

DEVELOPMENT TESTING AND EVALUATION OF A PROTOTYPE GEAR-DRIVEN DOUGH KNEADING MACHINE

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Abstract

The performance evaluation of a dough kneading machine developed and fabricated for domestic use and small scale baking was carried out. The machine consists of two rollers vertically aligned, a worktable, wooden frame and meshing gears and a crank lever arm. The machine was constructed and tested at no load and full load capacity. Some design consideration of importance includes viscoelastic properties of the material and operating time. The test result revealed a kneading efficiency 74.26% kneading capacity of 0.01kg/sec and 2.69% average percentage dough snapback. There is also a linear relationship between dough material and operating time.

Keywords

Ergonomics, dough, kneading, rheology, viscoelasticity

Introduction

The development of a gluten structure often referred to as "kneading" in dough (a mixture of flour and water with other ingredients) involves the stretching and folding of dough until its consistency becomes smooth. Kneading (formation of gluten) is an essential part of baking processes and its overall success stems from the material from which

the flour is made. Crop products such as wheat, rye, etc. constitute the source of proteins necessary for dough formation, and a significant factor that determines final product quality [1]. Flour obtained from agricultural products is an essential component of bread making processes and a contributor to the level and quality of gluten-forming proteins which depends heavily on the crop variety, agricultural practices and environmental effects [2].

Various means and mechanisms have been involved in kneading process which ranges from manual kneading (use of fingers, wooden rollers, bottles etc.) to simple machines such as knead rollers and more complex kneading machines. Conventionally, development of dough had been by hand mixing of flour, water, yeast and other ingredients in trough or on tabletop. The mixed dough is placed in metal container or troughs to allow the mixed dough to ferment. Manual kneading process is cumbersome and the desired texture is not easily achieved. Energy requirements to operate dough processing technology today is as high as eight horse power (8HP); consequent on this, they are expensive, bulky and capacities far exceed that which is required for domestic use [1].



Figure 1: Manual kneading mechanism a) Hand kneading, b) Wooden hand roller

Many kind of improvised versions of imported kneading machines have been developed, constructed and tested by local fabricators of agro-processing equipment; most of which neglects ergonomic considerations such as operator's working position [3], roller defects (Figure 2), non-uniform sheet thickness, weather variability and products deformation. Any working position which involves an unnatural posture, a twisted trunk or/and extended arm position will create undue fatigue and reduce production output [4, 5].

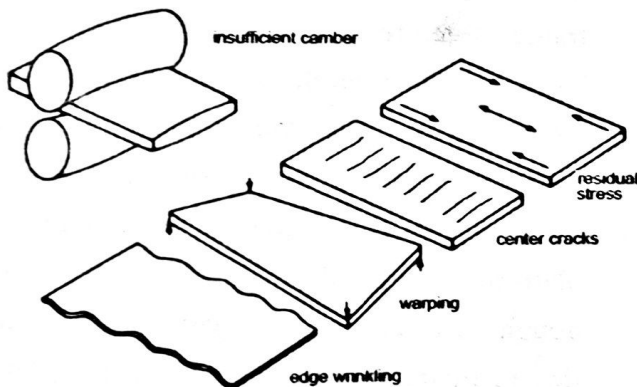


Figure 2: Roller defects on dough sheet [6]

In spite of these few locally fabricated machines, most of the processes involved in dough baking in Nigeria still largely utilize Manual Materials Handling (MMH) which continues to represent a major source of labour shortage in the workplace [4, 1]. The manual hand kneading operations are generally energy sapping, unhygienic (product wise),

inconvenient and characterized by low output and losses up to approximately 30% of incidences and direct costs [7, 4, 8].

A critical appraisal of locally available kneading machine indicated a necessity of improving on ergonomics design system complexity and roller clearance adjustability. The objective of this work is to design and construct a spur gear driven hand powered dough kneading machine with adjustable spring loaded roller bearing block mechanism for sheeting adjustment and stress relief during over-load cycles (machine handling a load beyond the designed safety factor and load carrying capacity) and roller aperture variability during kneading.

Materials and Method

Design considerations

Design considerations and assumptions made of essence include

1. Dough is assumed to be a nonlinear viscoelastic material [9, 10].
2. The dough is assumed to have sufficiently large viscosity to prevent the ascent of gas cells, and remain extensible for a long enough time during baking to avoid premature rupture of membranes between gas cells [11, 12].

3. Dough extensional rheological applications (mixing and sheeting) are assumed confined to a single or a limited range of strain rates. These strain rates are assumed larger than those associated with bread making being that it is extremely difficult to maintain regular extensional deformation at slow rates which is characteristic of bread making [13, 14].

General design and machine description

The major design component of the machine consists of a frame on which two rollers and the worktable were mounted. The two rollers, made from steel plated pipe, 320mm long, 76mm diameter, and approximately, 3mm thick; a driving shaft 350mm long, 16.6mm diameter and two pieces of mild steel washers to provide support on shaft and also limit the bending stress on the rollers were supported on spring loaded bearing blocks. The schematic diagram of the dough kneading machine is presented in Figure 3.

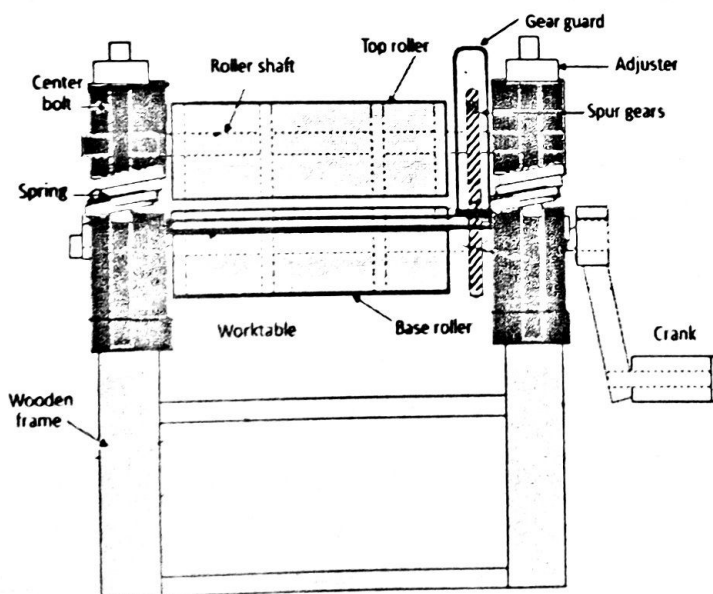


Figure 3: Schematic drawing of the roller machine

The two base bearing blocks (made of hard wood) mounted on the frame provide supports for the kneading head and the compression springs. The top bearing blocks provide support for the top roller which is spring loaded to adjust roller clearance between the top and lower rollers. The clearance adjuster is provided with four set of winged nuts on the two top bearing blocks to ensure easy of adjustment to achieve desirable thickness. The main drive shaft is integrated in the lower roller mounted on a spring loaded wooden block bearing on the frame. Two spur gears in mesh arranged laterally continually engage the two roller shafts with provision for adjustment without mesh disengagement. The spur gear constantly transmits power between the two rollers in opposing direction without direct contact.

A detachable hand crank is keyed to the right hand side rectangular end of the lower roller shaft for ease of operation. The frame structure is made of (50x50x5) mm hardwood. The height of the entire machine when mounted on the frame is 800mm, convenient for operators of an average height of 1680mm. The worktable provides a platform 5mm below the lower roller for dough rest. The critical parts that required design were the rollers, shaft, frame, hand lever and the selection of gears and bearings.

Dough kneading operation

The kneading operation is initiated by the operator applying a torque to the handle which transmits the motion to the base roller. This motion is simultaneously transmitted to the top roller through the mixed dough.

During this operation, the dough is placed on the worktable platform and fed into the gap between the two rollers arranged vertically. The rollers pick the dough and compresses it as it is pulled between the roller aperture thus stretching and kneading the dough; subjecting the material to deformation as it is constrained in-between them (Figure 4). This is repeated until a desired texture of dough is obtained

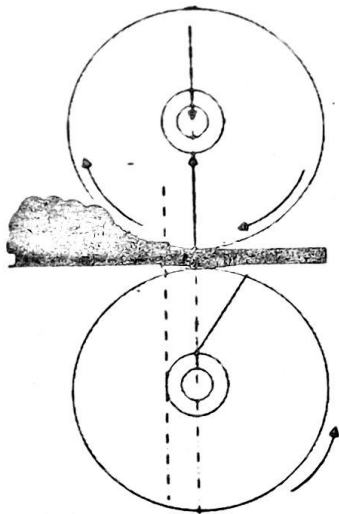


Figure 4: Roller configuration

Roller design

The design of the rollers is analogous to the design of two parallel cylinders in contact under the action of a uniformly distributed stress between the two contacting surfaces. Equation 1 was employed to determine the maximum pressure between the rollers [15].

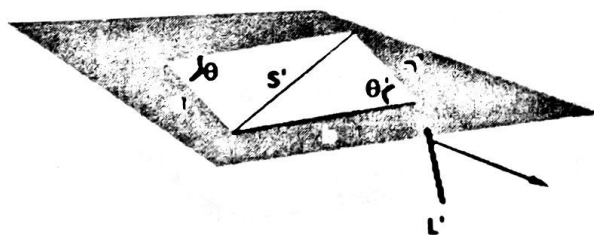


Figure 5: Shape of sheeting

where

L' is the final thickness.

L is the initial thickness;

S is the area of the initial drawn rectangle,

S' is the area of the shape after sheeting, calculated as the sum of the areas of two triangles (Figure 5) expressed mathematically as:

$$S' = \frac{1}{2} x(axb \sin\theta + a'xb' \sin\theta.)$$

where

a and b are adjacent sides of triangles and θ is the included angle of the triangle.

a' and b' are the opposite sides of triangles a and b,

θ' is the opposite angle of θ ,

Performance efficiency: The kneading efficiency was determined evaluating equation 10 [15].

$$\eta_k = \frac{\rho_c}{\rho_{uc}} \dots \dots \dots 10$$

where

ρ_c = Density of compressed dough kg/cm³

ρ_{uc} = Density of uncompressed dough.kg/cm³

Kneading capacity: The kneading capacity was also evaluated from equation 11.

$$Q_k = \frac{\text{Mass od dough (Kg)}}{\text{Time (Sec)}} \dots \dots \dots 11$$

where

Q_k = kneading capacity (Kg/sec)

Machine cost estimation

The cost estimation reflects the cost of production of a unit of the machine which when compare with current market price will help determine the sustainability of the

design [18]. The materials procured were based on the quantity needed for the manufacture of the machine. The cost of labour, local transportation and contingencies were also included in the costing.

Results

Machine description

Figure 6 below shows the prototype machine and the materials of construction were locally sourced. Mild steel and wooden materials were used in the overall construction of the machine except for the worktable constructed of improvised galvanized steel sheet (instead of stainless steel) was used because of the tendency of mild steel to react with dough ingredient.

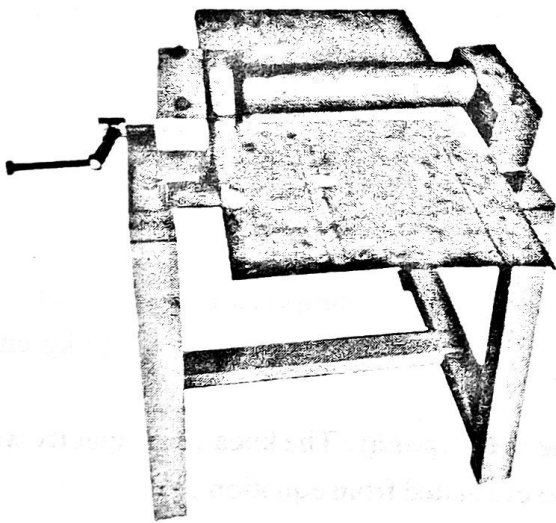


Figure 6: Front view of the machine

The rollers made of galvanized steel pipes were welded by a web at both ends to the shafts. The frame was constructed with 2x3 inches wooden plank while joints and members were fastened together with bolt and nut.

Important machine parameters determined include the maximum pressure

between the rollers determined as 7.24 kN/m^2 , the lower roller drive shaft diameter evaluated 22 mm. dimensions lever arm key, 8mm x 7mm, was obtained for F22mm diameter mild steel shaft. The critical load factor determined is 800kg which far exceeds the working load of 45kg.

Performance test

Performance test was carried out to determine functionality and performance characteristics of the machine include free rotation test and full load test. This is necessary in order to determine the performance characteristics of the machine. Each test description is as follows:

Free rotation test: For the free rotation test, the machine was set to run without load to ensure that there are no abnormalities or noise vibration which may be as a result of improper alignment during construction.

Full load test: To carry out the full load test, 3kg of dough was fed between the rollers and compressed. This was done repeatedly until satisfactory dough texture was achieved. The length of time over which the kneading operation took place was also recorded.

Snapback test: To determine dough snapback, 60mm by 40mm rectangle was drawn with marker near the center of the sheeted dough. The dough initial thickness was immediately measured by a vernier calliper at three different locations after drawing. The average of the three results was recorded as initial thickness L. This process was repeated at desired roller clearances, and similar measurements made of the lengths of

the four sides of the rectangle and the angles between the two sides one minute after resting sheeting.

Efficiency test: The machine performance efficiency and kneading capacity were determined using measured parameters and equations 10 and 11 respectively.

Results and discussion

The result of performance test carried out with 5kg and 7kg of dough is as shown in Table 1. The average densities of the uncompressed and compressed dough are 1217 kg/cm³ and 1639 kg/cm³ respectively. The mean time taken for unit mass of the dough to be kneaded to consistency in manual and machine operation was also noted for three (3) replicates and the result presented in Table 1.

Table 1: Mean physical characteristics of dough and machine performance

Material weight (kg)	Uncompressed volume (cm ³)	Uncompressed density (kg/cm ³)	Compressed volume (cm ³)	Compressed density (kg/cm ³)		Mean time taken (min)	
				Machine	Manual	Machine	Manual
3	2467	1216	1817	1651	1751	4.36	7.12
5	4103	1219	3050	1639	1684	8.69	12.30
7	5759	1216	4303	1627	1698	11.58	16.37

The result of performance characteristic indicates a linear relationship in kneading time with quantity of dough kneaded is shown in Figure 7. From the figure, the time taken for accomplishing kneading reduces as the load feed increases. This indicates that machine performance increases with increase in load.

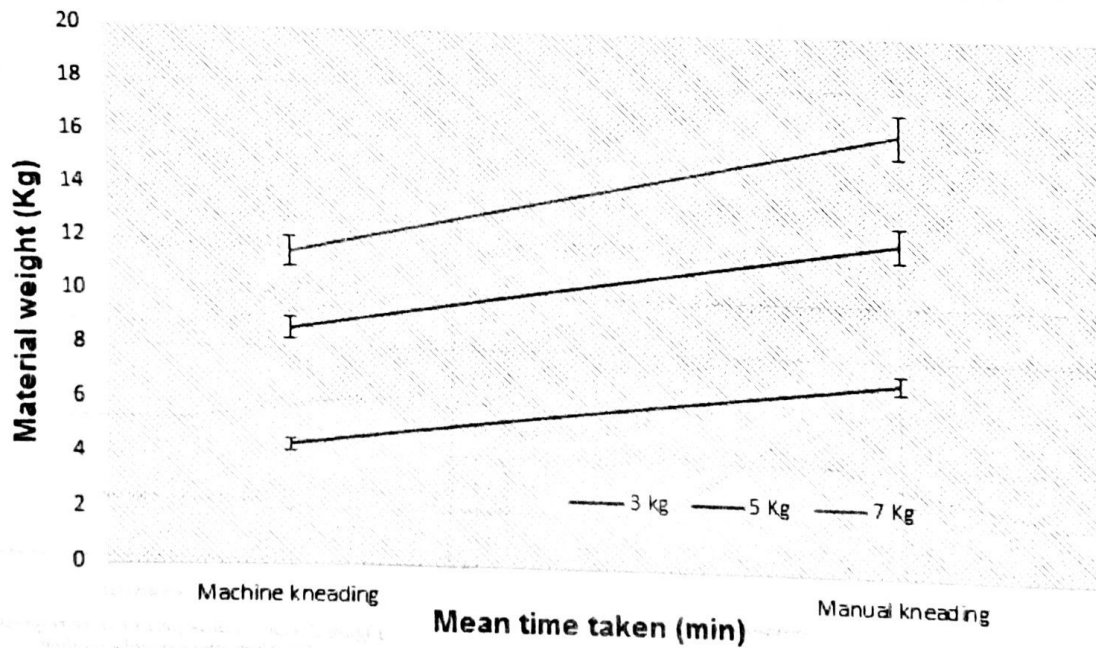


Figure 7: Time response chart to material kneading

Material response to deformation

The material response behaviour to deformation is indicated by the percentage snapback of the dough. This is particularly important avoid premature gas cell rupturing during baking [19, 14]. The sheeted material response to deformation with respect to sheeting gap and roller setting is shown in table 2.

Table 2. Roller settings at full load

Gap settings (h)mm	Roller gap H(mm)	Thickness L(mm)	Snapback (%)
3.0	2.09	2.12	1.63
2.5	2.0	2.06	2.69
2.0	1.8	1.90	2.26
1.5	1.5	1.60	1.99

For the samples tested, the material response is highest at percentage snapback of 2.96% corresponding to 2.5 mm height gap setting while the least deformation occurred when the gap setting is adjusted to 1.5.0 mm height. This is obvious from the viewpoint of the material thickness loaded. Figure 8 indicate the material response to deformation during kneading process. At 3.0 mm setting, the deformation curve experience a sharp decline indicating material failure. This trend is characteristic of all viscoelastic material that fails under load.

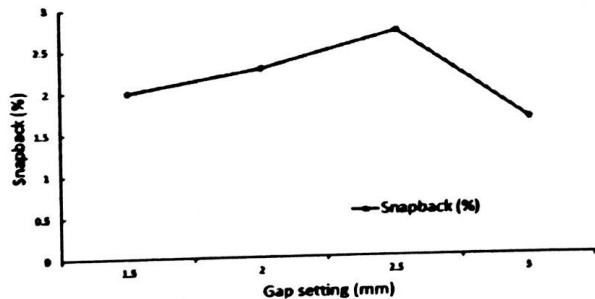


Figure 8: Material response chart to deformation during kneading

Performance evaluation

Table 3 shows the result of the comparison between machine and manual performances.

Table 3: Machine performance

Kneading capacity (Kg/sec)		Kneading efficiency (%)	
Machine	Manual	Machine	Manual
0.012	0.0070	73.65	69.45
0.010	0.0068	74.38	72.39
0.010	0.0071	74.74	71.61

Figure 8 shows the comparative performance responses of manual and machine operations. There is a progressive increase in machine kneading efficiency as the material load increases. This is evident by the linearity of the efficiency curve compare to manual kneading which showed some level of inconsistency in efficiency drive.

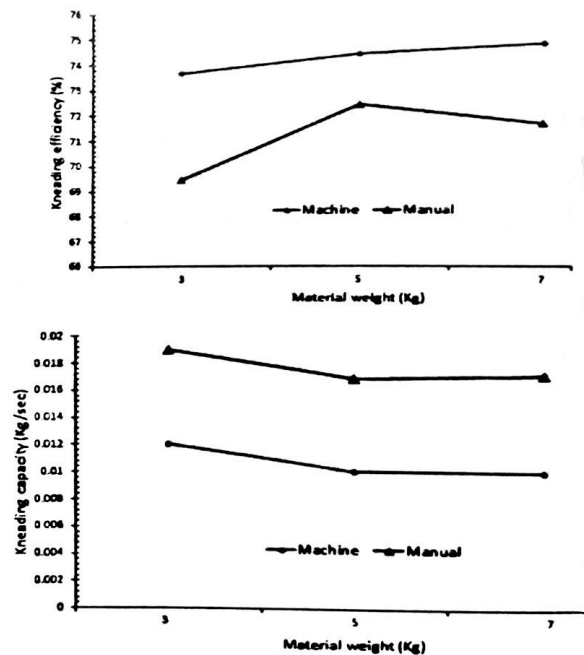


Figure 8: Comparative performance responses of machine and manual kneading

The graph also indicate a higher efficiency (74.26%) for machine operation. The kneading capacity of the machine evaluated from data result is 0.010kg/sec

Machine cost estimation

The estimated costs of material and personnel in the construction of the dough kneading machine to be N8, 430.00 which is has better cost effectiveness compare to literatures [1].

Conclusions

In this paper, some considerations had been used in the design and construction of a kneading machine and its performance evaluated and represented. The sheeting of the samples and the material time based characteristic imposed an empirical relationship between deformation conditions (response to failure strain). The viscoelastic property of the dough was evident from the snapback test which shows similar response trend of established model systems. The cost of machine production estimated at N10, 000.00 is cheap and affordable for small scale catering business.

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