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MODELLING OF A LOW COST CONCRETE MIXING MACHINE

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ABSTRACT

In this work, the modelling of a concrete mixing machine that can mix cement, sand, granite and water with an input power from a diesel engine is reported. Concrete that is mixed manually requires a lot more work and takes a long time to produce a mixture that has less compressive strength. Numerous small-scale construction projects still use the traditional method of mixing concrete because existing mixing machines are so expensive. The consistency achieved through mixing has a

Introduction

Concrete is a material widely used in the construction industry which comprises of cement, gravel, sand and water mixed in a defined ratio; that is cement, aggregate, and admixture materials are mixed (Kim, Tae and Chae, 2016; Ali and Shakebuddin, 2022). The production of concrete usually takes place on site and needs concrete mixing machines to speed up the process, and obtaining a consistent homogeneous mixture with good compressive strength. Concrete mixer is highly efficient in operation with shorter processing time and higher processing capacity when compared with manual method (Daniyan, Aderoba, Jimmy, Rominiyi and Adewumi, 2017). All the components to form the concrete material are put in the drum of the mixer which rotates inclined at a particular angle, and powered from a chosen source. Speed is an important time control requirement in the making of concrete. Drum speed as a variable taken into consideration in the design of concrete mixer influences the compressive strength of the produced concrete material. Speeds of between 20rpm and 25rpm have been encouraged for a tilting mixer; and the compressive strength of concrete is attained when the concrete mixer is 25rpm, and at speeds of 35 and 50rpm, the compressive strength are decreased (Hidayat, Suangga, Dwidarma and Yoshua, 2018). The objectives of this work were to design for the volumes of the drum and the maximum load of its content, design the mixer axle, determine the power requirement of the drum, model the machine to be relatively inexpensive to operate, and fabricate a low cost

significant impact on the compressive strength of concrete. In the objectives we are to design for the capacities of the drum and the batch, determine the power requirement, and fabricate a low cost mixer from locally available materials. This work is significant at promoting small businesses in the fabrication of low cost, locally made concrete mixers. The drum's volume for combining 50 kg of cement, and aggregate was discovered to be 4.45 x 10^8 mm^3 with content volume of 3.75 x 10^8 mm^3 and 4.84 kW would be the machine's power requirement due to the drum's low speed design at 25 rpm. The project proved that locally fabricated concrete mixers can be much less expensive compared to imported ones by an average 30.70%.

Keywords: Modelling, Low Cost, Locally Fabricated, Concrete Mixing Machine

mixer from locally available materials. It is significant at encouraging the establishment of small businesses in the fabrication of low priced, locally made concrete mixers; and intends to answer the question of whether locally fabricated mixers would be less expensive.

II. MATERIALS AND METHODS

Volume of Drum

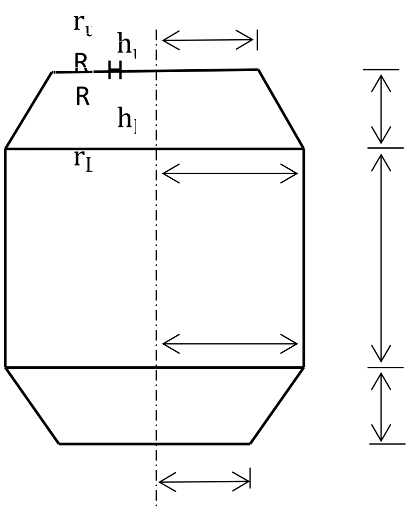

Figure 1: Mixer drum

The mixer drum is made up of three sections: the top conical frustum, middle cylindrical part, and the bottom conical frustum.

The mathematical relation for the inner volume (top, middle, and bottom section separated by the plus signs accordingly) of the drum is shown in equation (1).

$$V_d = \pi h_u \left(R^2 + r_u R + r_u^2\right)/3 + \pi R^2 H + \pi h_L \left(R^2 + r_L R + r_L^2\right)/3 \quad \mathbf{(1)}$$

where, V_d = volume of drum, h_u = height of upper frustum, R = radius of cylindrical section, r_u= radius at top of upper frustum, H = height of cylindrical section of drum, r_L= radius at bottom of lower frustum.

Inner volumes of upper frustum, cylindrical part and lower frustrum are given in equations (2), (3) and (4)

$V_{iuf} = \pi \mathrm{h_u} \left(\mathrm{R_i} + r_{\mathrm{iu}}\mathrm{R_i} + r_{iu}^2\right)/3$ **(2)**

where, V_{iuf}= inner volume of upper frustum, $\mathrm{R_i}$ = inner radius of cylindrical section, r_{iu} = inner radius of top of upper frustum, V_{ic} = inner volume of cylindrical part, V_{iLf}= inner volume of lower frustum, $\mathrm{h_L}$ = height of lower frustum, r_{iL}= inner radius of top of lower frustum.

$V_{ic}=\pi R_i^2 \mathrm{H}$ **(3)**

$V_{iLf}= \pi \mathrm{h_L} \left(\mathrm{R_i^2} + r_{\mathrm{iL}}\mathrm{R} + r_{iL}^2\right)/3$ **(4)**

where, V_{iLf}= inner volume of lower frustum, $\mathrm{h_L}$ = height of lower frustum, r_{iL}= inner radius of top of lower frustum.

The outer volume of the drum can be determined by including the 3mm thickness of the mild steel material to the dimensions.

The outer volumes of the upper frustum, cylindrical part, and lower frustrum can be found from equations (5), (6) and (7) respectively

$V_{ouf} = \pi \mathrm{h_u} (\mathrm{R_o^2} + r_{\mathrm{ou}}\mathrm{R_o} + r_{ou}^2)/3$ **(5)**

where, V_{ouf}= outer volume of upper frustum, $\mathrm{R_o}$= outer radius of cylindrical section, r_{ou} = outer radius of top of upper frustum, V_{oc} = outer volume of the cylindrical part, V_{oLf}= outer volume of lower frustum, r_{oL}= outer radius of bottom of lower frustum.

$V_{oc}= \pi R_i^2 \mathrm{H}$ **(6)**

$V_{oLf}= \pi \mathrm{h_L} (\mathrm{R_o^2} + r_{\mathrm{oL}}\mathrm{R} + r_{oL}^2)/3$ **(7)**

Substituting internal values into equation (1) obtains the inner volume of drum, V_{id}.

Mass of Empty Drum

Volume of plate material of the drum at top frustum, V_{muf}, is

$V_{muf} = V_{ouf} - V_{iuf}$

The volume of plate material of drum at cylindrical part, V_{mc}, is

$V_{mc} = V_{oc} - V_{ic}$

Total volume of drum plate is

$V_{dp} = V_{muf} + V_{mc} + V_{mLf}$

where, V_{dp} = total volume of drum plate, V_{muf} = volume of plate material of the drum at top frustum, V_{mc} = volume of plate material of drum at cylindrical section, V_{mLf} = volume of plate material of the drum at lower frustum.

Mass of empty drum is

$M_{dp} = \rho_{dp} * V_{dp}$ **(8)**

where, $M_{dp} = mass\ of empty\ mixer\ drum$; $\rho_{dp} = 7{,}960\text{kg/m}^3$ = density of mild steel material (Rajput, 1998).

Volume of Content of Drum

Using volume ratios of 1:2:4 for cement, sand and granites respectively, and a water to cement ratio (w/c) of 0.5. The capacity of the concrete mixer is to mix one bag (25kg) of cement with sand, granite and water.

Considering the ratio w/c = 0.5, then for 50kg of cement, water is 25kg. Volume can be got from equation (8). So that,

$V_w = M_w / \rho_w$

where, V_w= volume of water; M_w= mass of water; $\rho_w = 1000kg/m^3$= density of water,

Since the ratio of water to cement is 0.5, hence the volume of cement, V_{ce} can be found to be $0.05m^3$, $V_w = 25/1{,}000 = 0.025m^3$

The ratio of cement to sand, granite is 1:2:4, hence the volumes of sand, V_s and granite, V_g can be determined as, $V_s = 0.1m^3$, and $V_g = 0.2m^3$

The actual total volume of content is

$V_{vc} = V_w + V_{ce} + V_s + V_g$

Mass of Content of Drum

Mass of water, $M_w = 25kg$, mass of cement, $M_{ce} = 50kg$.

Mass of sand is

$M_s = \rho_s * V_s$

where, M_s = mass of sand, $\rho_s = 1{,}455kg/m^3$ = dry loose bulk density, DLBD of sand (Leinov, Lowe and Cawley, 2015).

Mass of granite, M_g, ρ_g = DLBD = $1{,}680\ kg/m^3$ (Yun, Jeong and Youm, 2014).

Total mass of content in drum is

$M_{tc} = M_w + M_{ce} + M_s + M_g$

where, M_{tc} = total mass of content in drum, M_{ce} = mass of cement.

Mixing Force

The mixing force is given in equation (9) by (Sin, 2018)

$$F_m = (M_{tc+d})g \qquad \textbf{(9)}$$

where, F_m = mixing force, M_{tc+d} = total mass of content in drum and mass of empty drum, g = acceleration due to gravity.

Torque and Power Requirement at the Drum

Power can be found from equation (10)

$$P = Fv \qquad \textbf{(10)}$$

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where, P = power, F = force, v = speed.

$v = \pi D_d N/60$

hence,

$v = (2\pi N/60) * R_d$

where, N = rotational speed, R_d = radius, D_d = diameter

and the torque, $\mathcal{T}$, is

$$\mathcal{T}_d = F * R_d \quad (11)$$

The average diameter of the drum is

$D_{avd} = (D_{uf} + D_c + D_{Lf})/3$

where, D_{avd} = average diameter of drum, D_{uf} = diameter of upper frustrum, D_c = diameter of cylindrical section, D_{Lf} = diameter of lower frustrum

The power relation can also be presented as in equation (12)

$$P = \mathcal{T}\omega \quad (12)$$

where $\omega = 2\pi N/60$ = angular speed, and $N = 25rpm$, so that, assuming an efficiency of transmission of 0.93, then the actual power required will be

$P + loss$ (at the drum)

Engine Specification

Using equation (12), then engine torque, $\mathcal{T}_e$ can be found

The specification of the engine is

Power = 4.84kW

Torque = 17.78Nm

Speed = 2,600 rpm

Design for Belt and Pulley

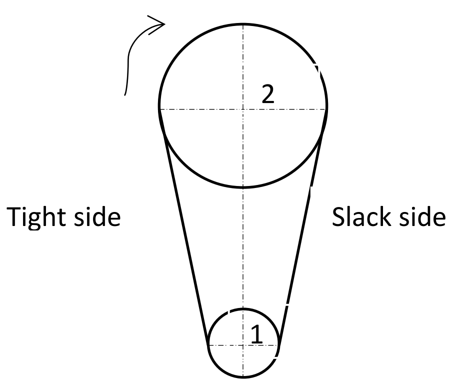

Figure 2: Belt drive 1

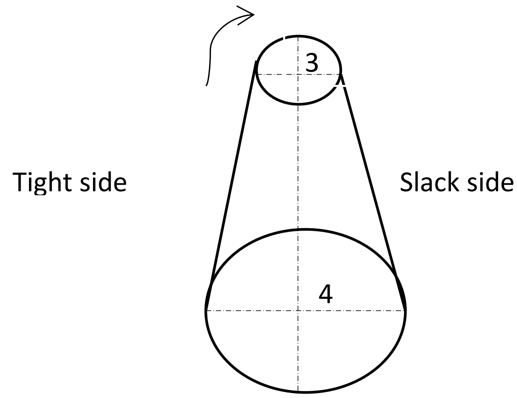

Figure 3: Belt drive 2

Speed of ratio for belt drive is given in equation (13) by (Sin, 2018)

$N_2/N_1 = d_1/d_2$ **(13)**

From the configuration of the compound belt drive as seen in Figures 2 and 3, where, $N_1 = 2600rpm$ = rotational speed of pulley 1, N_1 = rotational speed of pulley 2, $d_1 = 101mm$ = diameter of pulley 1, $d_2 = 386mm$ = diameter of pulley 2, $d_3 = 77.4mm$ = diameter of pulley 3, $d_4 = 440mm$ = diameter of pulley 4

$N_2 = N_1 * d_1/d_2$

For this design $N_3 = N_2$ = 680.31 rpm, and

$N_4 = N_3 * d_3/d_4$

where, N_3 = rotational speed of pulley 3, N_4 = rotational speed of pulley 4.

Center distance between belt drive 1, c_1,

$c_1 = (d_1 + d_2)/2 + d_1$ **(14)**

Length of first belt, L_{b1},

$L_{b1} = 2c_1 + \pi(d_1 + d_2)/2 + (d_1 + d_2)^2/4c_1$ **(15)**

Angle of contact for belt and pulley (drive 1)

$\theta = 180 - 2\beta$ **(16)**

where, θ = angle of contact, β = angle of lap, so angle of lap for belt 1, β_1 is

$\beta_1 = sin^{-1}(d_2 - d_1)/2c_1$ **(17)**

Tension in the Belt drive 1

$2.3\, T_1/T_2 = e^{\mu\theta}$ **(18)**

where, T_1 = tension on tight side of belt 1, T_2 = tension on slack side of belt 1, μ = coefficient of friction.

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Expressing the power as in equation (19)

$$P = (T_1 - T_2)\, v \quad (19)$$

Since, $v = 2\pi Nr/60$, where, $r = r_1$ = radius of pulley 1 = $d_1/2 = 0.101/2 = 0.051m$, $N = N_1$

$$T_1 - T_2 = 348.56\text{N} \quad (20)$$

From equations (18) and (20), T_1 = 1,344.27N and T_2 = 995.71N.

Center distance between belt drive 2, c_2

$$c_2 = (d_3 + d_4)/2 + d_3$$

Length of second belt, L_{b2}

$$L_{b2} = 2c_2 + \pi(d_3 + d_4)/2 + (d_3 + d_4)^2/4c_2$$

Angle of contact for belt and pulley drive 2

$$\beta_2 = sin^{-1}(d_4 - d_3)/2c_2$$

where, β_2 = angle of lap for belt 1.

Tension in the Belt drive 2

$$T_3/T_4 = e^{(0.3*2)/2.3} = 1.29 \quad (21)$$

where, T_3 = tension on tight side of belt 2, T_4 = tension on slack side of belt 2

$$P = (T_3 - T_4)\, v \quad (22)$$

Since $v = 2\pi Nr/60$, where, $r = r_3 = radius\ of\ pulley\ 3 = d_3/2 = 0.0774/2 = 0.039m$; N = N_3

$$T_3 - T_4 = 1{,}620.05\text{N} \quad (23)$$

From equations (21) and (23), T_3 = 7,206.43N and T_4 = 5,586.38N.

Shaft Design

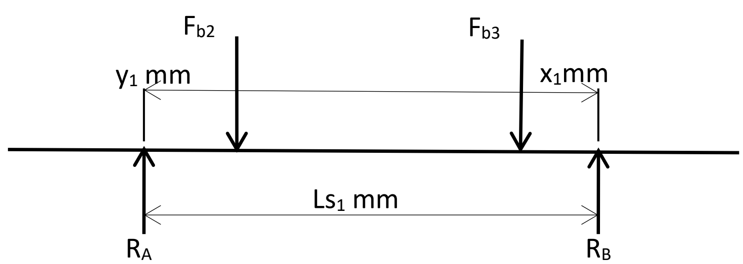

Figure 4: Shaft 1 through pulleys 2 and 3

The loads, F_{b2} and F_{b3} acting on pulleys 2 and 3 are

Pulley 2:

$$F_{b2} = T_1 + T_2 \quad (24)$$

F_{b2} = load acting on pulley 2

Pulley 3:

$$F_{b3} = T_3 + T_4 \quad (25)$$

F_{b3} = load acting on pulley 3

The torque acting on pulleys 2 and 3 are

Pulley 2:

$$\mathcal{T}_{b2} = (T_1 - T_2)r_2 \quad (26)$$

where, r_2 = radius of pulley 2, $\mathcal{T}_{b2}$ = torque acting on pulley 2

Pulley 3:

$$\mathcal{T}_{b3} = (T_3 - T_4)r_3 \quad (27)$$

where, $\mathcal{T}_{b3}$ = torque acting on pulley 3

The total torque is

$\mathcal{T}_{b(2+3)}$

Σ Moment about A = 0

$$R_{Bb} * L_{s1} - F_{b3} * Lx_1 - F_{b2} * y_1 = 0$$

where, R_{Bb} = reaction at bearing point B, F_{b2} = load acting on pulley 2, F_{b3} = load acting on pulley 3, L_{s1} = length of shaft 1.

The maximum bending moment for the shaft 1 is

$$BM_{s1} = (R_{Ab} * (L_{s1} - x_1) - F_{b2}(L_{s1} - (x_1 + y_1)) \quad (28)$$

where, R_{Ab} = reaction at bearing point A, BM_{s1} = maximum bending moment of shaft 1

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Since shaft is subjected to combined bending and twisting loads, the maximum shear stress theorem can be applied as

$d_{s1} = (32 * n_s/\pi * s_y * (M^2 + T^2)^{1/2})^{1/3}$ **(29)**

$n_s = n_1 * n_2; n_1 = 3$, and $n_2 = 3$ are safety factors for both ultimate loads ($n_1 = 3$)and material characteristics ($n_1 = 3$) (Bouchama, 2016); minimum yield strength for material (A36 carbon steel alloy) = 250MPa = s_y

where, d_{s1} = shaft 1 diameter, M = BM_{s1} = maximum bending moment, T = $\mathcal{T}_{b(2+3)}$ = maximum torque on shaft.

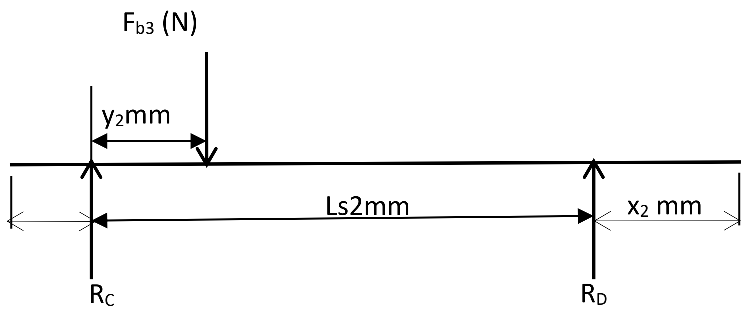

Figure 5: Shaft 2 through pulley 4

The torque acting on pulley 4 is

$\mathcal{T}_{b4} = (T_3 - T_4)r_4$ **(30)**

where, r_4 = radius of pulley 4, $\mathcal{T}_{b4}$ = torque acting on pulley 4

Σ Moment about D = 0

$(R_C * L_{s2}) - F_{b3} * (L_{s2} - y_2) = 0$

where, R_{Cb} = reaction at bearing point C, L_{s2} = length of shaft 2.

The maximum bending moment for the shaft 2, BM_{s2} is

$BM_{s2} = R_{cb} * y_2$

Using equation (27) the shaft 2 diameter, d_{s2} can be found.

Gear Design

The relations for the reference diameter of the bevel driver gear 1 is given in equation (31),

$D_{ref} = Zm_{od}$ **(31)**

where, m_{od} = 6mm = module used, D_{ref} = reference diameter, Z =12 = number of teeth; then,

From equation (13) the reference diameter of the driven bevel gear is

$D_{g2} = N_{g1} * D_{g1}/N_{g2}$

where, D_{g1} = reference diameter of driver bevel gear; D_{g2} = reference diameter of driven bevel gear; $N_{g1} = N_4 = 119.67rpm$ = speed of driver bevel gear; $N_{g2} = 25rpm$ = speed of driven bevel gear.

From the gear ratio relation, the number of teeth is given as,

$$Z_{g2} = Z_{g1} * D_{g2}/D_{g1} \quad (32)$$

$Z_{g1} = 12$ = number of teeth on driver bevel gear; Z_{g2} = number of teeth on driven bevel gear.

Mixer Axle Design

Figure 6: Mixer axle

Modelling the axle as a cantilever beam with uniformly distributed load as shown in Figure 6, then the bending moment relation at section X-X at a distance x from the fixed end has been given in equation (31),

$$BM_{ax} = -W_i/2 * (L_{ax} - x)^2 \quad (33)$$

The load intensity is

$W = F_m/ L_{ax}$ (N/mm), and the bending moment is

$BM_{ax} = -W * (L - 0)^2/2 \ in \ (Nmm)$

where, W_i = load intensity $(N/m \ or N/mm)$, $L_{ax} = 350mm = length \ of \ axle.$

Using the torque of the mixing load in the drum of 1,728Nm (or 1,728,000Nmm) and using equation (28), then the diameter of the axle can be found.

Bearing Selection

Mass of shaft is given as

$M_{s1} = \rho * V_{s1}$

where, M_{s1} = mass of shaft 1; $\rho = 7{,}800kg/m^3$ = density of material (A36 steel); V_{s1} = volume of shaft 1. The volume of shaft 1 is

$$V_{s1} = \pi d_{s1}^2 L_{s1} \quad (34)$$

The weight of shaft 1, W_{s1} is

$W_{s1} = M_{s1} * 9.81$

Also the volume, mass and weight of shaft 2 are

V_{s2}, M_{s2} and W_{s2} respectively.

Assuming the load reactions at bearings of shafts 1 to be the combined loads on the pulleys and shaft 1 weight; also the loads reactions at bearings of shafts 2 to be the combined loads on the pulleys and shaft weight.

Also, assuming the weight of each of shaft to be acting through its centre of gravity, and the weight equally distributed at the reactions, then the reactions at shaft 1 bearings R_{Ab} and R_{Bb} are

$$R_{Ab} = R_A + (W_{s1}/2) \quad (35)$$

$R_{Bb} = R_B + (W_{s1}/2)$ **(36)**

The reactions at shaft 2 bearings R_{Cb} and R_{Db} becomes

$R_{Cb} = R_C + (W_{s2}/2)$ **(37)**

$R_{Db} = R_D + (W_{s2}/2)$ **(38)**

Shaft diameters, speeds, misalignment, radial loads, axial loads and environmental condition (contamination) are among considerations for bearing selection. Cylindrical roller bearings have been selected to support shaft 1 and 2 respectively. These bearings can support above the high radial loads of the belt and reactions, being able to take some axial load or displacement, and their limiting speeds are way beyond the speeds encountered in this concrete mixer project.

Cost Consideration

Cost of imported mixers and the constructed machine would have to be compared to determine their affordability. Inflation in the Nigerian economy has risen, and for all items (year on change), the values for the years 2021, 2022 and 2023 according to Central Bank of Nigeria (CBN) data are shown in Table 1. The inflation rate relation given in equation (39) can be applied to find the current cost of the fabricated mixer.

$I_{fr} = (C_c - C_p)/C_p) * 100$ **(39)**

where, I_{fr} = inflation rate, C_c = current cost, C_p = previous cost

Table 1: Inflation Rate in Nigeria

All Items (year on change)	January	October	November	December		Year
Inflation (%)	-	15.99	15.40	15.53		2021
	-	21.09	21.47	21.32		2022
	21.82	-	-	-		2023

Source: CBN

RESULTS AND DISCUSSION

Table 2: Design Results

Drum	Volume of Drum (mm^3)	Volume of Content (mm^3)	Diameter of Drum (mm)	Mass of Content (kg)	Mixing Force (N)
	4.45×10^8	3.75×10^8	580	556.5	5958.6
	Rotational Speed (rpm)	Torque (Nm)			
	25	1728			

Belt Drive 1		Diameter (mm)	Speed (rpm)	Length (mm)	Centre Distance (mm)
	Pulley 1	101	2600		344.5
	Pulley 2	386	680.31		
	Belt			164	
Belt Drive 2	Pulley 3	77.4	680.31		336
	Pulley 4	440	119.67		
	Belt			168	
Axle		91		350	
Shaft	Shaft 1	40		100	
	Shaft 2	60		280	
Bevel Gear				Number of Teeth	
	Driver	72	119.67	12	
	Driven	344.65	25	58	
Bearing		Bore x Outer Diameter x Thickness (mm)			
	Bearing on Shaft 1	40 x 68 x 15			
	Bearing on Shaft 2	60 x 95 x 18			
Engine	Torque (Nmm)	Speed (rpm)	Power (kW)		
	17,780	2600	4.84		

Table 3: Cost Comparison

Mixer	Year	Capacity (Litres)	Batch (Litres)	Cost (N)	% Average Cost Reduction
Imported	2023	400	-	1,300,000.00	-
	2023	400	-	1,200,000.00	-
	2023	400	260	1,350,000.00	-
Locally Fabricated Adjusted for Inflation	2023	450	380	887,260.11	30.70
Locally Fabricated	2020	450	380	520,000.00	-

The concrete mixer for a 50 kg of cement, and aggregate has been found to have a drum volume and content volume (batch) of 4.45×10^8 mm^3 (450 litres) and 3.75×10^8 mm^3 (380 litres) respectively, and mixing force of 5958.6N with drum rotating at 25 rpm (Table 2). It was also predicted that the rotational speed of pulleys 1 and 2 of drive belt 1 were 2600 rpm and 680.31 rpm respectively with a belt length of 344.5mm; those of pulleys 3 and 4 of drive belt 2 were 680.31 rpm and 119.67 rpm accordingly with a belt length of 336 mm. Results showed that the diameter of shaft 1 connected through pulley 2 was 40mm with a length of 100 mm, and the diameter of shaft 2 connected through pulley 4 was 60 mm with length of 280 mm. The bevel driver and driven gear remodeled speed values at 119.67 rpm and 25 rpm respectively have enabled a lower power requirement of 4.84kW compared to a previous design. Table 3 shows that a significant reduction of an average 30.70% in cost was observed for the fabricated mixer at its cost of N887, 260.11 compared with the imported machines.

CONCLUSION

It was found that the volume of the drum for mixing a 50 kg of cement, and aggregate was 450 litres with a batch capacity of 380 litres. Shafts 1 and shafts 2 were found to be 40mm and 60mm respectively, and the low speed design of the drum at 25 rpm would enable a power requirement of 4.84 kW for the machine. In its contribution, this project proved that locally fabricated concrete mixers can be much less expensive compared to imported ones by an average 30.70%.

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