Design and Prototyping of a Low-Cost Manually Operated Bamboo-Cored Incense-Stick Making Machine[1]

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Abstract* - The design and prototyping of a low cost hand-operated incense-stick making machine to alleviate the labor intensive work associated with the production of bamboo-cored incense sticks is outlined in this paper. The machine is based on the mechanism of extruding the incense stick paste over the bamboo stick. The main components of this machine include a hand-crank, a compound gear-train system, rack and pinion system and an extruder. As the paste used is of a semi-solid nature and a high force was needed for extrusion, a confined compression test using Universal Testing Machine was carried out to obtain rough estimates of the force required for the extrusion. During this experiment a known force was applied, varied and exerted on the rack until the paste was extruded out of the die. Using this force estimate, a suitable two-stage compound gear-train system with mechanical advantage of 9:1 and a hand-crank was designed. The lever and gear-train system was designed ergonomically so that the applied force results in a minimal arm-muscle fatigue for the operator.

***Keywords-* incense-stick machine; extrusion; gear-train; mechanical advantage; rack and pinion**

I. INTRODUCTION

Incense-stick making machines that are currently available in India remain unaffordable to many poor workers who continue to make them manually by smearing the paste, which is a mixture of charcoal powder, wood powder and binding agent, around a bamboo stick. Such labor intensive work mostly involves about half a million poor women in rural and urban slum areas across India as reported in [1]. To aid the process of incense-stick making and to mitigate the issue of health problem arising from working for more than 8 hours a day in degraded workspaces and also to boost the income of poverty-stricken women workers, a hand-driven mechanism has been developed. The motivation for developing a low-cost solution to alleviate their problems and to boost their incomes originated when the first author of this paper made need-finding feasibility trips to various slum areas in Bengaluru, India only to witness that most of the women dwellers and their daughters who were involved in incense-stick making made them with their bare hands. Even more disturbing is the fact that these workers face severe the health hazards ranging from bruising of palm-skin to back-pain problems and are paid a pittance for such arduous work. A machine that will reduce the labor of incense-stick making is desperately needed as about 0.5 million women workers in India are involved in the industry as recommended in [2]. Development of such a machine will not only aid these workers in making incense-sticks but will also provide livelihood opportunities for other poor women workers who are either unemployed or are involved in challenging and labor-intensive non-cottage industries. With such a machine they will be able to make more sticks in the same given time, eventually earning more money. Various mechanisms have been developed in many Asian countries such as Vietnam, China etc to produce incense sticks which usually do not have bamboo cores. However, in India incense-sticks with bamboo core is very popular. A mechanism to produce such incense-sticks having a bamboo core was developed recently but the prohibitive cost and limitations make it an unviable solution. Market search of available electric incense-stick machines shows that most worked on principle of extrusion wherein the continuous streaming of paste and bamboo stick feed was easy to design. In view of the sporadic power outages in rural India, electric machines are also not viable. Most of the machines are too large to be used within the small living spaces of these workers' homes. The cost of an automatic incense-stick machine, pedal-driven machine, motor-driven semi-automatic machine, shown in Fig. 1(a)-(c), starts from INR 80000, INR 20000 and INR 32000 respectively.

The challenge then was to develop a machine that is affordable, hand-operated (so that workers did not lose their work during erratic electricity supplies in the rural areas), be of small-size to be stored in their little home, that should be easy to maintain and clean, and more importantly that one which will produce uniformly coated and high quality incense-sticks. In view of these constraints, a low-cost hand-operated incense stick making prototype was conceived and built after several design iterations. Details of this machine which is currently being field-tested in rural areas near Ahmedabad

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(a) Motor-driven, fully-automatic

(b) Pedal-driven, semi-automatic

c) Motor-driven, semi-automatic

Fig. 1. Types of incense-stick making machines that are available in the market

will be outlined in the subsequent sections.

II. PROTOTYPE EVOLUTION

The manual process of incense-stick making was analyzed to design the machine with working principle to be in line with the manual action. The manual process involves several stages such as smearing of incense paste, which is basically a mixture of charcoal powder, wood powder and binding agent, around a bamboo stick, as shown in Fig. 2. Several ideas were developed based on the given constraints.

First two prototypes which were developed had the working principle of smearing action of paste onto the bamboo stick. The first prototype, as shown in Fig. 3, would essentially flatten the paste, cut long strips of paste using a cutting roller, and then drop the strips into the gap between cylindrical roller and the wall. When stripes are in the gap, the bamboo stick is manually dropped into the gap and cylinder is rotated, thereby causing the strip to roll onto the bamboo stick. The frictional wooden cylinder and wooden wall would provide the force for the necessary rolling. The second prototype, as shown in Fig. 4, has a similar working principle to that of first prototype but has two rollers instead of one to imitate the manual to-and-fro rolling action of the manual rolling. The to-and-fro rolling is achieved by rotating the two rollers in different directions. The stick is dropped into the gap over the paste strip and by rotating the crank manually the paste is rolled onto the stick. The stick is then passed to the second roller where it is rolled in opposite direction.

(a) Bamboo stick is picked and placed on the wooden board

(b) Incense paste is applied near one end of the stick

(c) A normal pressure is applied on paste by the palm

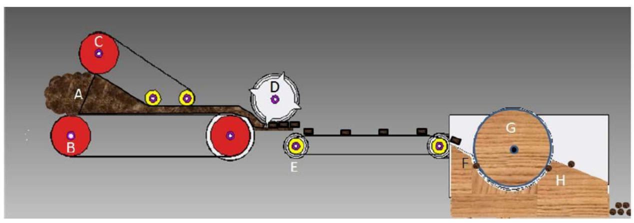
(d) The stick along with paste is rolled back and forth

(e) The paste is spread along the length of the stick

(f) The stick is detached from the paste.

Fig. 2. Stages involved in manual rolling process of incense-stick making

(a) First prototype



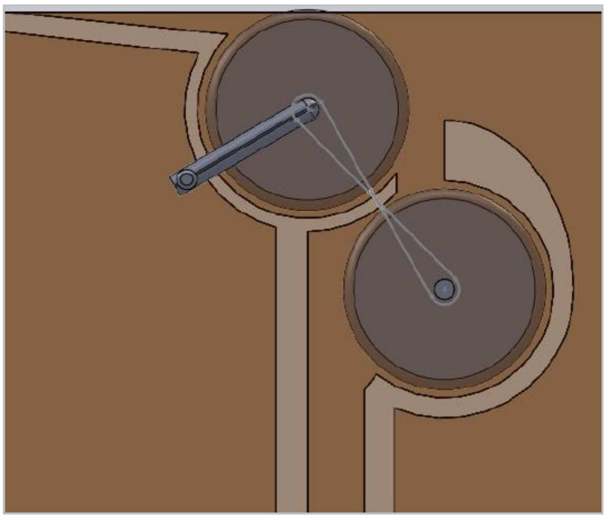
(b) Schematic representation of working process of the first prototype

Fig. 3. First prototypes developed on the principle of smearing of paste onto the bamboo stick using one cylindrical roller

Though these prototypes were able to roll the incense paste onto the bamboo stick, it was realized that the two designs were unreliable as continuous streaming of paste and bamboo stick was not feasible with the task of cutting the flattened paste into long strips and conveying it to the rollers being the difficult part.

A survey of the various electrically operated incense-stick making machines that are currently available in the market revealed that most of these worked on the principle of co-extrusion wherein the continuous streaming of paste and bamboo stick was easier to ensure in the design. A third prototype which worked on the principle of co-extrusion was then developed. Since the incense paste is of semi-solid nature it requires a very high force for extrusion. The prototype was designed to create and sustain high pressure in orders of 5MPa. The final prototype shown in Fig. 5 includes various mechanical components such as a hand-crank, compound gear-train system, rack and pinion system and an extruder.

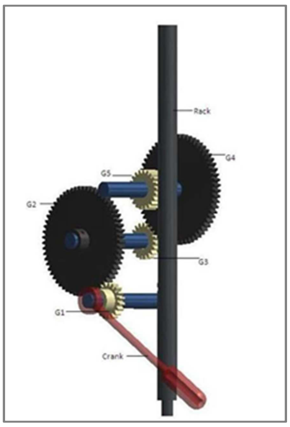
(a) Second prototype



(b) Schematic representation of working process of second prototype

Fig. 4. Second prototype developed on the principle of smearing of paste onto the bamboo stick using two rollers

(a) Third prototype



(b) Schematic representation of Hand-crank, compound gear-train system, rack and pinion system of the prototype.

Fig. 5. Third prototype developed on the principle of co-extrusion of incense paste and bamboo stick.

As shown in Fig 5(b), the hand-crank drives the first gear which further drives the compound gear system. The last pinion drives down the rack which doubles as a piston. The rack pressurizes the incense paste which is fed into the cylindrical pipe and pushes the paste into extruder housing. The extruder housing contains nozzle with central bore through which bamboo stick is fed. A small gap is maintained between the nozzle and the die where the paste comes in contact with the bamboo stick as is show in schematic diagram in Fig. 6. The vertical component of pressure inside the extruder chamber results in coating of the stick with the paste where as the horizontal component pushes the stick outside as the paste is coated to the remaining portion of the stick.

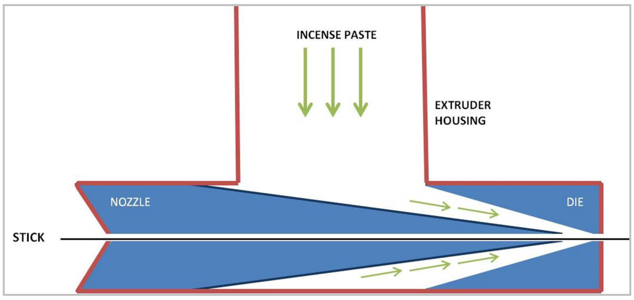


Fig. 6. Schematic representation of the extruder housing containing nozzle and die, and the flow of the incense paste.

III. DESIGN AND DEVELOPMENT

To design a mechanism based on the principle of co-extrusion it was necessary to determine the compressive force required to extrude the semi-solid incense paste through the die. For the same, an experimental set-up, as shown in the Fig. 7, was created and tried on Universal Testing Machine (UTM) from the IITGN Solid Mechanics Laboratory.

A varying compressive force was applied on the rack which further pressurized the incense paste fed into the cylinder until the extrusion of paste through the die occurs.

(a)Initial position during the experimental; the piston is just above the cylinder.

(b) Final position during the experiment; the piston is almost at the end of the cylinder

Fig. 7. Experimental set-up to determine the compressive force required for extrusion is being tried on Universal Testing Machine.

The inbuilt load-cell recorded the magnitude of the applied force and provided a graphical output. The compressive force can be estimated approximately roughly as

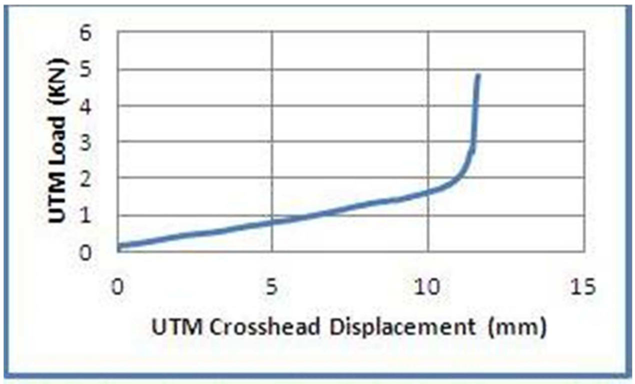
$$F = \frac{K\theta\mu}{XrC} \qquad (1)$$

where θ is the conical angle of the nozzle, μ is coefficient of friction of nozzle surface, r is inner radius of pipe, X is gap maintained between nozzle and die, C is the concentration of water in the incense paste and K is a constant comprising of paste quality and compressibility factor of paste. Fig. 8 shows the results of the controlled experiment on a 35mm pipe for two extreme possible conical angles tested for the nozzle inside the extruder unit shown in Fig. 6, while keeping factors such as the concentration of paste and the gap between nozzle and die constant.

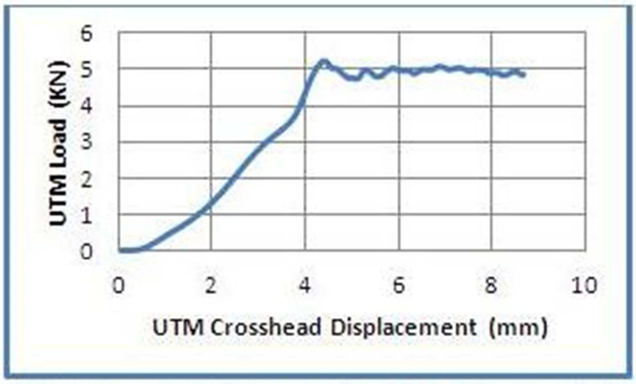
It is evident that about 5KN force is required for the extrusion process. A force of 5.2KN and 4.8KN is recorded when a nozzle of 9.8^0 and 3.3^0 is used respectively, validating the equation (1).

Ergonomically safe force that an average woman worker can apply with her left arm can be considered to be in the range of 140-180N as reported in [3]. Since the machine is to be used for longer durations with less effort, the mechanism was designed with an input force of 50N. For designing a hand-driven mechanism it was necessary to amplify this force 100 times to achieve a force of 5KN. For the same, a two-stage compound gear-train and hand-crank system, shown schematically in Fig. 9, was designed to provide a gear reduction ratio of 1:9. The following Table 1 provides the essential sizing information used in the design.

An output force of 5.1KN is developed by amplifying the input human-arm force of 50N. Note that a single-staged compound gear train system could have been designed but is not used here as one of the gears would have been 10 times larger than it's mating gear making it bigger, heavier and expensive to manufacture. A three-stage compound gear-train system is also avoided for the reason that it will increase the number of gears making the system heavier and expensive.



(a) Loads for nozzle with conical angle 3.3˚; Peak force recorded is 4.8KN



(b) Loads for nozzle with conical angle 9.8˚; Peak force recorded is 5.2KN

Fig. 8. Graphical Load output from UTM showing the peak compressive force required to extrude incense paste from 35mm pipe for nozzles of two extreme conical angle

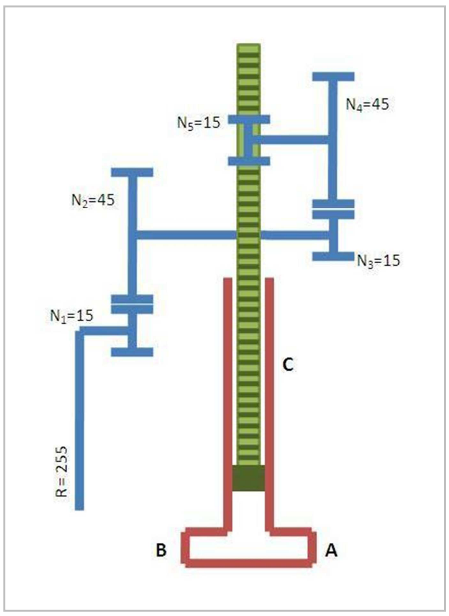


Fig. 9. Levai gear representation of hand-crank + gear-train system designed to amplify small human-arm force into large desired force.

TABLE I. Hand-Crank and Compound Gear Train System

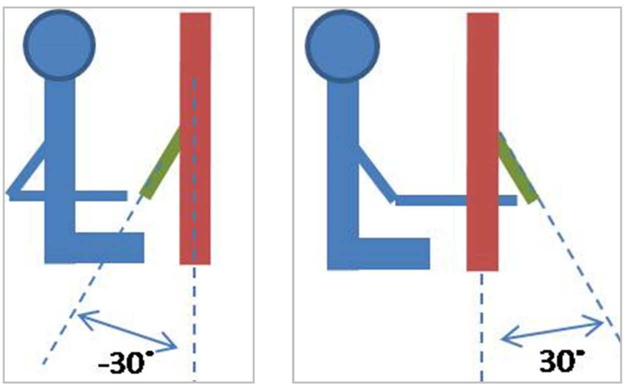
Input Force (N)	50
Handle Length (mm)	255
N1	15
N2	45
N3	15
N4	45
N5	15
Diameter Cylinder (mm)	35
Output Force (N)	5100
Pressure (MPa)	5.3

A reversible ratchet handle is chosen for hand-crank so that a reverse rotation would lift the rack out of the pipe for further feeding of the paste into the pipe. Since the handle is to be attached at middle of the frame, a longer handle, which is also expensive, will increase the height of the machine. The price vs. length comparison of market-ready ratchet handle is given in [4]. Thus, a handle of 255mm in length is chosen. The diameter of the cylinder is chosen to be 35mm which is a standardized size that is easily and cheaply available in the market thereby reducing manufacturing costs.

A. *Hand-crank Rotation Optimization*

The hand-crank rotation is optimized so that it's easier for the operator to rotate the handle and hence extrude the incense-stick in small rotation. The handle rotation also decides the amount of paste that is extruded and hence the size of the incense-sticks that can be extruded. As seen in the Fig. 10, the user while seated in criss-cross-applesauce position could rotate the handle through 60^0 such that the arm of the user remains at same horizontal position.

Consider a schematic representation of an incense-stick as shown in Fig. 11. B being the diameter of the incense-stick, A being the diameter of the bamboo stick, C being the length of stick coated with paste, D being the uncoated length and E being the total length of the incense-stick.



(a) Initial position of the hand-crank; about 30˚ towards the user

(b) Final position of the hand-crank; about 30˚ away from user

Fig. 10. Schematic representation of intended range of hand-crank rotation by the user seated in criss-cross-applesauce position

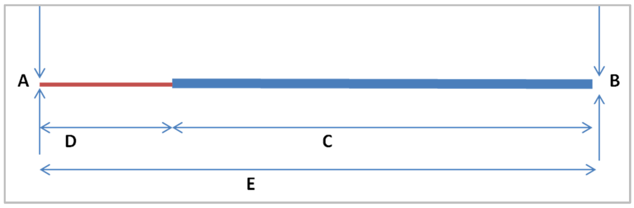


Fig. 11. Schematic representation of dimensions of the an incense-stick

The angle of rotation of hand-crank required for extruding an incense-stick of length E can be expressed as

$$\theta = \frac{1440 N_2 N_4 m (E - D)(B^2 - A^2)}{N_1 N_3 N_5 \pi r^2} \qquad (2)$$

where N_1, N_2, N_3, N_4 and N_5 is number of tooth in gear as shown in Fig. 9, m is module of the pinion which meshes with the rack, and r is inner radius of the pipe wherein paste is fed. The bamboo stick of diameter 2mm is largely produced throughout India and the length of bamboo stick which is not coated with the incense paste is usually about 30mm. Using Eqn. 2, for A = 2mm and D = 30mm and with values from Table I, a parametric representation of incense-sticks of various diameters and lengths that can be produced by limiting the hand-crank rotation to 60^0 can be calculated and represented graphically as shown in Fig. 12. The usable range illustrates the range of incense-sticks of various thicknesses and lengths that can be produced within 60^0 rotation limit. The unusable range illustrates the range of incense-sticks that can be produced above 60^0 rotation limit but is however not recommended. It is evident that incense-sticks of maximum length of 300mm with maximum diameter of 4mm can be produced easily within the given rotation. Likewise, an incense-stick of 100mm length and 7mm thickness can thus be extruded.

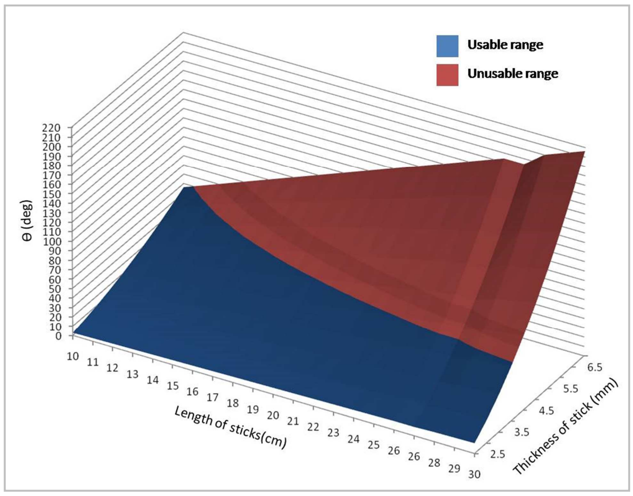


Fig. 12. Range of incense-sticks with various diameters and length that can be produced by the machine

B. *Gear Analysis*

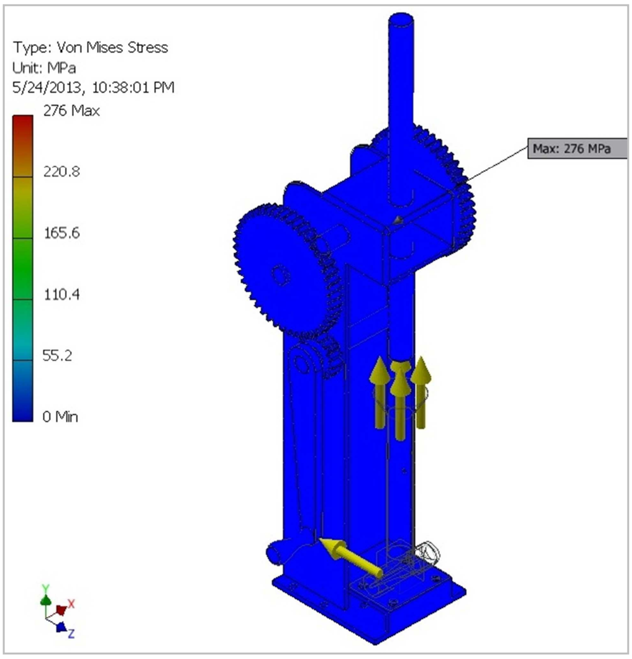
It is evident from the schematic diagram of the gear train system, Fig. 9, that maximum force is experienced by the pinion which meshes with the rack. The tangential force on the gear tooth is in order of 5KN. The bending moment acting upon the gear tooth, when calculated using the defined procedure in AGMA [5] is a function of various factors such as Geometry factors, Application factor, Size Factor, Load Distribution factor, Rim thickness factor, Dynamic factor and more importantly it's a function of face width and module of pinion. A module of 3 and face-width of 20mm gives it a safety factor of 0.82; a module of 3 and face-width of 25mm gives a safety factor of 1.02; while a module of 3 and face width of 40 gives a safety factor of 1.64 which is incorporated for gear design used in this prototype. Note that these results are valid for a bending stress of 323.6MPa (Grade 2 Hardened Steel, 300H_b). It is safe to assume that remaining gears have safety factors higher than the pinion. However the face-width for all the remaining gears is kept at 10mm to cut down the material and manufacturing costs.

C. Shaft Size Optimization and Pipe Selection Analysis

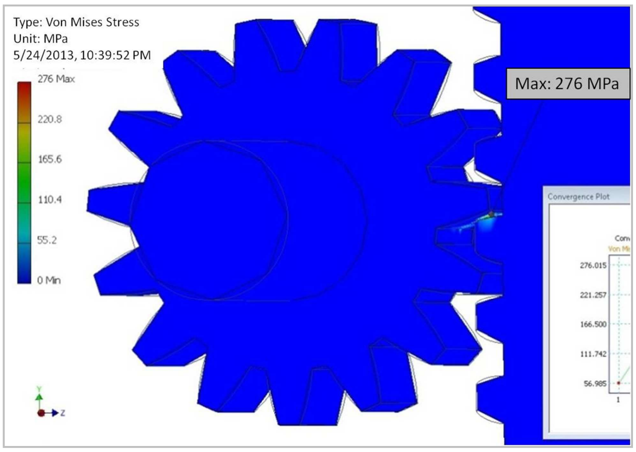
The schematic of the gear train system shown in Fig. 9 consists of three shafts. Each shaft is optimized to use an appropriate amount of material to avoid extra weight and material cost. The shaft experiences tangential force, radial force and moment from the gear and reaction forces from the fixed support. Selecting Mild Steel material, which is cheaper and easily available, and desiring a safety factor of 2 for each shaft, the maximum bending and torsional stress is estimated using ordinary strength of materials analytical methods. The diameter of the shaft is then derived from the estimates of the stresses. On this basis, a 12mm diameter round bar is used for shaft 1, a 21mm round bar for shaft 2 and a 29mm round bar for shaft 3. This completes the rough sizing of the shaft diameters. The stainless steel pipe is used for feeding the incense paste can corrode easily in view of the water content in the paste. The rack exerts a pressure of 5MPa on the incense paste inside the cylindrical pipe. It is assumed that the incense paste exerts the same pressure on the wall. Using stress formulae for a thick-walled cylinder subjected to an internal pressure, a 32 DN 5S (NPS Pipe Sizing) pipe can withstand an estimated maximum tangential stress of 18.5MPa [6]. The selected pipe is this safe from failure as the estimated stress is insignificant when compared to Stainless Steel's yield strength of 520MPa.

D. Stress Analysis Using Finite Element Analysis

Finite element analysis (FEA) is used to estimate the stress on the complete prototype within the framework of *Autodesk Inventor 2013* [7]. The prototype is primarily built using Mild Steel. An estimated force of 100N is applied at the tip hand-crank. Since a pressure of 5MPa is required for the extrusion process it is assumed that the same pressure acts on the rack. Hence, an upward pressure of 5MPa is applied on the rack keeping the base of the frame constrained. Bonded contacts are assigned between moving and fixed components. To keep the estimation of the stress on the pinion simple, the extrusion assembly and the pipe are excluded from FEA. Preliminary FEA of the entire system is performed to determine the areas of high stress concentration. The computation estimates, shown in Fig. 13, shows that the pinion which meshes with the rack experiences the highest stresses and force.



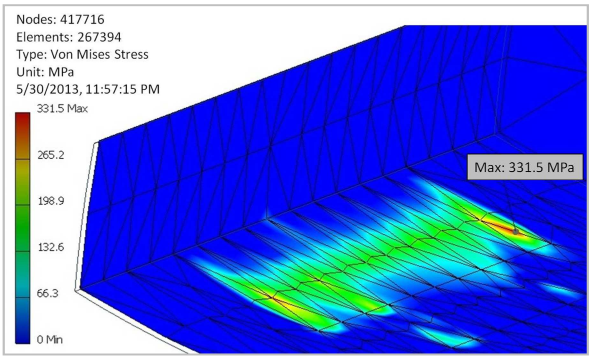
(a) Stress simulation results depicting a maximum stress of 276MPa



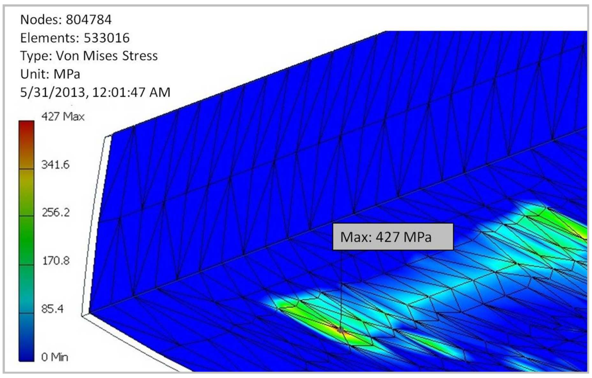
(b) Results depicting the maximum stress being experienced by the pinion tooth

Fig. 13. von Mises Stress results for stress simulation of the system performed in Autodesk Inventor

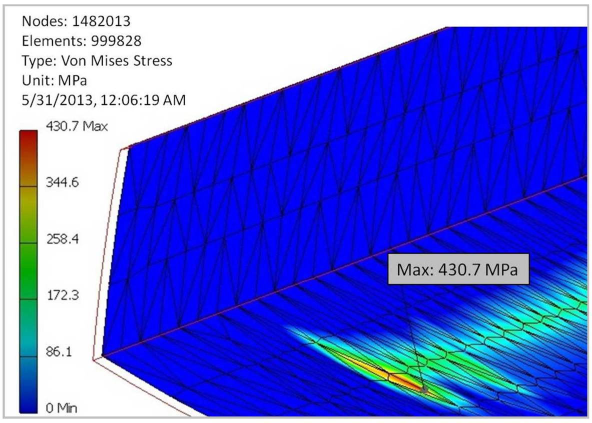
The stress acting on the pinion is computed further by increasing the number of finite elements progressively to estimate the converged estimate of the stress. Fig. 14(a)-(c) shows a zoomed view of pinion tooth region where the variation of the maximum stress from 217.1MPa to 430.7MPa as the number of elements is increased from123189 to 999871 can be seen. The convergence of the computed value of von Mises Stress vs. the inverse of the number of elements shown in Fig. 15 indicates a value of 430.7MPa is reached as the mesh is refined. The factor of safety based on the FEA results is about 0.57 for pinion made of ASTM A36 Mild Steel. If the pinion is made of 1095 Stainless Steel (Q&T 425˚) [8], the factor of safety can be increased to1.8. Computational analysis such as these provides some insight into material selection and its impact on cost effective reliable system performance.



(a) Number of elements- 267415; von-Mises stress- 331.5MPa



(b) Number of elements- 533016; von-Mises stress of 427MPa



(c) Number of elements 999871; von-Mises stress- 430.7MPa

Fig. 14. von Mises stress estimates for different number of elements acting at pinion tooth. The stresses increases as the number of elements is increased

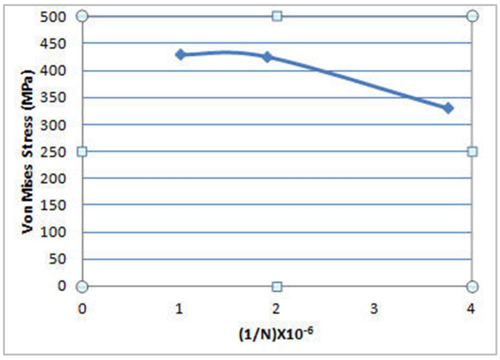
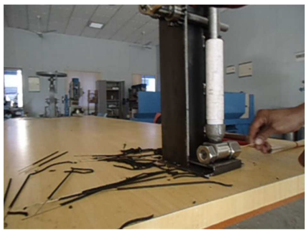


Fig. 15. Convergence of Computed von-Mises Stress

IV. PROTOTYPE TESTING AND RESULTS

Testing of the prototype to assess the quality of the incense-stick extruded indicated the production of incense-sticks with near circular cross-section and centrally placed bamboo stick which is not possible to achieve when these are manually rolled. Fig. 16 shows a series of snapshots of the trial runs conducted by a user. And from these it was observed that a hand-crank rotation of 30^0 is needed to extrude one incense-stick. From video analysis it was noted that it took about 2 seconds for feeding the stick and cranking the handle while it takes 3 seconds for an average women worker to manually roll an incense-stick as detailed in [8] and [9]. A couple of improved prototypes have been installed at a nearby village, about 45 km from Ahmedabad. These prototypes received an enthusiastic response from the women workers. They proposed having a pipe of larger diameter so that large amount of incense-paste can be fed. They also suggested for provision of slight backlash in the gear-train system to cease the extrusion of paste after bamboo stick is co-extruded along with the paste.



(a) The user is feeding the bamboo stick into the nozzle

(b) Bamboo stick is fed until 20% of the stick is outside the die so that its uncoated

(c)The user starts cranking the handle; extrusion iniates

(d) The user rotates the handle by about 30^o such that stick is extruds out of die completely

(e) Incense-sticks being arranged

f) Uniformly coated incense-stick with perfect circular cross-section is produced by the machine.

Fig 16. Snapshots of the trial run being performed on the prototype

V. CONCLUSION AND FUTURE WORK

It has been demonstrated that the mechanism developed makes good quality incense-sticks. The incense stick maker is cheaper than existing machines in the market, is compact making it easier to be kept in a small living space, and is easier to operate. The quality of incense-sticks, various cross-sectional shapes and length that can be produced by the machine cannot be otherwise achieved manually. It is felt that this incense stick maker can succeed as a viable product in India. Innovations such as low cost pedal power and low cost automation to create a motor-driven version of the same machine to mitigate or eliminate the effort expended in manually operating this machine are in the works. It is estimated that this motor-driven mechanism would be still cheaper than the available machines in the market. Intensive field-testing will be carried out in the State of Karnataka where a large number of incense-stick workers are found and the feedback used to improve the machine. The possibility of coupling several of these machines together for parallel operation will be explored as well.

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