood blunting cutters is attributed to the presence of the sand [27][25][26].

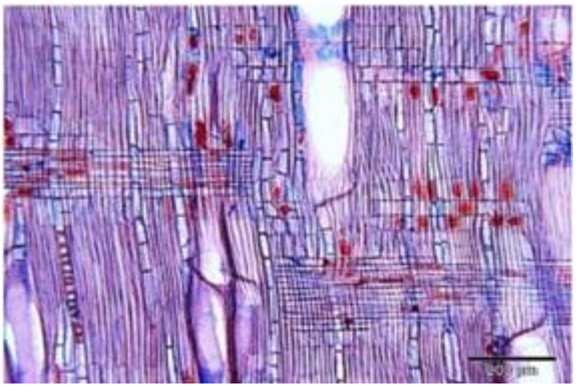
Figure 4 (abc) show the microscopic features of *Chrysophyllum albidum*as seen by [25].



Cross section -a



Transverse Section- b



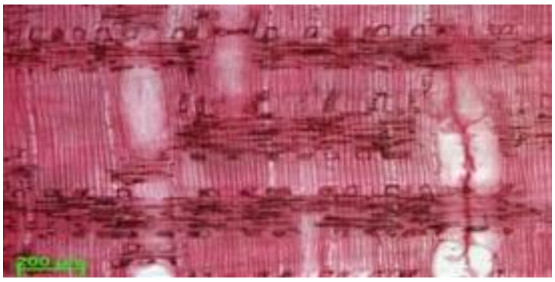
Radial Section -c

Figure 4: Microscopic feature of *Chrysophyllum albidum*

Figure 5 (abcd) show the microscopic features of *Chrysophyllum albidum* as seen by [26].

Cross section –a

Transverse section-b



Radial section-c

Inter- vessel pitting-d

Figure 5: Microscopic feature of *Chrysophyllum albidum*

Moisture content

Moisture content (m. c.) is the amount of sap/moisture in the wood and is expressed as percentage; the lower the percentage figure, the drier the wood. This low moisture content is reached through seasoning. Since wood cannot be seasoned to zero percent moisture content there will always be moisture in it. It is for this reason that[30] warned wood products manufacturers that improper moisture levels in wood can affect the quality and durability of their products so they should control moisture in the wood they use since wood products manufacturers' reputation depends on the moisture levels in the wood. Again, wood is hygroscopic so when designing and constructing with wood in mind, there is the need to consider the fact that wood continues to absorb or lose moisture according to the humidity of the immediate surroundings[16]. Therefore, wood should be dried such that its m. c. would be in equilibrium with the moisture of the environment it is intended to be used. Most cabinet and furniture wood should be dried to moisture content of 7 to 10 percent and that hardwood with moisture content of more than 12% should not be used in furniture manufacture. Therefore, the wood for furniture should be dried to about 5% to 6% m. c. and then stored until the m. c. in the wood is equivalent to the e.m. c. of the environment where it will be used to reduce the stress and strain within the wood[16][1][20]. In Ghana the e.m.c differs from place to place. Where the study took place for instance the e.m. c. is between 12% and 15%. Even though these researchers have recommended m. c. of 7% to 10%, the wood for the study was seasoned to 10% m. c. and allowed to equilibrate with the environment.

Materials and Methods

Material

The materials that were used for the study included: *Chrysophyllum albidum* was used for the study because it has straight grains thus making it easy to work with, a medium to high density wood averaging about 700kgm^{-3} at 12% m. c. making it suitable for the project. It has good fastening ability including nailing, screwing and gluing. However, it blunts cutting tools very quickly [24][28]. Its ability to dull cutters quickly discourages many woodworkers from working with the solid wood. The selection of the species was to help the researcher confirm some of the characteristics of the wood that have been reported in literature.

Samples of the wood were taken from *Asukese* Forest Reserve in the Brong Ahafo Region of Ghana. The reserve is a semi deciduous natural forest located at 7.46^0 North and 2.54^0 East. The sizes of the planks used for the study were (100 mm x 300 mm x 2400mm). Twelve planks of the wood were sawn to the following dimension using the circular saw (30mmx100mmx2400mm). The sawn boards were then taken to Logs and Lumber Limited, Kumasi (LLL) for seasoning. The wood was seasoned from an initial moisture content of 80% m. c. to 10% m. c. using a kiln at LLL.

After 27 days, the boards were taken from the kiln and sent to the wood workshop of Design and Technology Education Department of the University of Education, Winneba - Kumasi Campus (UEW-K). The boards were kept for 30 days to allow the m. c. in the wood to be in equilibrium with the relative humidity of the surrounding environment. It also allowed all the stresses built up in the wood during seasoning to be released.

Methods

Experimental design, Completely Randomised Design (CRD) mathematical model was used to obtain a sample size of 12 working chairs for the study. It was based on three factors:

i. The type of joints used in the chair construction- 2
ii. The length of tenons of the joints - 2
iii. The length of tails of the joints - 2

The construction of the chairs was based on the design, the cutting list and the working drawing. Figure 6 shows the working drawing whilst Table 1 shows the cutting list. Six chairs were constructed using mortise and tenon joints but varying the lengths of tenon. The variation was reached by using the width (w) of the rail on which the tenon was cut as the reference dimension. The rail width was 75mm and three of the chairs were constructed with a length of tenon of ½w (38mm). The other three chairs were constructed with a length of tenon equal to ⅔w (50mm).

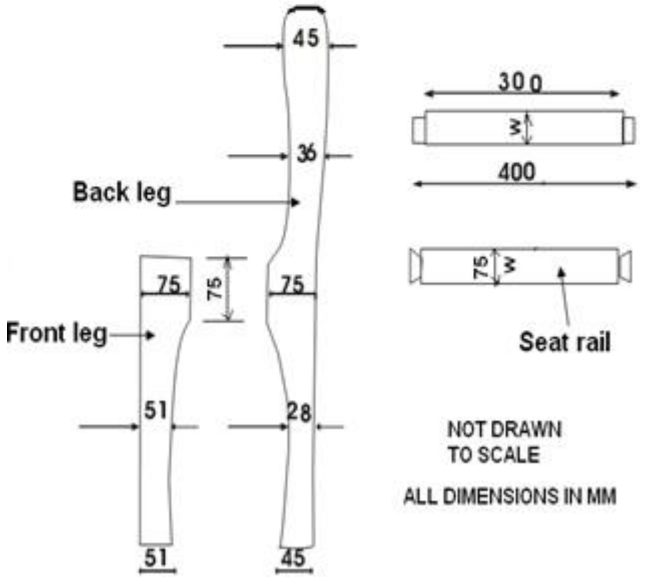


Figure 6: Working Drawing of the Working Chair

The width of the tenon was however kept constant at 55mm. The construction of the chairs using mortise and tenon joint followed this order;

- The chair parts were cut and planed to the required sizes based on the cutting list (Table 3.).
- The positions of the joints were accurately marked out
- All tenons were cut and all mortises were mortised to fit
- The chair members were try-assembled to check for joint fitness. Squareness and other minor errors were checked

Six chairs were again constructed using dovetail halving joint but varying the lengths of tail. The variation was reached by considering the width (w) of the rail on which the tail was cut. The rail width was 75mm and three of the chairs were constructed with a length of tail of ½w (38mm). The other three chairs were constructed with a length of tail equal to ⅔w (50mm).

The width of the tail was determined by the slope used (1 in 8). The operational sequence for constructing the dovetail halving jointed chairs was as follows; The chair parts were cut and planed to the required sizes. The positions of the joints were marked out accurately- sliding bevel was used to take a slope of 1in 8 for the marking out of the tails and sockets. The slope of 1 in 8 was used because *Chrysophyllum albidum* is a hardwood[17].

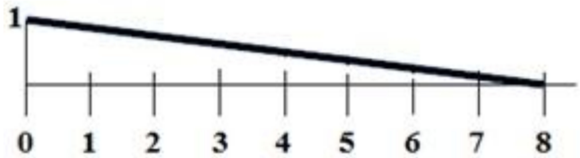


Fig 7: The slope for the dovetail joint construction

- All the tails were cut first and used to trace for the sockets which were cut to fit.
- Try-assembly was conducted on all chair members to check for the fitness of the joints, squareness of the assembled chairs and other errors.

Table 1: Cutting List of the Working Chair (All dimensions in mm)

Parts of the Chair	Quantity	Nominal	Finished	Material
Front Legs	2	450x80x35	435x75x30	
Back Legs	2	880x80x35	860x75x30	*Chrysophyllumalbidum*
Front Rail	1	440x80x35	400x75x30	
Back Rail	1	420x80x35	380x75x30	*Chrysophyllum albidum*
Side Rails	2	420x80x35	370x75x30	
Backrest Rail	1	420x80x35	380x75x30	
Seat	1	500x450x13	480x420x13	Plywood
Connecting				
Rails-	1	440x50x35	400x45x30	*Chrysophyllum albidum*
Front	1	420x50x35	380x45x30	
Back				

All the twelve chairs constructed were assembled and glued with PVA the most common glue used in Ghana. The gluing process was carried out in this order:

- All the surfaces of the parts to be glued were cleaned off dust and oil
- The glue was applied to both surfaces of the joint to be glued. The glue was evenly spread over the surfaces of both parts using brush.
- The parts were assembled and clamped together. Squareness was checked and the necessary corrections were made.
- The clamps were tightened continuously until glue began to ooze out of the joint. All the joints were inspected to ensure that there was no opening between the rail and the back leg. Those joints with slight openings were re-clamped.
- The works were left in the clamps for 8 hours for the glue to set before the clamps were released.

The glued chairs were left for 28 days to cure before testing though curing time of PVA is one week.

Testing

The ANSI/ BIFMA standard [31][32] method was used to test the constructed chairs to ascertain the durability and the strength of the joints used at rocking position.

Application – the test can be applied to all chairs constructed using leg-and-rail joints.

Purpose – the purpose of the test was to evaluate the ability of chair to withstand fatigue stresses and wear by rocking

i. The unit was placed on a test platform and restrained in a manner that would maintain the impact location on the seat.
ii. A test bag of approximately 400mm in diameter containing dry sand and mass 57kg was attached to a cyclic device that permitted free fall to the seat.
iii. The front legs were 150mm away from the test platform as shown in figure 8.
iv. The test bag was set 25mm above the seat surface and measured from its centre[31].
v. The cyclic device was set at 28 cycles per minute. (This was within the permitted cycle of between 10 and 30 cycles per minute by [31].
vi. The bag was centered side to side on the seat and positioned not more than 13mm from the most forward surface of the back rest during free fall. The bag should not touch the back rest during the free fall.

In the ANSI/BIFMA standard of testing chairs, 100,000 cycles before failure of the joint is considered acceptable. In the present study, the chairs were tested to failure of the joint and the extent of failure of joint was the gauge of A4 duplicating paper (0.12mm).

Average cycles of between 247 and 3592 were obtained. The differences in the cycles were due to the test set up. While in the ANSI/BIFMA standard all the four legs of the chair were set on the test platform, in this study only the back legs were set on the platform. This was because the variable of interest was the joint between the seat rail and the back leg. The results were analysed using tables, bar charts and analysis of variance.

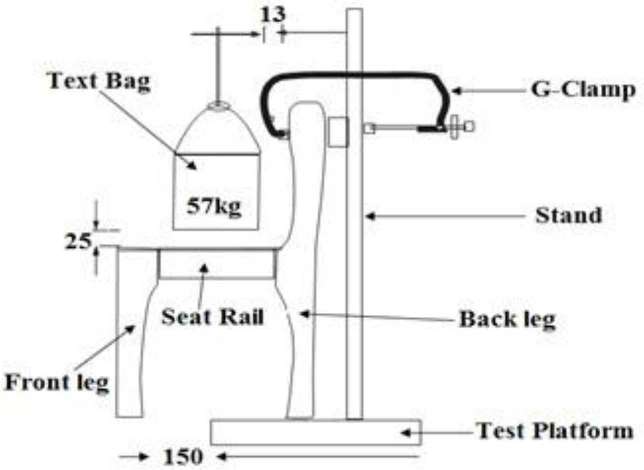


Fig 8: Rocking impact test – cyclic

Results

Table 2 shows the raw data obtained from the chair joints that were tested. Tables 3 show the strength differences between the types of joints used in the construction of chairs. Using the mortise and tenon and dovetail halving joints the results are as follows:

With a length of 38mm and using the mortise and tenon joint with PVA as adhesive, the average number of cycles before the failure of the joints was 247. When dovetail halving joint was used with the same adhesive and the length of tail of 38mm, the average number of cycles before failure of the joints was 420 (Table 3). The percentage increase in the average number of cycles of dovetail halving joint chair failing over that of mortise and tenon joint chair was 70.0%.

When the length of tenon was increased to 50mm and using mortise and tenon joint with the PVA, the average number of cycles before failure of the joints was 285.With the length of tail of 50mm, and the same adhesive that is PVA but using dovetail halving joint, the average number of cycles before failure of the joints was 1246 (Table 3). The percentage increase in the average number of cycles of the dovetail halving joint chair failing over that of mortise and tenon joint chair was 337.2%.

Table 2: Raw Data Obtained from the Test

		Joints Used (B)			
		Mortise and Tenon (B1)		Dovetail Halving (B2)	
Adhesive Used (A)		Length of Tenon (C)		Length of Tail (C)	
		C1=38mm	C2=50mm	C1=38mm	C2=50mm
A1= PVA	R1	253	275	421	1290
	R2	248	283	426	1265
	R3	241	296	412	1184
Total		742	854	1259	3739
A2=UF	R1	284	2576	497	3584
	R2	297	2483	508	3605
	R3	291	2635	493	3586
Total		872	7694	1498	10775

N = 24 = a. x b. x c. x. n Where N = Sample size R= Replicate
a = number of factor A a = 2
b = number of factor B b = 2
c = number of factor C c = 2
n = number of Replicates n = 3

Table 3: Strength variation between Mortise & Tenon and Dovetail Halving Joints

Joint Used (B)					
Adhesive Used		Mortise & Tenon (B_1)		Dovetail Halving (B_2)	
		Length of Tenon (C)		Length of Tail (C)	
PVA (A)		C_1=38.0mm	C_2=50.0mm	C_1=38.0mm	C_2=50.0mm
		Number of Cycles Before Failure			
		Cycles	Cycles	Cycles	Cycles
Replicate	1	253.0	275.0	421.0	1290.0
	2	248.0	283.0	426.0	1265.0
	3	241.0	296.0	412.0	1184.0
Sum		742.0	854.0	1259.0	3739.0
Average		247.0	284.7	419.7	1246.3
SD		6.0	10.6	7.1	55.4
COV		2.4	3.7	1.7	4.4

Table 4 is the analysis of variance (ANOVA) of the raw data in Table 2. In Table 4, the ANOVA showed a significant difference between the adhesives used in bonding the joints and the strength of the working chair, ($F_{0.05,1,16} = 4.49 \leq F_0 = 7212.26$). On how the types of joints affect the strength of the chair, ANOVA showed a significant difference between the types of joints used in the construction of the chair and the strength of the working chair, ($F_{0.05,1,16} = 4.49 \leq F_0 = 1796.24$). On the length of tenons or tails, ANOVA revealed a significant difference between the lengths of tenons or tails and the strength of the working chair, ($F_{0.05, 1, 16} = 4.49 \leq F_0 = 12415.85$).

Table 4: Analysis of Variance of Table 3

Source of Variation	Sum of Squares	Degrees of Freedom	Means Sum of Squares	F-ratio	$F_{0.05, 1, 16}$	
A- Adhesive	8455001.1	1	8455001.1	7212.26	4.49	Significant
B- Joint	2105745.1	1	2105745.1	1796.24	4.49	Significant
C- Length of Tenon/ Tail	14556395.1	1	14556395.1	12416.85	4.49	Significant
AB	3876.2	1	3876.2	3.31	4.49	Not Significant
AC	7601627	1	7601627	6484.31	4.49	Significant
BC	969222	1	969222	826.76	4.49	Significant
ABC	315.2	1	315.2	0.27	4.49	Not Significant.
Error	18757.3	16	1172.31			
Total	33710936	23				

Discussion

It was hypothesized at the beginning of the study that "the type of joint used in the construction of the working chair does not affect the strength of the chair significantly". However, the results of the test indicated otherwise. The results indicated that the chairs with the dovetail halving joints were much stronger than the chairs with mortise and tenon joints. This is in consistent with literature. Even though[33][18][13][10][11] agreed that mortise and tenon joint is used where exceptional strength and wearing qualities are needed, the results of the test favoured dovetail halving joint. [16] argued that the interlocking and wedge – shaped nature of the dovetail joints can resist pulling forces better.[20] also stated that the inherent strength obtained from the tails or pins of the dovetail joints resist the pulling forces that are applied to it. [22]. argued that dovetail halving joint is used where great strength is required. According to[17], in every design, it is important to make a good selection of joints since the various types of joints are used for specific purposes. The dovetail halving joint was specifically selected for the construction because of its interlocking nature of the tails or pins. The results of the ANOVA failed to accept the hypothesis I which stated that the type of joint (dovetail halving or mortise-and-tenon) to be used in the construction of the working chair will not affect the strength of the chair. This implied that the type of joints used in the construction of the working chair had influence on the strength of the chair. On the effect of the length of tenons or tails on the strength of the working chair, the results of the ANOVA failed to accept the hypothesis that "differences in the length of tenons or tails to be used in the construction will not affect the strength of the working chair". On the other hand, the results showed that the strength of the working chair depended on the length of tenons or tails used in the construction of the chairs. Results in Tables 2 and 3 and ANOVA results presented in Table 4 showed the significant effect of length of tenons or tails on the strength of the working chair. The results were in concert with literature that when the length of tenon or tail of a joint is increased the strength of the joint is also increased because the gluing area of the joint is increased [20][16]. This implied that the length of tenons or tails used in the construction of the joints determined the strength of the chair. However, in this research, only two different lengths were used so the maximum length to give the optimum strength to the chair was not determined. Even though[16] argued that the strength of the joint depended on the length of tenon or tail used in the construction of the joint, the maximum length to give the optimum strength was not given.[21] stated that a large width and long length of tenon in mortise and tenon joint construction also give the joint a good resistance to lateral and twisting forces thereby making the joint stronger and difficult to fail.[12] also stated that when the tenon is too long, it will be subjected to undue pressure as a result of wood movement and when the tenon is too short, the joint will fail because of the small glue area it will have. Therefore, a mortise that will go half way into the stile is recommended hence the use of ½ w and 2/3 w lengths of tenons or tails.

Conclusions

Mortise and tenon joint has been a long standing traditional joint for leg-and-rail construction. However, it is associated with withdrawal problems when bonded with PVA adhesive because it is not creep resistant and also the tenon has no locking mechanism. The purpose of the study was therefore to find out if dovetail halving joint could be used as an alternative joint for leg-and-rail construction since it has a locking tail. It was also to determine the length of tenon or tail that would give higher strength to the chair. From the study, it came to light that the two factors that were considered had significant influences on the strength of the working chair. The main factor that was considered in the study was the type of joint used in the construction of the chair. This showed significant difference in the strength of the chair joint. When the results of the study were tested at 5% significant level, the type of joint used in the construction showed significant difference in the strength of the working chair. The implication was that the strength of the chair had something to do with the type of joint used in its construction. The findings showed that the chairs constructed with dovetail halving joints were stronger than the chairs with mortise and tenon joints[22][16][15]. The last factor in the study was the length of tenons or tails of the joints used in the construction. The research revealed that the longer the tenon or tail used in the construction, the stronger the chair. At 5% significant level, analysis of variance of the results showed significant effect of the length of tenons or tails on the strength of the chair. Tables, bar charts and percentages used to analyse the results also confirmed this. The implication was that as the tenon or tail length is increased, the surface area for glue application is also increased to increase the strength of the chair [12][10][11][21].

References

1. Feirer, J.L. (1988) Cabinet Making and Millwork; California Glencoe Publishing Company
2. McWilliam, H. O. A and Kwamina-Poh, M. A. (1975). The Development of Education in Ghana; London, Longmans Green & Co. Ltd.
3. Chou, Ya-Kuan and Hsu, Ting-Chun (2016) A Study on Learning Motivation in Woodwork. Heritage International Journal of Cultural and Creative Industries.
4. Graham, C. K. (1971) The History of Education in Ghana; London Macmillan Publishers.
5. İmirzi, HansanOzgur, Tuncbilek, Yusuf, and Efe, Hasan (2016) Bending Moment Capacities of Frame Type Furniture Corner, Joints Constructed of Solid Wood and Wood Based Panels, Faculty of Technology Wood Products Industrial Engineering, Gazi University, 06500, T.
6. Peters, A. (1987) Encyclopedia of Furniture Making; New York, Sterling Publishing Co.
7. Beazley, M. (1989) The International Book of Wood; London, Mitchell Beazley Publishers.
8. Hammond, J.J., Donnelly, E. T., Harrod, W. F., Rayner, N. A. (1980) Woodworking Technology; Massachusetts McKnight Publishing Company.
9. Eckelman, C. A., Haviarova, E. H, Zui Gibson (2001) Considerations in the design and development of school furniture for developing regions based on local resources. Forest product journal, 51 (6) 56 – 63.
10. Roff, D. (2001) Musings on Mortise and Tenon, Woodworker's Supply Newsletter (http://www.swcp.com/~awa/mortise_and_tenon.htm).
11. Alexander, J.D.(1994) Making a Chair from a Tree: An Introduction to Working Green Wood (Fine Woodworking.com 2007).
12. Kirby, I (2002) Mortise and Tenon: A Primer; Woodworkers' Journal.
13. Tankut, A.N and Tankut, N (2005) The Effects of Joints Forms (Shape) and Dimensions on the Strengths of mortise and Tenon Joints. (http://journals.tiubikat.gov.tr/agriculture/issues/tar-05-29-6/tar-29-6-8-0412-16.pdf)
14. Kim, G. (2003) A History of Seating in the Western World (www.uq.edu.au/aeol/jun98/seating.pdf
15. Halstead, G. R. (1999) A Brief History of Medieval European Joinery; (www.medievalwoodworking.com/articles/joinery.html).
16. Jackson, A. and Day, D. (1997) Woodworker's Manual; London, Harper Collins Publishers.
17. Walton, J. A. (2007) Woodwork in Theory `and Practice; Sydney, The Australian Publishing Company.
18. Baylor, C. (2007) Mortise and Tenon Joint –Simple and Strong (diydata.com 2007).
19. Acar, M., Diler, H., Balikci, E., Demirci, S. and Erdil, Y. Z. (2016). Withdrawal force capacity of T-type furniture joints constructed of various heat-treated wood species. IInd International Furniture Congress. 114.
20. Wagner, W. H.(1970) Modern Woodworking; Illinois, The Goodheart-Willcox Co. Inc.
21. Brekke, V. (2007) Mortise and Tenon Neck Joint (www.soundtoearth.com 2007).
22. Ryan, V. (2002) Tee Halving, Dovetail Halving and Half Lap Joints (www.technologystudents.com)

23. Burch, M. (2002) Dovetail Joints for Quality Construction. http://www.extremehowto.com-Dovetail
24. Irvine, F. R. (1961) Woody Plants of Ghana; London, Oxford University Press.
25. Lens, F (2002) Plant Resources of Tropical Africa http://insidewood.lib.ncsu.edu/description.2
26. Campbell, A and Gasson, P (2002) Plant Resources of Tropical Africa. http://insidewood.lib.ncsu.edu/description.2
27. OtengAmoako, A.A, Zurercher, E, Abbiw, D.K, Osei – Agyekumhene, I, Rogenmoser, C. (2006) 100 Tropical Africa Timber Trees from Ghana; Accra, Graphic Packaging.
28. Agyemang, V.K, Ayarkwa, J, Owusu, F.K., BoachieDapaah, A.S.K, Addae-Mensah, A., Appiah S.K., Oteng-Amoako, A., Adam, A.R., Pattie, D. (2003) Technological and Investment Profile of Some Lesser Used Timber Species of Ghana; ITTO International Organization Centre, Pacifico, Yokohama. (2-6, 34-35,68pp).
29. IUCN (2004) Red list of threatened species: Global species assessment IUCN Publication.
30. Welch, B. (2006) The Importance of Measuring Moisture Content in Wood (www.modernwoodworking.com).
31. American National Standard for Office Furniture (ANSI/BIFMA -2003).
32. American National Standard for Office Furniture (ANSI/BIFMA -2014)
33. Demirci, S., Acar, M., Balikci, E., Diler, H., and Erdil, Y. Z. (2016). Comparison of some physical and mechanical properties of various heat-treated and non-treated wood. IInd International Furniture Congress. 121.