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DESIGN OF MINI COMBINED HARVESTER

Abstract: In this research, various problems associated with harvesting of agricultural food grains by local farmers in Nigeria were identified. The aim of the research was to design low cost multipurpose mini combined harvester for production using locally available materials at affordable cost. The research was to ensure improved performance and low cost maintenance of harvester for use by farmers in developing nations. The modelling of the chassis and other components of the combined harvester was done using Solid works 2014. The selection of materials for the design was achieved using Cambridge Engineering Selector (CES) 2014. Calculations for the design of each components and power requirements to determine the engine specifications were carried out to ensure optimal performance. The output of the research was the development of mini combine harvester which is a microcosm of large capital intensive harvester, at affordable cost to small scale farmer in developing nations. The research ensures the use of mechanised farming equipments designed and developed from local materials for effective harvesting and transportation of agricultural produce.
Key words: chassis, design, grains, harvester, material selection, modelling.

Konstrukcija mini kombajna za žetvu. *U ovom istraživanju, identifikovani su različiti problemi u vezi berbe poljoprivrednih žitarica od strane lokalnih poljoprivrednika u Nigeriji. Cilj istraživanja je bio da se dizajnira jeftin višenamenski mini kombajn, a za proizvodnju se koristi lokalno dostupni materijali po pristupačnoj ceni. Istraživanje je bilo usmereno da se obezbede bolje performanse i jeftino održavanje kombajna za upotrebu od strane poljoprivrednika u zemljama u razvoju. Modeliranje šašije i drugih komponenti kombajna je urađeno pomoću Solid Vorks 2014. Izbor materijala za konstrukciju je vršen korišćenjem Cambridge Engineering Selectora (CES) 2014. Proračuni u cilju projektovanje svake komponente kombajna kao i potrebne snage je bio da se utvrde specifikacije motora kako bi se osigurale optimalne performanse. Izlazni rezultat istraživanja je bio razvoj mini kombajna koji je mikroverzija velikog i skupog kombajna, po pristupačnoj ceni za obim rada kod malog farmera u zemljama u razvoju. Istraživanje osigurava upotrebu mehanizovane poljoprivredne opreme konstruisane i razvijene od strane lokalnih materijala za efikasno sakupljanje i prevoz poljoprivrednih proizvoda.*
Ključne reči: šasija, dizajn, žitarice, kombajn, izbor materijala, modeliranje.

1. INTRODUCTION

Agricultural in Nigeria still remains the source of raw material to both local and international industries despite years of neglect following the emergence of oil economy [1, 2]. According to Engineering Export Promotion Council (EEPC) [3] report, it was indicated that 82 million hectares out of Nigeria's total land area of 91 million hectares are arable and only about 34 million are being cultivated. But despite the setback in agricultural sector in Nigeria on account of oil boom, agricultural still account for a significant shares both in Gross Domestic Product (GDP) and total export [4].

Mechanization remains one of the biggest challenges especially to the local farmers. Faborode [5] reported that agricultural mechanization in Nigeria is less than 2%, while 98% of the production is done by traditional methods and the effect of this methods is low output [6]. Lamidi and Akande [7] indicated that the major constraints to successful farm mechanization in Nigeria are non-affordable farm machineries to local farmers. Hitherto, majority of farmers still employ hand tools for cultivation and harvesting processes [8]. This predicament is not unconnected with lack of access to loan facilities and higher interest rate. The high yield grains and seedling made available to farmers by government must be complimented by affordable machinery especially for harvesting and transportation from farm to markets. Abdulkareem [9] was however optimistic on varieties of indigenous technological tools recently developed in various forms.

As part of the government initiative towards becoming one of top 20 economies in the world by year 2020. Nigeria government has challenged the indigenous engineers among others, on the design of low cost farm machineries and equipment [10]. This is in a bid to increase productivity and to enhance quality of farm operation and effective land usage [11]. In addition, government of Nigeria also set up several institutes like, The Lake Chad Research Institute (LCRI) working alongside with Support To Agricultural Research For Development Of Strategic Crop (SARD-DC) to research into the production problems of popularly grown crop such as rice, wheat, millet, barley, cassava and sorghum at the same time find a generic improvements. Also, some institutes were set up to encourage local farmers on mechanized farming through agricultural scheme.

Harvesting among the major operations, is the culmination of the farming processes and could be

achieved through different methods depending on the type of the crop to be harvested; it involves cutting, gathering threshing, cleaning, transporting and stacking of the grains. In Nigeria, Harvest of grains is traditionally done manually using sickle, knife or scissors which involve intensive labour, cost and time consuming (see Fig. **1**).

Fig. 1. Harvesting [12] and Transportation of Harvested Grains

2. COMBINE HARVESTERS

Grain harvesters can be described as various designs of tools, machine and system used during the harvest of grains. It can be classified into two categories such as traditional methods and mechanical methods. However, the entire operation can be divided into four stages such as cutting, threshing, separating and cleaning depending on the methods used.

The world first engine operated combine harvester

was built by George Stockton Berry in the year 1888, a self-propelled machine that burned fuel off the land. The machine was the first and the largest header of 40 feet tractor that work both forward and backward, also, the first to harvest over100 acres of land in a day with the aid of head light at night time, it took five year to build and was sold at cost of $4500 apiece [13].

Several development trends was followed after the discovery of the machine, many leading manufactures were merged and international harvester company was formed in 1902.Due to increase in demand and performance of the machine several development has occur ever since by different manufacturers. The trends of Improvements from the size of the machine to work rate, improvement of threshing, separating and cutting efficiency, reduction of gathering loss, reduction of grain damages, reduction of operation fatigues have been witness. However, other important improvement like usage comfort and safety, automatic adjustment, electronic controls and it ergonomics has evidence that combine harvester witnesses a significant transformation.

There are several types of combine harvester current available but their selection depends on the factors like size of the farm, types of the crop, and the available capital. It is a very unique machine as it cuts, transports, threshes, separates and as well stores the grain [14].

From all review of grain harvester it was evidence that a good amount of work has been done in developed countries. But taken the cost into account it is an obstacle to the local farmers and needs of the small scale farmers remained unmet which is a challenge to indigenous engineers in developing countries [14].

However, in some other developing countries such as Thailand, Pakistan, and India a great response to the challenge have been made. In India, an indigenous combine harvester have been tested and introduced to market, the Swaraj- 8100 manufactured by Punjab tractors limited. The machine was tested for 75 hours on different field at operating speed of 2-3 km/hr in first gear at 1850 rpm. The overall performance of the machine was found to be satisfactory but still expensive for small scale farmers [15].

Meanwhile in Africa, particularly Nigeria a lot of research work and development into grain harvesters has been done. Abdulkareem [9] currently stated that there are many indigenous technological objects developed in various forms. For grain harvesters, machine such as thresher and strippers are available in the market. Researchers are currently working on improving threshing machines into combine, according to Ademosun et al. [16] who stated that development of grain harvesters is in progress.

Olukunle [14] developed an indigenous self-propelled combine harvester for cowpea and soya bean. The machine is capable of operating at 0.33ha/h at estimated feed rate of 322.22kg/h between 100 to 600 rpm. Although, machine was tested in various operational conditions and the cost of the machine was estimated to ₦450, 000 and it full scale 3 row will cost ₦1, 200,000. Comparing the machine to the modern combine harvester it is very cheap. However,

considering the small scale farmers the cost is very high which require further development.

Therefore, the design of multipurpose low cost combine harvester was aimed at fulfilling the above challenge. Although, currently there is no engine manufacturing company in Nigeria but it is locally available at affordable price. Some of the design targets of the low cost combine harvester include it ability to operate under different weather conditions efficiently, suitability for temporary storage on farm and transportation of farm products.

3. DESIGN METHODOLOGY AND MATERIAL SELECTION
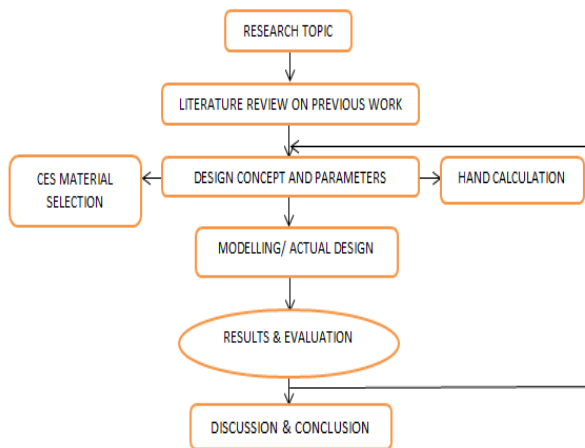
3.1 Design methodology flow chart

Fig. 2. Design Methodology Flow Chart

The research is followed by in-depth knowledge of concept design with assumed parameters, hand calculations, 3D modelling, material selections, operation systems of the harvester taking into consideration the aim and objectives with the background knowledge. Results from the design were evaluated and discussed. Finally, a comprehensive conclusion is drawn based on all the results obtained.

3.2 Hand calculations of Design Parameters:

The following are the parameters used for the calculation of stress and strain on the chassis:

− Total Length of required chassis pipe, L=11.371m, Approximated to 12m.
− Total Surface Area of chassis, A=12 x 0.03 = 0.36m^2
− Material: AISI 1045
− Density of the material, ρ = 7850kg/m^3
− Young modulus of the material, E= 210 GPA
− Yield strength: 530x 10^{6}N/m^2
− Mass of the chassis, M=28.62kg
− Approximated total weight on the chassis, W=640kg = 62784N
− Moment of inertia, I=3.5977 x10^{-4}m^4

The engineering stress and strain on the chassis were calculated with Equations 1 and 2 respectively:

$$\sigma_c = \frac{W_c}{A_c} \qquad (1)$$

$$\varepsilon_{ch} = \frac{\sigma_{ch}}{E} \qquad (2)$$

Treating the chassis as uniformly distributed load to calculate for deflection, y

$$y = \frac{5WL^4}{384 \times EI} \qquad (3)$$

Substituting for W = 6278.4N, L = 2.01m, E = 210GPA, I = 3.5977 X 10^{-4} m^4 in Equation 3, gave the value of deflection, y = 1.76 mm.

The Factor of safety was calculated according to Equation 4, and given the ultimate and actual stresses of 53000 N/m^2 and 17000 N/m^2.

$$FOS = \frac{Ultimate\ Stress}{Actual\ Stress} \qquad (4)$$

The power required for Threshing, P$_1$ was calculated from Equation 5.

$$P_1 = \frac{MV^2}{1-f} + A_{w1} + B_{w^3} \qquad (5)$$

The following parameters were considered for calculation of power:

M: Total Mass of the Material Feed to the Drum (kg/S), i.e. Mass of the Grain +Mass of the Straw.
Using Wheat for Calculation: 450 kg/h
Approximated Grain Straw Ratio in Mass is 1.5

Total Mass of the Wheat = 450+1.5×450 = 1125kg/h
= 0.31kg/S

V: Tip Speed of the Drum (m/s) = 35m/s
F: Friction Coefficient Range between 0.7-0.8 for this type of Material
A$_{W1}$: Factor Accountable to the Resistance of Bearing taken to be 3.0 X10^{-2} kgfm
B$_W$^{3}: Factor Accountable For the Air Resistance Taken to Be 0.48 X10^{-2} kgfm

Grain	Straw Ratio	Average Weight (kg)
Barley Straw	1.2	21.74
Corn Straw	1.0	31.75
Oat Straw	1.3	14.515
Sorghum Straw	1.4	25.40
Wheat Straw	1.5	27.22
Wheat Straw (Winter)	1.7	27.22

Table 1. Different Grain Straw Ratio and their Average Weights [17]

W: Angular speed of the drum (rad/s) assumed to be 800 rpm = 84 rad/sec

Calculating for the power using Equation 5, showed that Power, P$_1$ = 1.27 kW

It was assumed that the same amount of power will be required to operate the auger and the reel, so the combined power sum is 2.54 kW.

And the power need of the conveyor was calculated from Equations 6-9.

$$P_2 = T_e \times \frac{V}{1000} \qquad (6)$$

$$T_e = TC + TL + TH \qquad (7)$$

$$TC = F_1 \times L \times CW \qquad (8)$$

$$TL = F_2 \times L \times MW \qquad (9)$$

T_e = The effective tension on the belt
V = Velocity
TC = Sum of tension required to move the empty belt
TL = Tension required to move the load on the belt horizontally
TH = Tension required to lift the load
F_1 = Coefficient of friction=0.02
L = Length of the belt =1.68m
CW = Total weight of conveyor belt components=12 kg
TC = $0.02 \times 1.68 \times 12 = 0.40$N
F_2 = Friction factor to move the load horizontal
L = Length of the belt
M_W = Material weight =0.31KG/S
TL = $0.02 \times 1.68 \times 0.31 = 0.010$N
TH = $H \times M_W$
H = Difference in the elevation of the pulleys (M) = 0.37m
TH = $0.37 \times 0.31 = 0.11$N
Therefore
T_e = 0.40+0.011+0.11 = 0.52N
P_2 = 0.52 ×35 /1000 = 0.0182 HP or 0.014 kW

And the power required for blower was calculated from Equation 10

$$P_3 = Q \times \frac{PF}{33000} \times \mu \qquad (10)$$

The following parameters were used for the calculation of power required for the blower:
Q = Flow Rate = 125.6 m/s
PF = Atmospheric Pressure =101325 N/m^2
M = Efficiency Coefficient =1.7
P_3 = 125.6 ×101325/33000 × 1.7 = 12726420/5610= = 2.26 kW

The Power requirement for Shaft transmission was calculated from Equation 11.

$$P = F \times V \qquad (11)$$

F = Total weight of mini combine harvester = 640 kg = 6278 N
V = Assumed to be 1.2 m/s
P = 6278 X 1.2 = 7533 Nm/s = 10.10HP or 7.53 kW

The total power sum required:
= 7.53+2.26+0.014+2.54
=12.34 kW

The total power was rounded up to 13 kW considering all the transition loss

The design capacity of the container was calculated as shown below:

The container was rectangular box with internal dimensions given as $0.9 \times 0.45 \times 0.30$ m
Volume of container, Vc was 0.128 m^3

Converting the volume to bushels and then to kilogram through following expression:
0.128/0.36 = 3.5 bu

While 1 bu = 27.22 kg
3.5 bu = 95.25 kg
To calculate for amount of grain per m^2.

And considering wheat for the calculation, an average mass of 1000 grains (extra strong) range form 0.040-0.044 kg at 210 m^2.

The total amount of grains contained in 95.25 kg was estimated at 23000 grains.

3.3 Selection of materials

For engineering applications, selection of materials is considered an important and challenging task. Choosing materials wrongly may increase the product cost and possible failure of the product. During the selection, properties and behaviour of the material depends on several factors that needed to be considered to ensure the quality of the product is not compromise [18]. The selection process are often simplified into 4 categories namely: manufacturing processes, functional requirement, cost considerations and operational parameters [19]. All the four categories were considered in the design of the low cost harvester using Cambridge Engineering Selector (CES) 2014 software while the criteria for the design were adapted from [20-23]. There are thousands of different materials available in the market and it will be difficult to process all the detail knowledge of the materials [24].

The material selections for the machine components were carried out, setting the variable limit of the parameters. Density was first set against the yield strength, the results obtained was narrowed down by setting the price against young modulus. Then yield strength against young modulus. After all the analyses were conducted, appropriate materials most suitable for the machine were chosen. The chosen materials considered are shown in Table 2.
Engine specifications

Based on the power requirements from the calculation of approximately 13 kW, a Honda G630 air cooled 4 stroke OHV petrol engines; electric starter of net power of 15.5 kW (20.8 HP)/3600 RPM was selected. The engine was mounted at the center of the chassis in other to drive the rear shaft and other components (auger, reel, cutter, conveyor, blower and thresher) with the aid of pulleys. It was designed to start from the entrance door to the engine compartment next to the driver, this makes it easier to stop the engine, for easy maintenance of the engine and other components.

Fig. 3. Honda G630 Engine [25]

4. CAD MODELING AND ASSEMBLY

4.1 Concept Design

With the present agricultural mechanization situation in Nigeria, the idea of low cost multipurpose mini combine harvester came up as a result of the current demand by Nigerian farmers. The harvester was designed with back wheel drive and consists of chassis, main body and engine unit in conjunction with reeling, cutting, threshing and storage units. The machine will in addition to providing better operation condition for the operator with availability of seat and cover, it was also designed to provide good visibility lighting when required. With the aid of attachment, combine harvester can as well serve as mower, plough, seeder and the engine can be used for irrigation.

The power transmissions was achieved through the use of B type 2 V-groove pulley and rubber belt to transmit power from the engine to the wheel shaft, then to cutter blades along with rotational motions of auger, reel, conveyor belt and thresher. The conveyor, auger and thresher rollers were designed using standard seam tube steel of 10 m thickness with different diameters. Also, basic type food grade belt was selected for the conveyor while most of the fasteners used for the design were nails apart from special connection areas like body to chassis, engine, tires to shaft etc.

During the design, consideration for past design types, operations, efficiency, materials and cost were examined, several factors such as weather, topography and farming system about the region of operations were also considered in order to meet the demand of the local farmers.

Based on the design assumptions, the concept design of low cost multipurpose mini combine harvester was modelled using Solidworks 2014. The Fig.4 shows the side view of the combine harvester.
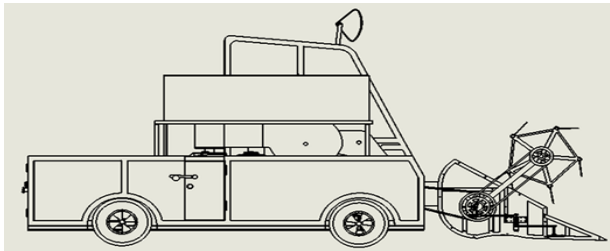

Fig. 4. Side View of the Combine Harvester

4.2 Chassis

There are different types of chassis, and they vary from ladder, twin tube to space frame types. For this design, the concept for the harvester chassis was adopted from Abdulrahman [26]. The chassis was a conventional type space frame ladder structure with two long side member and 7 sides cross members. It was designed for easy fabrication by welding using square steel pipe of 30 × 30 × 2.6 mm and 2000 mm length ×1220 mm Width, it could be fasten to the body by bolts 60.50 mm.

And according to the calculation the total square steel pipe length required was approximated to be 12 m with the total weight of 640 kg .Other fixtures such as shaft, steering, steering arms, engine and hitch will be attached to the chassis also with the aid of different bolt sizes.
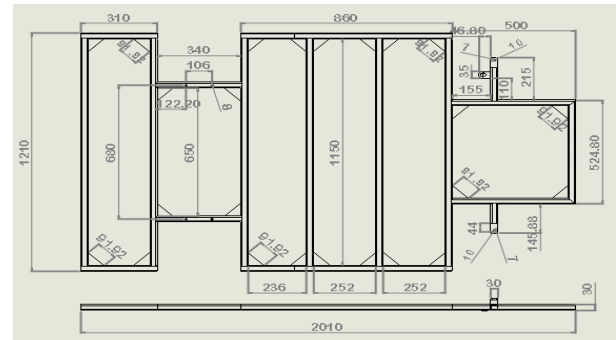

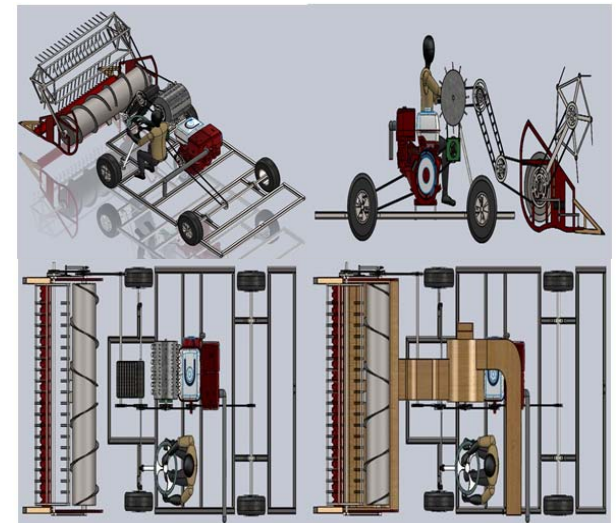Fig. 5. Sketch of combined harvester chassis

Fig. 6. Different Views of Combined Harvester Chassis and Components

4.3 Harvester body

One of the design requirement is to make the harvester compacted, the main body of the harvester was 1170 × 1008 × 440 mm at the front end (driver side) while the rest of the body was 2000 × 1220 × 440 mm. The body was designed using Mahogany and other attachments (such as conveyor cover, threshing housing and cutting bucket) using oak wood. A plastic sheet was also attached to the body in order to protect the storage unit and the engine during operation. Accessibility for engine maintenance was also considered which leads to provision of entrance door to the engine compartment. The storage unit was designed to be accessible both from inside and outside as may be required.
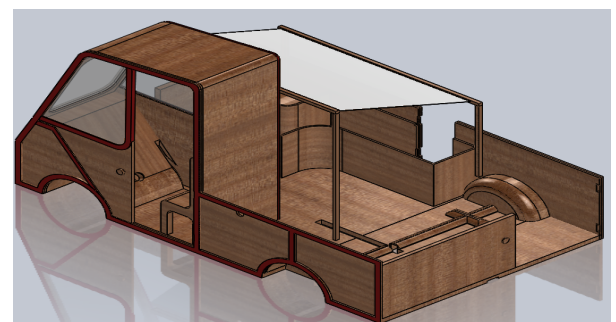

Fig. 7. View of the Combine Harvester Body

4.4 Machine operation system

The design adopted for the harvester was based on the existing designs but different in size, materials and cost. Major operating system of the harvester is made up of five compartments: The Header consisting of reeling unit, cutting unit, bucket and the auger. The feeder comprising the conveyor belt and driven roller. The Threshing unit consist of threshing drum, sieve and the blower. Transmission system unit which consists of Engine, shafts, Pulleys Belts, wheels and Hub, brakes and suspension system and finally, the storage Unit consisting of grain pan and cover.

The cutting and gathering process of the grain will be accrued from the reeling unit and cutting unit, which will then be conveyed from the auger to the feeder and presented to the threshing unit. The grain will be threshed at rotational force with the aid of threshing combs attached to threshing drum at line intervals. These threshing combs comprise of small rod made of metal called tongs and each of it is carved into small arc. The small clearance between the sieve and the comb will allow detachment of the grains

After detachment of the grains from the ears, the sieve will separate the grains directly to the storage and the straw will be blown out through the straw channel to the ground. Although, general threshing problem is either over threshed or under threshed. Over threshing, which could damage grains due to high speed of the thresher is taking care of by the speed of the engine but with possibility of fine straws escaping with the grains which can easily be cleaned later before storage. However, all these processes cannot be achieved without the transmission system.

For the suspension system, it is not generally necessary to have suspension in place for the harvester based on the design speed of the machine. The design is single axle back wheel drive with engine in the middle operating at the speed of 1-2 m/s. More so, the types of tyre and wheels used for the harvester were the most common car type which can provide certain amount of shock absorption on the road, reduction of unnecessary motion and support for the harvester weight.

The tires used for the harvester was common pneumatic type which can both change and maintain directions, it also allow tractions and brake force to the road surface. They will be mounted on the hubs welded to the axle in the front and shaft at the rear end. Apart from the tires, other components were fabricated at low cost.

Although, the harvester does not have standard braking system because of it speed but a provision for stopping mechanism was provided. The entrance door beside driver seat leads to the engine compartment for driver to have access to the engine at any point in time in case of emergency. Also, there is provision for hand lever near the driver seat link to the rear tires that can bring the harvester to a halt. The harvester will also have supportive components such as lightning, hitch, windows and shield cover and belts cover.

For the Hitch, it mechanism allow rotation of two axes in other to accommodate attachment such as furrows, seeders and rakers and possibly a trailer within the capacity range of 8-10 HP. The lightning will also provide good visibility during night time for farmer to work this is sourced directly from the engine coil unit while the shields and cover belt did not only provide protection for driver and the engine during bad weather conditions but also protect them from accident against foreign objects.

5. RESULT AND DISCUSSION

Calculations of stress, strain, deflection of the chassis and the total power required by the combine harvester was done. From the calculated results obtained, it was observed that the chassis will definitely withstand the design load.

The calculated stress, strain and deflection on the chassis using steel material AISI 1045 with yield strength of 530 MN/m^2, gave 1.7×10^4 N/m^2, 8.305x 10^{-8} and 1.76 mm respectively. The displacement of the chassis can be seen as negligible considering it with a higher factor of safety of 3.1 and compared with previous work of Abdulrahman [26] on static analysis on similar chassis with displacement of 5.57mm and a factor of safety of 1.7. The total calculated power required by the combine harvester was 12.34 kW (approximated to 13 kW) to cater for transmission losses.

The selection of material for the combine harvester was done with the aid of CES. It is an effective and precise tool that helps in arriving at an appropriate and cost effective material. The results obtained from the material selection are shown in the Table 2. From the power requirement of the combine harvester, the motor recommended and readily available in the market was a Honda G630 air cooled 4 stroke OHV petrol engines; electric starter of net power of 15.5 kW (20.8 HP)/3600 rpm.

6. CONCLUSION

This research has clearly demonstrated that it is quite possible to design for manufacture of a multipurpose mini combine harvester aimed at solving farmer's problem of harvesting and transportation in developing nations. The combine harvester is designed not only to harvest, thresh and store grains but also to drive other farm implements and used for irrigation purpose when engine is connected to a pump.

The calculated results obtained showed that the chassis was able to withstand the design load the harvester may be subjected to as long as high strength material is used for the chassis construction. The result also revealed a deflection of 1.76 mm when the chassis is subjected to maximum load, which it was safe to use considering a factor of safety of 3.1 incorporated in the design.

Finally, the materials that have been carefully selected for the combine harvester design were those available locally. Low price square hollow pipe have been used in the designed for construction of chassis. Other materials selected namely: plywood, polythene and plastics for vehicle body and single cylinder engine to drive the harvester could be sourced locally for

manufacturing. All these were attempted to ensure the cost of production was significantly reduced and the combine harvester is readily accessible to small scale farmers.

Components	Size (mm)	Materials	Density (kg/m³)	Young Modulus (MPa)	Yield Strenght (MPa)
Chassis	30x30 × 2.6	AISI 1045 steel	7850	205000	530
Shafts	666.35 × 20	AISI 1045 steel	7850	205000	530
Conveyors	447x180	Natural rubber	930	1.2	21
Auger	1213 × 250	Carbon stainless steel (sheet)	7858	205000	282.69
Reels	1250 × 20	Cast iron	6800	172000	526
Cutter Blades	1165×120×10 1105×120×10	Tool steel	7600	206000	1680
Main Body	Various	Mahogany	640	10.60	49
Bucket	-	Oak	850	20600	43.2
Conveyor Cover	-	Oak	850	20600	43.2
Hitch	-	Cast iron	680	172000	526
Pulleys (Various)	Various sizes	Cast iron	680	172000	526
Bolts	Various sizes	Cast iron	680	172000	526

Table 2. Different Selected Materials for the Design [20]

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