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# MECHANICAL PROPERTIES OF PF AND MUF BONDED JUVENILE HYBRID EUCALYPTUS PLYWOODS PRODUCED IN GHANA

HARUNA SEIDU[1,2], RÓBERT NÉMETH[1], FRANCIS WILSON OWUSU[2], JAMES KORANG[2], APPIAH-KUBI EMMANUEL[3], JAMES KUDJO GOVINA[1,2], FATH ALRHMAN A.A YOUNIS[1], SAFIA IBRAHIM[2]

[1]UNIVERSITY OF SOPRON, HUNGARY
[2]CSIR-FORESTRY RESEARCH INSTITUTE OF GHANA, KUMASI -GHANA
[3]AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT, GHANA

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## ABSTRACT

To obtain the mechanical properties of plywood produced from six yearold hybrid Eucalyptus in Ghana was the objective of this research. The samples for the experiment were prepared and tested according to GS EN 326-1, GS EN 310, GS EN 314-1, and GS EN 314 -2. The data obtained were analysed using the factorial ANOVA analysis. The mean results obtained for the various treatments were MOE (6520 – 7638 N/mm$^2$), MOR (53.29 – 60.56 N/mm$^2$, shear strength (2.47 – 5.51 N/mm$^2$), failure (72 -90%) and density (725 – 748 kg/m$^3$). The orientation of the surface veneer caused variations among treatments whiles the adhesives PF and MUF largely did not cause any variations among treatments. This study has proven that it is possible to produce sufficiently strong and resistant plywood from the juvenile wood of eucalyptus.

KEYWORDS: Plywood, eucalyptus, mechanical properties, phenol formaldehyde, melamine urea formaldehyde, longitudinal, transverse orientation.

## INTRODUCTION

Ghana continues to be one of the major exporting plywood countries, however, the indiscriminate logging and dwindling of large-diameter timber, require innovative ways of sustaining and increasing the production of plywood in the country. Though several wood-based panels such as medium-density fibreboard (MDF), particle board, and oriented strand board (OSB), plywood remains the most demanded wood-based panel (Chapman 2006, Gonçalves et al. 2018, Mantanis et al. 2018, Rathke et al. 2012, Yu and Fan 2017). According to the Forest Product Statistics (2021), the production of plywood makes up 118 million $m^3$ representing about 32.2% of the worldwide supply of wood-based panels. Plywood is used widely for several products in the construction industry, including ceilings, cabinets, doors, furniture and many others. According to research, the density, and mechanical properties of plywood depend on the quality of the veneer, the glue layer, the compression of pressure during production etc. (Kajaks et al. 2012, Okuma 1976, Bekhta et al. 2012, 2020). Ghana has been one of the supplying countries in the plywood industry to the world market. In a report published by FLEGT IMM (2022), Ghana's export of plywood volumes was estimated by ITTO as 16,904 $m^3$ in the year 2020, a sharp decline from the 2018 export of 24,000 $m^3$, which can be attributed to the dwindling of the natural forest at an alarming rate, in the last few decades, and this is due to the indiscriminate logging of trees (Ewudzie et al. 2018). Also, the global demand for premium wood species has contributed significantly to this phenomenon.

The raw material needs of the local plywood production cannot be overlooked as there is demand for bigger-diameter logs for production. In Ghana, the traditional species dominating plywood production are mainly the *Ciberpentandra, Lovoaklaineana*, etc (Ghana Forestry Commission 2011). This situation is affecting the carbon sink potentials of the Ghanaian natural forest. Innovative and sustainable measures are being explored to supply the market while protecting the forest cover to curb this problem. In supporting this agenda, a forest organisation is exploring the use of fast-growing eucalyptus(*Eucalyptus globulus*) as a raw material to produce plywood to augment the increasing demand from the European and American markets using an efficient veneer-processing technology. This will sustainably boost the contribution to the forest product of 3% of the Gross Domestic Product of Ghana, which contributes about $240.9 million in total exports (Tuffour-Mills et al. 2020).

Plywood is a popular wood-based composite made from various tree species usually of bonded veneer which has some advantages over solid wood (Bal and Bektaş 2014). According to the GS EN 314-2 (2017) plywood is classified into three types (class 1, class 2 and class 3) depending on the type of construction intended to be used. It has been established that parameters, including wood species, density, structure, moisture content, number of veneer layers, and the adhesive type and spreading, have a significant impact on the mechanical characteristics of plywood, particularly the bending strength (MOR) and modulus of elasticity (MOE) (Daoui et al. 2011, Salca et al. 2020, Wang et al. 2006, Aydın and Çolakoğlu 2008).

Considering these facts, this study seeks to explore the performance of 11-layer plywood made of veneer material sliced from 6 years old trunks with the following objectives: *1)* Establish the mean density and mechanical properties of plywood bonded by PF and MUF, *2)* Compare the determined properties of the transverse and longitudinal veneer orientations of the two-plywood and *3)* Determine the effect of the PF and MUF on the density, MOE, MOR, shear strength and WF.

## MATERIALS AND METHODS

### Location of MIRO plantation in Ghana

*Eucalyptus globulus* extracted from the MIRO eucalyptus plantations at Agogo in the Asante-Akyem North district of the Ashanti region of Ghana. Melamine-urea-formaldehyde (MUF) and phenol- formaldehyde (PF) glues used were purchased in the open market for the study and they were used without any modifications. The MUF used was milky white with a viscosity of 90 cps at 30°C, it was within a pH of 7.0 – 8.0 and a gel time of 140 min also it had a specific gravity of 1,190 g/cm$^3$. The specifications of the PF glue were reddish-brown for colour, a viscosity of 120 cps with a pH range of 11.5 – 12.5 at specific gravity of 1168 g/cm$^3$ and a gelling time of 15 min. Fig. 1 shows the location of Asante Akyem North District where MIRO forestry is situated in green colour. Since the trunks were 6 -years old, we assume that the wood used for the study is juvenile wood. The formation of mature wood for eucalyptus species begins at 10 years of age, after which several of the technological properties tend to stabilize until ages close to 15 years (Resquin et al. 2022, Santos et al. 2021).

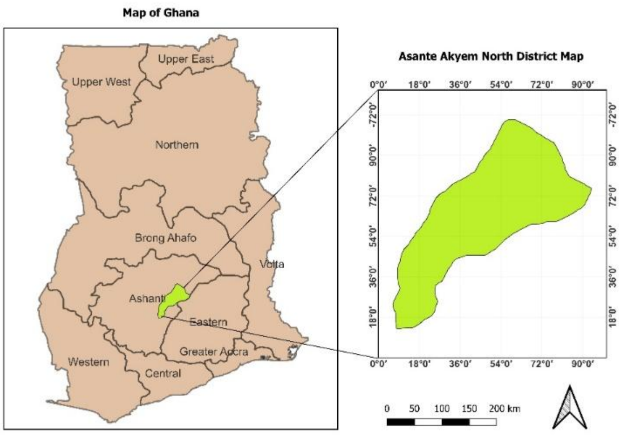


*Fig. 1: Location of Asante Akyem North District.*

**Sample preparation**

The logs obtained had varying diameters of 150 mm to 200 mm and were shortened into 122 cm. The logs were debarked, and the veneers were cut from the automated feeder assembly at MIRO Ghana Limited.The pieces of veneer had a nominal thickness of 1.6 mm and were stitched together to form a broader veneer sheet using the manual feed stitching machine which uses nylon for the stitching in a zigzag pattern. The sheets were dried to a moisture content of 8 to 10%. The layers were arranged with 6 sheets along the length of the plywood with 5 sheets being used as crossband layers. The veneer sheets were bonded at a glue spread rate of 120 g/m$^2$ using an automated 8 ft glue spreader and pressed at 1.8 MPa at a temperature of 140°C. The 11 layers plywood had a final thickness of 18 mm. Plywood 1 and 2 were produced using PF and MUF respectively.

Samples for the determination of modulus of elasticity (MOE) and ultimate strength in static bending (MOR) were prepared based on GS EN 326-1 (2017) and GS EN 310 (2017) from the two plywood of dimensions 1220 x 2440 mm labelled 1 and 2. Each of the plywood was sampled and labelled ‘A’ and ‘B’, with ‘A’ representing samples, prepared transversely to the surface grain. The halves marked ‘B’ had samples prepared longitudinally to the surface grain direction as illustrated in Tab. 1. The bending test samples had a nominal cross-section of 18 x 50 mm and a length of 410 mm with a span of 360 mm. Samples for the shear bonding test were prepared according to GS EN 314 (2017). The length of the samples was 150 mm with a shear area of 25 mm at the centre. The dry-density samples were prepared from each of the bending samples at a dimension of 20 x 50 mm which followed the sequence of numbering the bending samples.

*Tab. 1: Series of plywood samples.*

| Adhesive | Sample category | Surface veneer orientation | Number of samples |
|---|---|---|---|
| PF | 1A, bending | Transverse | 10 |
| | 1B, bending | Longitudinal | 10 |
| | 1A, shear bonding | Transverse | 10 |
| | 1B, shear bonding | Longitudinal | 10 |
| MUF | 2A, bending | Transverse | 10 |
| | 2B, bending | Longitudinal | 10 |
| | 2A, shear bonding | Transverse | 10 |
| | 2B, shear bonding | Longitudinal | 10 |

*MUF- melamine urea-formaldehyde, PF-phenol formaldehyde.

Samples for the bending test were conditioned in a climate chamber for eight days at a temperature of 20°C and 65% relative humidity following GS EN 310 (2017). Samples were kept in a desiccator to maintain the conditioned state. The shear bonding samples were conditioned based on GS EN 314-1 (2017) by immersing in the samples in water for 24 h at 22°C, followed by boiling in a water bath for 4 h. The samples were then dried in a ventilated drying oven for 18 h at 60°C after which they were boiled again for another 4 h and finally cooled in water at a temperature of 22°C.

**Testing**

MOE and MOR samples were tested following GS EN 310 (2017) and the bonding quality using GS EN 314-1 (2017) and GS EN 314-2 (2017). The crosshead speed for the bending test was set to 10 mm per min with a preload of 30 N. The loading point had a radius of 15 mm and the supports points with a radius of 7.5 mm. The crosshead speed for the shear bond test was set to 8 mm per min a preload load of 30 N. Fig. 2 shows the image of how the shear test is conducted. The modulus of elasticity ($E_m$), modulus of rupture ($f_m$), shear strength ($f_v$) and densities (ρ) were calculated based on Eqs. 1, 2, 3 and 4, resp.:

$$E_m = \frac{{l_1}^3(F_2 - F_1)}{4bt^3(a_2 - a_1)} \quad (1)$$

where: $l_1$- the distance between the centres of the supports, (mm), $b$ - the width of the sample, (mm) and $t$ - the thickness of the sample, (mm). $F_2 - F_1$ is the increment of load, (N), and $(a_2 - a_1)$represents the increment ofdeflection, (mm) at the mid-length of the sample,

$$f_m = \frac{3F_{max}\, l_1}{2bt^2} \quad (2)$$

where: $F_{max}$ is the maximum load, (N),

$$f_v = \frac{F}{l_1 \times b_1} \quad (3)$$

$$\rho = \frac{m}{v} \quad (4)$$

where: $F$ - the failing force of the sample, (N), $l_1$and $b_1$represent the length and width of the shear area, $m$ - the mass of the sample, (kg), and $v$ - the oven dry volume of the samples, ($m^3$).

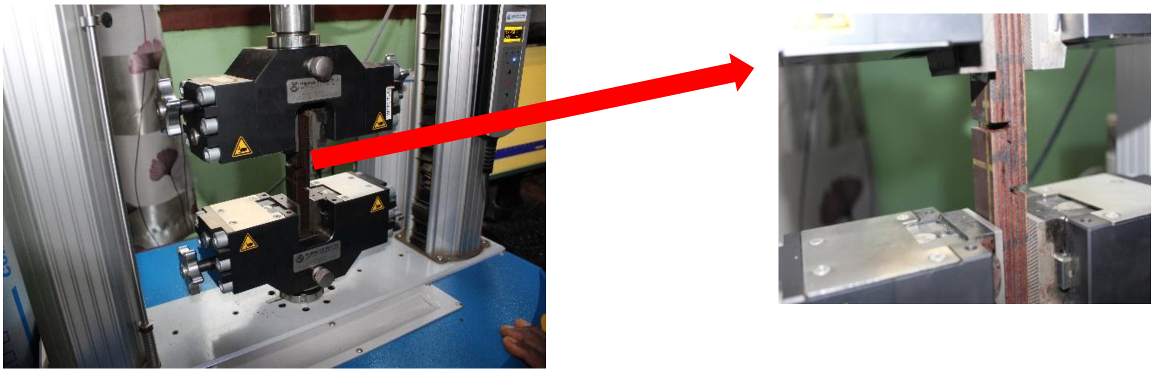

*Fig. 1: Shear test piece in a universal testing machine.*

## RESULTS AND DISCUSSION

### Density and mechanical properties of plywood bonded by PF and MUF glues

Tab. 2 shows the mean values with their corresponding standard deviations of results recorded for both the longitudinal and transverse orientation of specimens sampled from PF and MUF-bonded eleven-layer plywood. Considering the various tests conducted, there was a clear trend that suggests, there were generally higher mean values for all longitudinal surface veneers specimens than the transverse ones. This results pattern is consistent with findings in a study by Ranjan, et al. (2022) which recorded higher values for the along-the-grain samples than that of across-the-grain. In the case of density, both MUF and PF-bonded plywood recorded the same mean values for both transverse and longitudinal orientations. However, the longitudinal orientation recording higher values is consistent with several studies. According to Blomqvist et al. (2014), Ivanov et al. (2008), Labans et al. (2019) , there is greater strength and stiffness in the longitudinal direction of a veneer than in the transverse direction, this they attributed to the fact that the transverse orientation could easily bow and break, than in the longitudinal direction. With this study, higher values recorded for the longitudinal orientation could be attributed to most of the veneer being in the longitudinal orientation within the 11-veneers cross-lamination. Also, the higher influence of the outside layers, since they were longitudinally placed. The densities range (724.64 – 747.74 kg/$m^3$) of the juvenile eucalyptus used for this study competes favourably when compared to the hornbeam (700 – 720 kg/$m^3$) as recorded in a study conducted by Bekhta et al. (2022). Based on the findings of Ranjan et al. and Bekhta et al. (2022), it can be concluded that plywood produced from juvenile eucalyptus is denser than the poplar (435 – 560 kg/$m^3$). Considering the bonding strength, Fig. 3 shows tested shear samples laid side-by-side for wood failure determination.

*Tab. 2: Mean results of density, MOE, MOR, shear strength and percentage wood failure for longitudinal and transverse for both PF and MUF at 12% moisture content.*

| *Adhesive* | | *Density kg.m$^{-3}$* | *MOE Nmm$^{-2}$* | *MOR Nmm$^{-2}$* | *Shear Nmm$^{-2}$* | *WF (%)* |
|---|---|---|---|---|---|---|
| | | | *Transverse orientation (A)* | | | |
| *PF* | *Mean* | *743.26* | *6520* | *55.26* | *2.47* | *71.5* |
| | *St. dev.* | *±20.89* | *±546.48* | *±6.98* | *±0.99* | *20.95* |
| *MUF* | *Mean* | *724.64* | *6661* | *53.29* | *3.30* | *89.5* |
| | *St. dev.* | *±20.45* | *±366.38* | *±5.91* | *±1.09* | *15.13* |
| | | | *Longitudinal orientation (B)* | | | |
| *PF* | *Mean* | *742.65* | *7248* | *60.56* | *3.47* | *75.00* |
| | *St. dev.* | *±47.13* | *±397.98* | *±7.47* | *±0.64* | *17.79* |
| *MUF* | *Mean* | *747.74* | *7637* | *56.31* | *5.51* | *82.10* |
| | *St. dev.* | *±21.67* | *±426.19* | *±7.34* | *±0.97* | *22.31* |

*WF – wood failure (%), MOE – modulus of elasticity, MOR – modulus of rupture, St. dev. - standard deviation.


*Fig. 3: Tested shear samples showing above 80% wood failure.*

**Transverse and longitudinal veneer orientations**

A factorial ANOVA analysis was used to compare the differences between the longitudinal and transverse orientation results to ascertain the significant difference at the 0.05 level. Tab. 3 displays the arrangements being compared, the sum of squares, the degree of freedom, the mean sum of squares, the F- values, the p-values based on the Tukey comparison method, and the significant indication parameter. A comparison of MOEs shows that the p-value corresponding to the F-statistics of the factorial ANOVA was lower than 0.05 which strongly suggests that one or more pairs of the treatments (1A – 1B and 2A- 2B) were significantly different. This implies that the mean difference of the longitudinal and transverse orientation for both adhesives were significantly different with the longitudinal orientation samples having significantly higher values. Considering the comparison of MOR for the longitudinal and transverse orientation, the results indicate the p-values corresponding to the F-statistics of the ANOVA were higher than 0.05. This suggests the treatments (1A- 1B and 2A – 2B) were not significantly different despite the longitudinal orientation recording a higher value than the transverse orientation. The p-value for the shear comparison indicates that the corresponding to the F-statistics was lower than 0.05 which strongly suggests one or more pairs of the treatments are significantly different. Based on the ANOVA results, it can be concluded that the longitudinal orientation displayed significant resistance to shear stress for bonding. This confirms the accession by the work of Auriga et al. (2020) which recorded a similar trend and attributed the higher resistance to shear to a stress transfer through the axial direction of the veneer which increased the resistance against shear stress. The wood failure examination, which is a very subjective test, the ANOVA revealed that the p-value corresponding to the F-statistic of the factorial ANOVA was higher than 0.05, suggesting that the treatments (1A – 1B and 2A – 2B) were not significantly different. The mean densities for the longitudinal and transverse in the case of PF did not differ significantly as their p-values were higher than 0.05. However, there was a significant difference in the case of MUF, which could be attributed to the grain direction of the surface veneer. The significant difference recorded for densities of the MUF bonded plywood could also be a result of compression of the veneer during hot pressing and the quantity of the glue spread (Okuma 1976, Kurt and Cil 2012).

*Tab. 3: Comparison of longitudinal and transverse orientation for both PF and MUF (n = 10 in each treatment).*

| Test | Treatment | Sum of square, SS | DF | Mean sum of square, MSS | F-value | Tukey p-value | Sig. |
|---|---|---|---|---|---|---|---|
| MOE ($N/mm^2$) | 1A – 1B | 2,642,645.20 | 1 | 2,642,645.20 | 11.570 | 0.001 | 1 |
| | 2A – 2B | 4,764,832.01 | 1 | 4,764,832.01 | 30.160 | 0.001 | 1 |
| MOR ($N/mm^2$) | 1A – 1B | 140.19 | 1 | 140.19 | 2.681 | 0.128 | 0 |
| | 2A – 2B | 45.60 | 1 | 45.60 | 1.030 | 0.324 | 0 |
| Shear ($N/mm^2$) | 1A – 1B | 6.62 | 1 | 6.62 | 9.631 | 0.006 | 1 |
| | 2A – 2B | 24.29 | 1 | 24.29 | 22.550 | 0.000 | 1 |
| WF (%) | 1A – 1B | 61.25 | 1 | 61.25 | 0.162 | 0.692 | 0 |
| | 2A – 2B | 273.80 | 1 | 273.80 | 0.754 | 0.397 | 0 |
| Density ($kg/m^3$) | 1A – 1B | 1.80 | 1 | 1.80 | 0.001 | 0.971 | 0 |
| | 2A – 2B | 2,660.50 | 1 | 2,660.50 | 5.888 | 0.026 | 1 |

*A- longitudinal orientation, B – transverse orientation MOE, DF – degree of freedom 1 – PF and 2 – MUF, Sig. -significance, 1 – difference of means is significant at the 0.05 level, 0 – difference of means is not significant at the 0.05 level.

**Effect of the PF and MUF on the density, MOE, MOR, shear strength and WF**

The results in Tab. 4 show the comparison of the two adhesives, that is, the PF and MUF whether they had any significant effects on the difference of mean variations of the veneer orientation. To complete this objective, the significant difference was determined based on the Tukey method of factorial ANOVA analysis at a significant level of 0.05. The comparison was done between 1A – 2A as transverse PF and transverse MUF respectively as well as 1B and 2B as longitudinal PF and longitudinal MUF respectively. According to the ANOVA results of the longitudinal comparison, the p-value corresponding to the F-statistics was lower than 0.05 which strongly suggests that 1B and 2B were significantly different. Interestingly, the rest of the ANOVA tests conducted on MOE, MOR, WF, and Density resulted in a p-value higher than 0.05 suggesting the treatments (1A- 2A and 1B- 2B) for all the tests were not significantly different which is in line with the study by Bal and Bektaş (2014), Ozalp et al. (2009) stated that the adhesive MUF and PF used for the bonding of the veneers, statistically did not have a significant difference in their strength properties. This means that per the tests conducted both MUF and PF glues largely did not differ in performance.

*Tab. 4: Comparison of PF and MUF for both longitudinal and transverse orientations (n = 10 in each treatment).*

| Test | Treatment | Sum of squares, SS | DF | Mean sum of square, MSS | F-value | Tukey P-value | Sig. |
|---|---|---|---|---|---|---|---|
| MOE ($N/mm^2$) | 1A – 2A | 98,982.45 | 1 | 98,982.45 | 0.457 | 0.508 | 0 |
| | 1B – 2B | 760,110.05 | 1 | 760,110.05 | 4.472 | 0.051 | 0 |
| MOR ($N/mm^2$) | 1A – 2A | 19.45 | 1 | 19.45 | 0.467 | 0.503 | 0 |
| | 1B – 2B | 90.39 | 1 | 90.39 | 1.650 | 0.215 | 0 |
| Shear ($N/mm^2$) | 1A – 2A | 3.49 | 1 | 3.49 | 3.206 | 0.090 | 0 |
| | 1B – 2B | 17.84 | 1 | 17.84 | 26.441 | 0.001 | 1 |
| WF (%) | 1A – 2A | 560.80 | 1 | 560.80 | 1.199 | 0.288 | 0 |
| | 1B – 2B | 1,051.25 | 1 | 1,051.25 | 3.854 | 0.065 | 0 |
| Density ($kg/m^3$) | 1A – 2A | 1,729.80 | 1 | 1,729.80 | 4.066 | 0.059 | 0 |
| | 1B – 2B | 120.05 | 1 | 120.05 | 0.089 | 0.768 | 0 |

*A- longitudinal orientation, B – transverse orientation MOE, DF – degree of freedom 1 – PF and 2 – MUF, Sig. - significance, 1 – difference of means is significant at the 0.05 level, 0 – difference of means is not significant at the 0.05 level.

## CONCLUSIONS

Currently, the situation in the plywood industry in Ghana requires an innovative solution such as using six years old eucalyptus to produce plywood to augment the dwindling production and supply of the product to the international markets. The study investigated the mechanical properties of plywood produced from six years old eucalyptus bonded by PF and MUF for both the longitudinal and transverse orientation. The following mean results ranges were obtained for all the treatments; MOE (6520 – 7638 $N/mm^2$), MOR (53.29 – 60.56 $N/mm^2$, shear (2.47 – 5.51 $N/mm^2$), wood failure (72-90%) and density (725 – 748 $kg/m^3$). The transverse and longitudinal comparison of the treatments indicated the variations were significant for MOE, and insignificant variations were recorded for MOR and percentage wood failure. Comparison of 1A and 1B were not significant however, 2A and 2B recorded significant variations. The results imply the orientations largely affected the results with the longitudinal orientation resisting much more load than the transverse orientation. The adhesives, PF and MUF largely did not have any significant effect on the results since the variations were not significant. With our tests, we have proven that it is possible to produce sufficiently strong and resistant plywood from the juvenile wood of eucalyptus.

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HARUNA SEIDU*, RÓBERT NÉMETH, JAMES KUDJO GOVINA, FATH ALRHMAN, A.A YOUNIS
UNIVERSITY OF SOPRON
FACULTY OF WOOD ENGINEERING AND CREATIVE INDUSTRIES
BAJCSY-ZSILINKY STREE 4. H-9400 SOPRON
HUNGARY
*Corresponding author: haruna.seidu@phd.uni-sopron.hu

FRANCIS WILSON OWUSU, JAMES KORANG, SAFIA IBRAHIM
CSIR-FORESTRY RESEARCH INSTITUTE OF GHANA
P. O. BOX 63, FUMESUA - KUMASI
GHANA

APPIAH-KUBI EMMANUEL
AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL DEVELOPMENT
P. O. BOX 1277, KUMASI
GHANA