The Indonesian Journal of Computer Science
www.ijcs.net
Volume 13, Issue 4, August 2024
https://doi.org/10.33022/ijcs.v13i4.4375

Contact Stress Analysis of Spur Gears and Performance Evaluation in Oat flake Rolling Machine

Chit Ko Ko[1], Htay Htay Win [2], War War Min Swe[3], Aung Kyaw Soe[4]
foxhole.chicz@gmail.com, htayhtayw@gmail.com, warwarminswe288@gmail.com, aungkyawsoe.tu@gmail.com
[1,2,3,4] Department of Mechanical Engineering, Mandalay Technological University,Myanmar.

Article Information

Received : 30 Aug 2024
Revised : 1 Sep 2024
Accepted : 3 Sep 2024

Keywords

Contact Stress Analysis,
ANSYS Software,
gear teeth,
FEA

Abstract

This paper focuses on examining the structural integrity of spur gears within an oat flaking machine. This machine functions by compressing oat grains situated between a pair of horizontally aligned rollers. These rollers, set to revolve at a speed of 400 rpm and a gap of 0.45 mm, process the grains into flakes. The rotation of the rollers is facilitated by spur gears, which are propelled by a belt drive connected to an electric motor. Following a fractional rotation, the processed oats are ejected as flakes. The power transmission between gears occurs through the interaction of meshing teeth. The contact stress on the spur gear is determined using Hertz's theory, and the analysis of contact stress across two meshing spur gear teeth is executed with varying number of gear teeth via ANSYS software. The findings are delineated, and the results from finite element analysis simulations are juxtaposed with theoretical calculations. The theoretical values for effective stress and strain in contact stress analysis are 60.75 MPa and 0.51309×10^{-4}, respectively, while simulation values are 61.78 MPa and 6.1846×10^{-4}. Theoretical and simulation results are nearly the same. Therefore, the design is safe for oat flake rolling machine. The machine's performance was tested with 0.45 mm and 0.6 mm flakes over three days. For 0.45 mm flakes, the average capacity was 28.99 kg/hr with 99.46% efficiency, while for 0.6 mm flakes, it was 48.14 kg/hr with 99.73% efficiency. These results confirm that the machine operates reliably and efficiently at both settings.

A. Introduction

The demand for processed oat products has been increasing due to their nutritional benefits. Efficient oat flake rolling machines are essential for producing high-quality flakes. This research focuses on improving the drive mechanism of an oat flake rolling machine to enhance its performance. Figure 1 shows the components of the oat flake rolling machine.

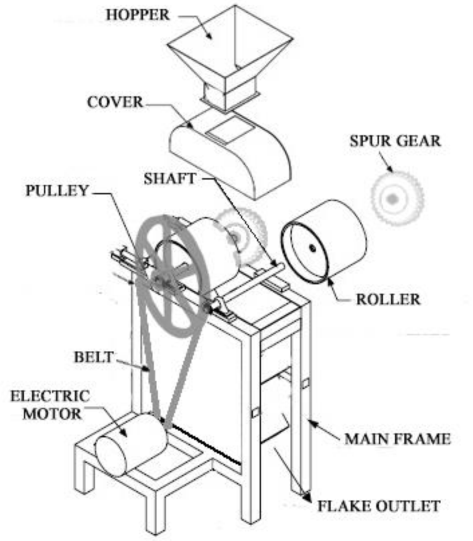

Figure 1. Oat Flake Machine Components

Within the power transmission system of an oat flaking mechanism, gear drives serve as a pivotal method for the transfer of energy between shafts, potentially altering rotational speeds in the process. Amongst gear types, spur gears are prevalent due to their straightforward tooth design and parallel shaft alignment, which ensures consistent speed and torque transmission. Notable for their high efficiency and precision, spur gears are advantageous for their design simplicity, cost-effectiveness in production and maintenance, and lack of axial thrust. Figure 2 illustrate the spur gear teeth.

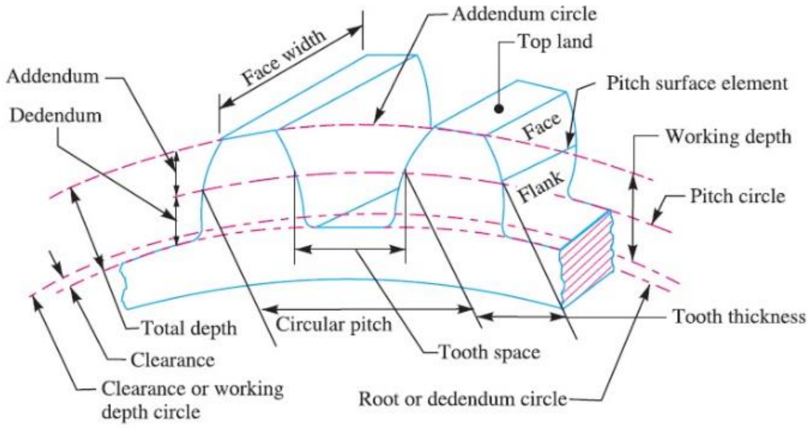

Figure 2. Spur Gear Teeth

The pursuit of enhanced load-bearing capabilities with minimized gear drive weight yet augmented strength in gear transmission has propelled design optimization and gear tooth stress analysis to the forefront of engineering research.

Spur gears are typically utilized to maintain a steady drive ratio, with various stress types manifesting in loaded, rotating gear teeth.

B. Research Methodology

Gear design varies significantly based on its intended application and size requirements. In instances where the dedendum circle diameter marginally exceeds the shaft diameter, particular attention is paid to the gear's structural integrity. The research methodology involves a theoretical structural analysis of the gear, wherein von-Mises stress and effective strain are meticulously computed to assess performance under operational stresses. This analysis is facilitated by the utilization of ANSYS 17 Software, a robust tool for finite element analysis that enables precise simulation of gear behavior under various load conditions.

C. Design Consideration of Spur Gears

The design of spur gears is a systematic process that necessitates a comprehensive understanding of mechanical requirements and operational constraints. Factors such as gear ratio, material selection, tooth profile, and dimensional accuracy are critical in determining the gear's functionality and longevity. This section delves into the various considerations that underpin the design of spur gears. Theoretical models and empirical data converge to inform design choices, ensuring that the gears meet the stringent demands of the oat flake rolling machine's drive system. Table 1 shows the specifications of gear teeth in various number of teeth.

Table 1. Spur Gear Specification

No.	Description	Value	Unit
1.	Pitch circle diameter, D_p	128	mm
2.	Number of teeth	32	-
3.	Pressure angle	14.5	degree

In theoretical structural analysis of spur gear, von-Mises stress and effective strain are calculated.

Circular pitch, $p_c = \frac{\pi D}{T}$ (1)

Diametral pitch, $P_d = \frac{T}{D} = \frac{\pi}{p_c}$ (2)

Module, $m = \frac{D}{T}$ (3)

Actual transmitted load, $W_t = F_t = \frac{P}{v} \times C_s$ (4)

Velocity factor, $C_v = \frac{3}{3+v}$ (for ordinary cut gear) (5)

$y_p = 0.124 + \frac{0.684}{N}$ (6)

Where, D = Diameter of the pitch circle, and

https://doi.org/10.33022/ijcs.v13i4.4375

T = Number of teeth on the wheel
v = velocity of the gear
N = number of teeth
P = Power transmitted

Contact Stress Calculation Using Hertzian Contact Stress Equation

The design of spur gears is informed by the Hertzian contact stress equation. This research investigates the structural behaviors of spur gears, such as von-Mises stress and effective strain, through both theoretical calculations and numerical simulations. Stress analysis is performed on spur gears made from different number of teeth to evaluate their performance under varying conditions.

The contact stress is calculated by using Hertzian contact stress equation which is;

$$\text{Contact Stress, } \sigma_c = \left[\frac{F_t\left(\frac{1}{r_p \sin\phi} + \frac{1}{r_g \sin\phi}\right)}{b\pi\left(\frac{1-\upsilon_p{}^2}{E_p} + \frac{1-\upsilon_g{}^2}{E_g}\right)} \right]^{\frac{1}{2}} \tag{7}$$

Where, F_t =Actual transmitted load,
T = Turning moment on the spur gear
d = Pitch Circle diameter of the spur gear
r_p=radius of the pinion, r_g = radius of the gear
υ_p=Poison ratio of the pinion,
υ_G**=** Poison ratio of the pinion
E_p= Modulus of Elasticity of the pinion,
E_g = Modulus of Elasticity of the gear

$$\text{Principal stresses, } \sigma_{1,2} = \frac{1}{2}\left(\sigma_x + \sigma_y\right) \pm \frac{1}{2}\sqrt{\left(\sigma_x - \sigma_y\right)^2 + 4\tau_{xy}{}^2} \tag{8}$$

$$\text{Von Mises stress, } \bar{\sigma} = \frac{1}{\sqrt{2}}\sqrt{\left(\sigma_1 - \sigma_2\right)^2 + \left(\sigma_2 - \sigma_3\right)^2 + \left(\sigma_3 - \sigma_1\right)^2} \tag{9}$$

$$\text{First principal strain, } \varepsilon_1 = \frac{1}{E}[\sigma_1 - \upsilon(\sigma_2 + \sigma_3)] \tag{10}$$

$$\text{Second principal strain, } \varepsilon_2 = \frac{1}{E}[\sigma_1 - \upsilon(\sigma_1 + \sigma_3)] \tag{11}$$

$$\text{Third principal strain, } \varepsilon_3 = \frac{1}{E}[\sigma_3 - \upsilon(\sigma_1 + \sigma_2)] \tag{12}$$

$$\text{Effective strain, } \bar{\varepsilon} = [\frac{2}{3}(\varepsilon_1^2 + \varepsilon_2^2 + \varepsilon_3^2)]^{\frac{1}{2}} \tag{13}$$

Where, σ_1 = First Principal Stress
σ_2 = Second Principal Stress
σ_3 = Third Principal Stress
υ = Poisson Ratio
E = Young's Modulus

$$\text{Shear Stress } \tau_{xy} = \frac{16T}{\pi d^3} \quad (14)$$

Where, T=Torque acting on the spur gear,

d= diameter of the spur gear

Table 2 shows the theoretical result spur gear calculation. Contract stress value, Von-Misses stress and effective strain values are calculated.

Table 2. Theoretical Result of Spur Gears

No.	**Process**	**Value**	Unit
1.	Circular pitch, P_c	12.56	mm
2.	Actual transmitted load, W_t	278.16	N
3.	Velocity factor, C_v	0.528	-
4.	Lewis form factor, y_p	0.124	-
5.	Shear Stress, τ_{xy}	0.00432	MPa
6.	Contact Stress, σ_C	60.75	MPa
7.	Von Mises Stress, $\bar{\sigma}$ (contact)	60.75	MPa
8.	Effective Strain, $\bar{\varepsilon}$ (contact)	0.513×10^{-3}	-

D. Effective Stress and Strain Calculations Using FEA

The structural behaviors of spur gears, specifically von Mises stress and effective strain, are analyzed both theoretically and numerically in this research using ANSYS software.

Finite element analysis is conducted to assess the impact of tooth count on the gears' structural resilience and deformation, focusing on gears with 28, 30, 32, and 34 teeth to identify the maximum stress and strain tolerances. Additionally, stress analysis is performed on spur gears composed of various materials to determine their durability. Figure 3 shows the 3D model of spur gear contact.

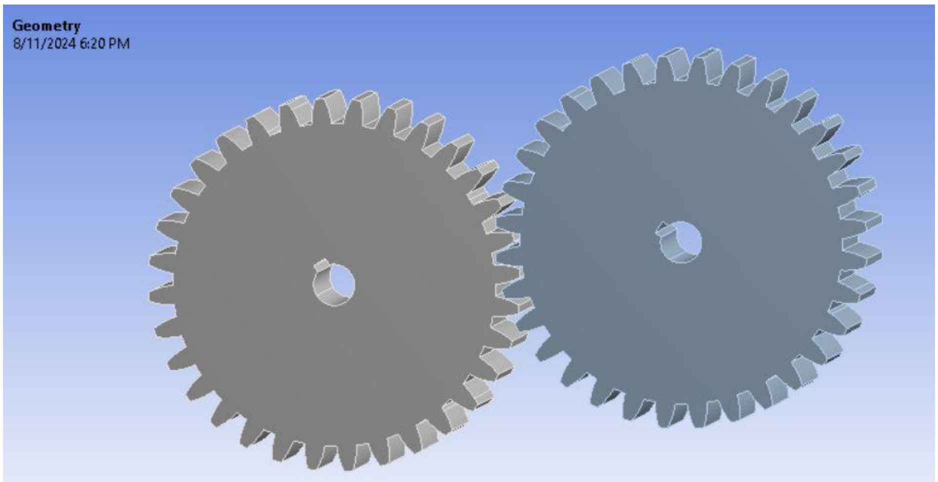

Figure 3. 3D Model of Spur Gear Set

Figure 4 shows the meshing of spur gear contactand This geometry model is meshed using high smoothing, resulting in a quality mesh with 22,926 nodes and 4,110 elements.

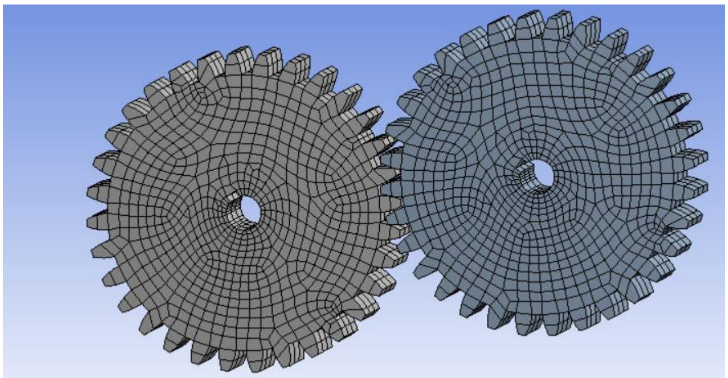

Figure 4. Meshing of Spur Gear Contact

Figure 5 shows the boundary condition of spur gear contact. The fixed point is set at the hub of the driving spur gear, while frictionless support is applied to the surface of the driven spur gear. The actual transmitted tooth load (F_t) of 278.16 N is applied in the X-direction on the surface of the driving spur gear tooth, with a turning moment of 17.8 Nm. The static tooth load (W_s) with a magnitude of 3898.757 N acts on the teeth of the driven spur gear in contact with the driving spur gear.

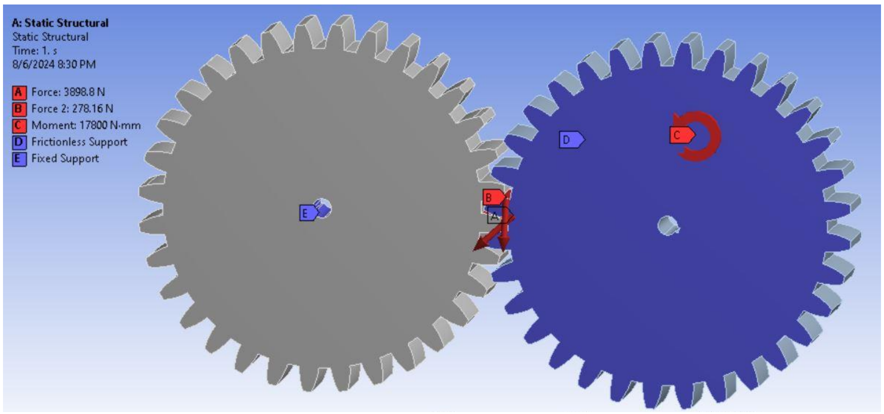

Figure 5. Boundary Condition of Spur Gear Set

Figure 6 illustrates the simulation result of effective stress of spur gear contact in 28 teeth. The maximum effective stress value is 78.248 MPa and the minimum effective stress value is 2.1909×10^{-4} MPa.

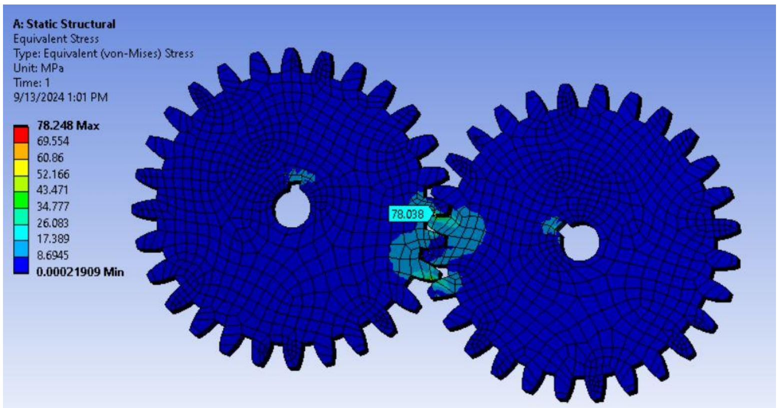

Figure 6. von-Mises Stress of Spur Gear Contact in 28 Teeth

Figure 7 shows the simulation result of effective strain of spur gear contact in 28 teeth. The maximum effective strain value is 7.6777×10^{-4} and the minimum effective strain value is 4.7293×10^{-9}.

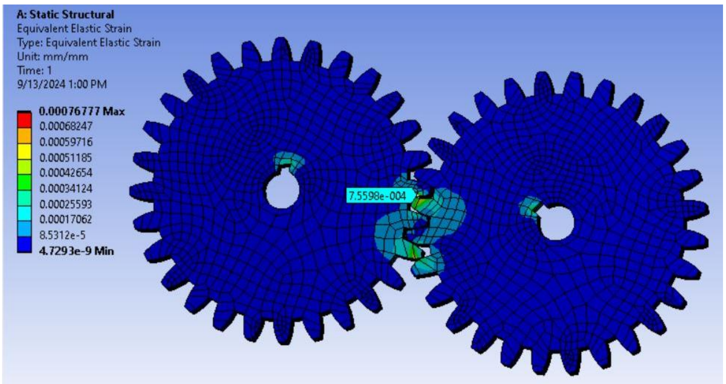

Figure 7. Effective Strain of Spur Gear Contact in 28 Teeth

Figure 8 shows the simulation result of effective stress of spur gear contact in 30 teeth. The maximum effective stress value is 71.649 MPa and the minimum effective stress value is 6.826×10^{-4} MPa.

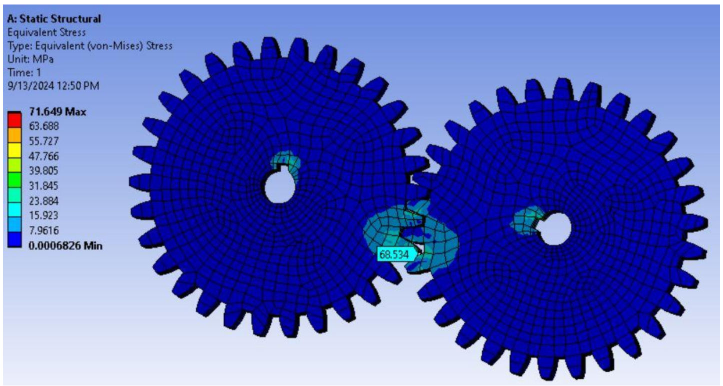

Figure 8. von-Mises Stress of Spur Gear Contact in 30 Teeth

Figure 9 shows the simulation result of effective strain of spur gear contact in 30 teeth. The maximum effective strain value is 6.962×10^{-4} and the minimum effective strain value is 1.06×10^{-8}.

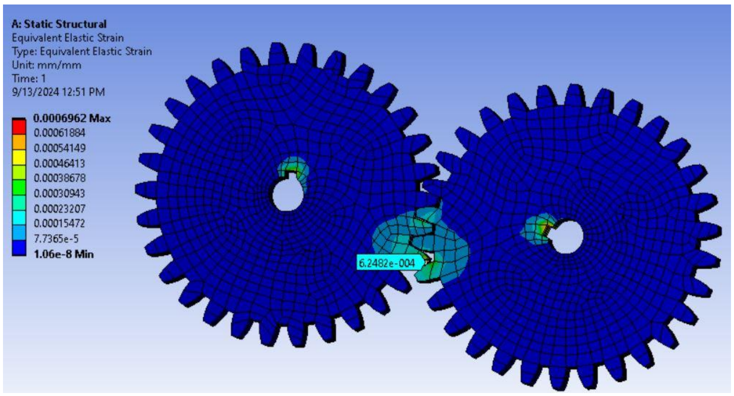

Figure 9. Effective Strain of Spur Gear Contact in 30 Teeth

Figure 10 shows the simulation result of effective stress of spur gear contact in 32 teeth. The maximum effective stress value is 61.78 MPa and the minimum effective stress value is 1.2819×10^{-3} MPa.

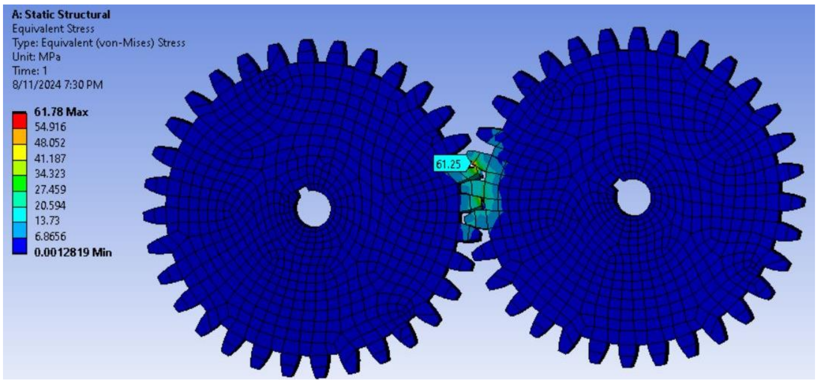

Figure 10. von-Mises Stress of Spur Gear Contact in 32 Teeth

Figure 11 shows the simulation result of effective strain of spur gear contact in 32 teeth. The maximum effective strain value is 6.1846×10^{-4} and the minimum effective strain value is 2.5355×10^{-8}.

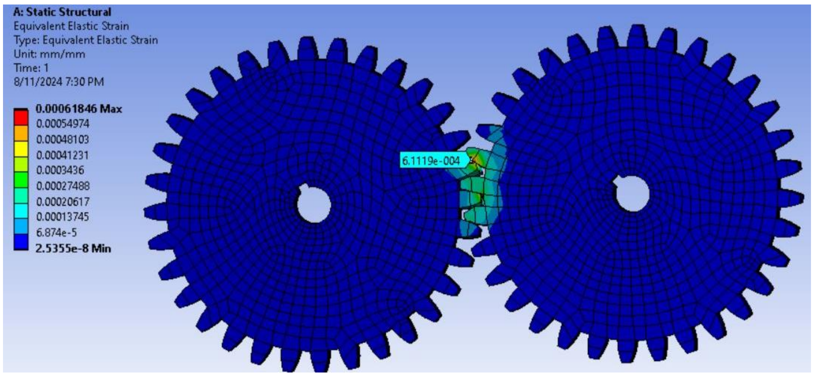

Figure 11. Effective Strain of Spur Gear Contact in 32 Teeth

Figure 12 shows the simulation result of effective stress of spur gear contact in 34 teeth. The maximum effective stress value is 57.537 MPa and the minimum effective stress value is 4.0166×10^{-4} MPa.

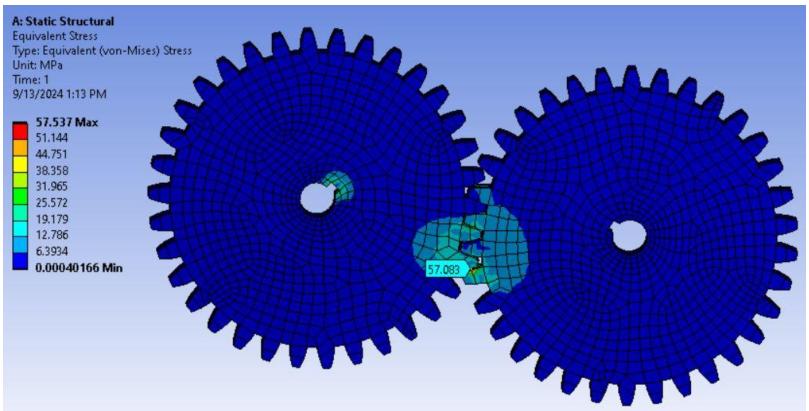

Figure 12. von-Mises Stress of Spur Gear Contact in 34 Teeth

Figure 13 shows the simulation result of effective strain of spur gear contact in 34 teeth. The maximum effective strain value is 5.6367×10^{-4} and the minimum effective strain value is 1.5234×10^{-8}.

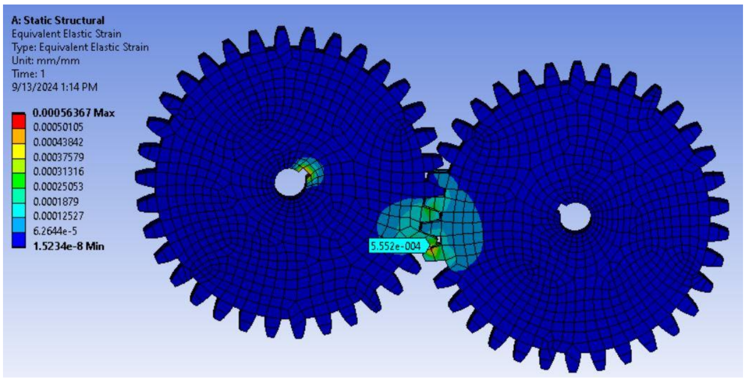

Figure 13. Effective Strain of Spur Gear Contact in 34 Teeth

Figures 14 and 15 show the simulation results of von-Mises stresses and effective strains in gears with different numbers of teeth.

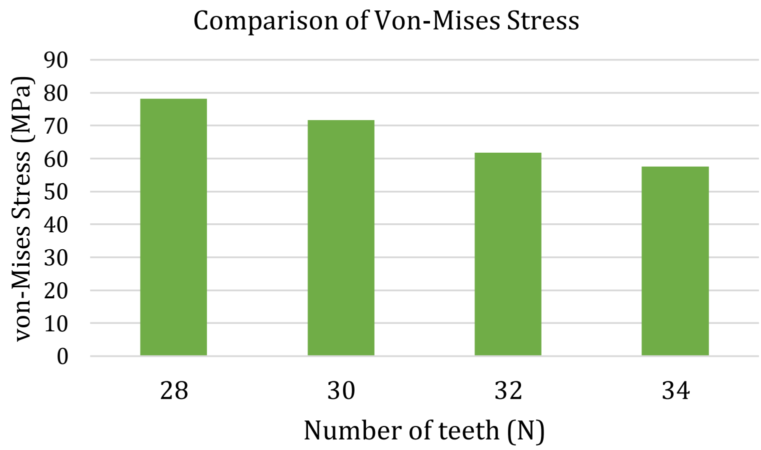

Figure 14. Simulation Result of von-Mises Stress in Different Gear Teeth

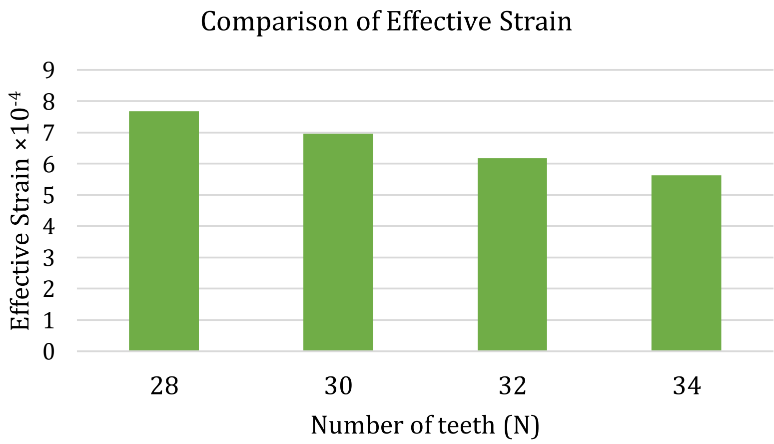

Figure 15. Simulation Result of Effective Strain in Different Gear Teeth

The 32-teeth gear shows a von Mises stress of 61.78 MPa, closely matching the calculated result of 60.75 MPa, and offers better structural integrity compared to the 28-teeth gear with 41.165 MPa, the 30-teeth gear with 52.129 MPa, and the 34-teeth gear with 75.652 MPa.

With an effective strain of 6.1846×10^{-4}, it aligns well with the calculated value of 5.3109×10^{-4}, offering better flexibility than the 28-teeth and 30-teeth gears while staying below the strain in the 34-teeth gear with 7.5518×10^{-4}.

The 32-teeth gear provides balanced and reliable performance and is a technically sound and cost-effective choice compared to other tooth counts.

Additionally, a structural analysis of the spur gears used in the machine was performed. The analysis, based on Hertzian contact stress equations and both theoretical and numerical simulations, focused on von Mises stress and effective strain across gears with different numbers of teeth.

Table 3 illustrates the comparison results for the contact stress analysis of the spur gear. The theoretical and simulation results of von Mises stress are 60.75 MPa and 61.78 MPa, respectively. The theoretical and simulation results of effective strain are 5.1309×10^{-4} and 6.1846×10^{-4}, respectively.

Table 3. Comparison Result for Contact Stress Analysis of Spur Gear

No.	Process	Theoretical	Simulation	% Deviation
1.	Effective Stress	60.75 MPa	61.78 MPa	1.69
2.	Effective Strain	5.1309×10^{-4}	6.1846×10^{-4}	17

Fabrication of Oat Flake Rolling Machine

In the oat flaking process, semiautomatic oat flake rolling machines are designed to enhance production efficiency and reduce manual labor. The key components, such as rollers and spur gears, are fabricated from durable materials to withstand operational stresses. The rollers, made of ductile iron, have an outer diameter of 127 mm, an inner diameter of 15 mm, and a length of 254 mm. These dimensions ensure the consistent production of oat flakes with minimal grain breakage. The spur gears, with a pitch circle diameter of 128 mm and a face width of 36 mm, are made of grey cast iroj. This material choice provides the necessary strength to resist tooth loads during operation. Figure 16 shows the components of the oat flake rolling machine.

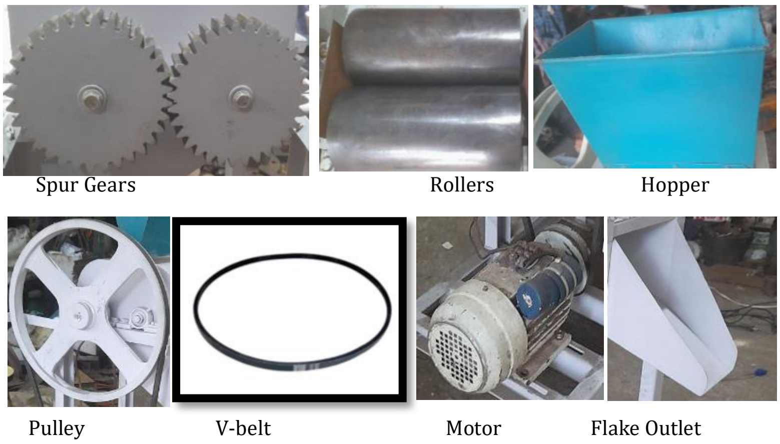

Figure 16. Components of the Oat Flake Rolling Machine

Figure 17 illustrates the construction of the oat flake rolling machine.

Figure 17. Construction of the Oat Flake Rolling Machine

Figures 18 and 19 illustrate the assembly process of the oat flake rolling machine. Figure 18 shows the initial assembly stages, while Figure 19 depicts the completed assembly of the machine.

Figure 18. Assembling the Oat Flake Rolling Machine

Figure 19. Assembly of Oat Flake Rolling Machine

The fabrication process begins with machining the rollers and shafts using a conventional lathe to achieve precise dimensions. The 1hp motor drives the machine, connected via a pulley system to the spur gears that, in turn, drive the rollers. The machine also features a hopper with a volume of 1.2454×10^{-4} cubic meters, ensuring a controlled feed of oat grains into the rollers. Once the components are machined, they are assembled meticulously to ensure smooth operation. The resulting oat flake rolling machine is robust, efficient, and capable of producing high-quality oat flakes consistently. The speed of the machine was measured using a tachometer, as shown in Figure 20.

Figure 20. Measuring Speed with Tachometer

Performance Evaluation of Oat Flake Rolling Machine

The oat flake rolling process involves precise adjustments and measurements to produce flakes of varying thicknesses. In this study, the performance of an oat flake rolling machine was assessed using two different flake thicknesses: 0.45 mm and 0.6 mm. The machine was tested over a period of three days for each thickness, with five trials conducted each day. Key performance parameters included the weight of the oat seeds (W_d), weight of the flaked oats (W_f), flaking time (T), capacity (C), and efficiency (η).

The capacity of the machine in kg/hr calculated by using the formula:

$$C = \frac{W_f \times 3600}{1000 \times T} \qquad (15)$$

Where:

W_f = weight of the flaked oat in grams.
T = flaking time in seconds.
The factor 3600 converts seconds to hours.
The factor 1000 converts grams to kilograms.

The efficiency of the flaking process calculated by using the formula:

$$\eta = \frac{W_f}{W_d} \times 100 \qquad (16)$$

Where:

W_f = weight of the flaked oat in grams.
W_d =weight of the oat seed before processing in grams.
The result is expressed as a percentage.

Figure 21 illustrates the process of making oat flakes using the oat flake rolling machine.

Figure 21. Processing the Oat Flake with Oat Flake Rolling Machine

Figure 22 shows the weights of the oats before and after flaking, with a flake thickness of 0.45 mm.

Figure 22. Weights of the Oat, Before and After Flaking (0.45 mm oat flake)

Figure 23 shows the weights of the oats before and after flaking, with a flake thickness of 0.6 mm.

Figure 23. Weights of the Oat, Before and After Flaking (0.6 mm oat flake)

Figure 24 shows the feeler gauge used to adjust the roller clearance for achieving oat flakes of 0.45 mm and 0.6 mm thickness. This helps ensure that the flakes are consistent and accurate. Adjusting the clearance properly is important for maintaining the machine's performance and getting the right quality of oat flakes.

Figure 24. Feeler Gauge

Figures 25 and 26 illustrate the roller clearance settings used to achieve flake thicknesses of 0.45 mm and 0.6 mm, respectively.

Figure 25. Roller Clearance for 0.45 mm Oat Flake Thickness

Figure 26. Roller Clearance for 0.6 mm Oat Flake Thickness

For the 0.45 mm flake thickness, the machine's capacity and efficiency were evaluated over three days. The capacities recorded were measured in kg/hr, with detailed averages and efficiencies provided for each day. Similarly, the 0.6 mm flake thickness was tested under the same conditions, with capacities and efficiencies documented for each trial.

Table 4. Performance of Oat Flake Rolling Machine with 0.45 mm Thickness (Day 1)

No.	Weight of oat seed W_d, g	Weight of flaked oat W_f, g	Flaking Time T, sec	Capacity C, kg/hr	Efficiency η, %
1	1000	988.1	122	29.5082	98.81
2	1000	977.2	130	27.6923	97.72
3	1000	995.4	116	31.0345	99.54
4	1000	995.6	133	27.0677	99.56
5	1000	998.3	146	24.6575	99.83
Average Value		990.72	129.4	28.3920	99.092

Table 5. Performance of Oat Flake Rolling Machine with 0.45 mm Thickness (Day 2)

No.	Weight of oat seed W_d, g	Weight of flaked oat W_f, g	Flaking Time T, sec	Capacity C, kg/hr	Efficiency η, %
1	1000	990.3	133	27.0677	99.03
2	1000	996	135	26.6667	99.60
3	1000	996.1	137	26.2774	99.61
4	1000	998.2	132	27.2727	99.82
5	1000	996.6	136	26.4706	99.66
Average Value		995.64	134.6	26.95	99.544

Table 6. Performance of Oat Flake Rolling Machine with 0.45 mm Thickness (Day 3)

No.	Weight of oat seed W_d, g	Weight of flaked oat W_f, g	Flaking Time T, sec	Capacity C, kg/hr	Efficiency η, %
1	1000	997	134	32.8358	99.70
2	1000	997.9	137	31.3874	99.79
3	1000	997.3	138	31.8841	99.73
4	1000	996.3	141	31.9149	99.63
5	1000	998.1	143	31.6688	99.81
Average Value		997.72	138.6	31.9382	99.732

Table 7 Performance of Oat Flake Rolling Machine with 0.6 mm Thickness (Day 1)

No.	Weight of oat seed W_d, g	Weight of flaked oat W_f, g	Flaking TimeT, sec	Capacity C, kg/hr	Efficiency η, %
1	1000	995.8	74	48.6486	99.58
2	1000	999.2	90	40	99.92
3	1000	997.4	80	45	99.74
4	1000	994.8	79	45.5696	99.48
5	1000	997.5	63	57.1429	99.75
Average Value		996.94	77.2	47.2722	99.694

Table 8. Performance of Oat Flake Rolling Machine with 0.6 mm Thickness Day 2)

No.	Weight of oat seed W_d, g	Weight of flaked oat W_f, g	Flaking Time T, sec	Capacity C, kg/hr	Efficiency η, %
1	1000	996.8	67	53.7313	99.68
2	1000	998.2	72	50	99.82
3	1000	997.6	76	47.3684	99.76
4	1000	998.3	78	46.1538	99.83
5	1000	996.4	71	50.7042	99.64
Average Value		997.46	72.8	49.5915	99.746

Table 9. Performance of Oat Flake Rolling Machine with 0.6 mm Thickness (Day 3)

No	Weight of oat seed W_d, g	Weight of flaked oat W_f, g	Flaking Time T, sec	Capacity C, kg/hr	Efficiency η, %
1	1000	996.8	74	48.6486	99.68
2	1000	997.1	77	46.4935	99.71
3	1000	997.8	79	45.3165	99.78
4	1000	997.7	73	49.3151	99.77
5	1000	998.1	75	48	99.81
Average Value		997.5	75.6	47.5547	99.752

E. Results and Discussion

The design of spur gears was calculated using the Hertzian contact stress equation. This research focused on analyzing the structural behaviors of spur gears, including von Mises stress and effective strain, through both theoretical calculations and numerical simulations. Stress analysis was performed on gears with different numbers of teeth, leading to the selection of Grey Cast Iron for the gear material based on structural analysis.

The results showed that a gear with 32 teeth exhibited lower maximum von-Mises stress and effective strain compared to other gear tooth counts. The theoretical von Mises stress was calculated at 60.75 MPa, closely aligning with the simulation result of 61.78 MPa. Similarly, the theoretical effective strain value was 5.1309×10^{-4}, compared to the simulation result of 6.1846×10^{-4}.

In this study, the performance of an oat flake rolling machine was evaluated using two different flake thicknesses: 0.45 mm and 0.6 mm. The machine was tested over three days for each thickness, with five trials conducted per day. The parameters measured included the weight of oat seeds (W_d), weight of flaked oats (W_f), flaking time (T), capacity (C), and efficiency (η). The results are summarized below.

The performance of the oat flake rolling machine with a 0.45 mm flake thickness over three days is presented in Tables 4, 5, and 6. On Day 1, the machine had an average capacity of 28.392 kg/hr and an average efficiency of 99.092%. On Day 2, the capacity averaged 26.95 kg/hr, with an average efficiency of 99.544%. On Day 3, the machine showed improved capacity at 31.9382 kg/hr, with an average efficiency of 99.732%. The average capacity for 0.45 mm oat flakes over Days 1, 2, and 3 is 28.9934 kg/hr, with an average efficiency of 99.456%.

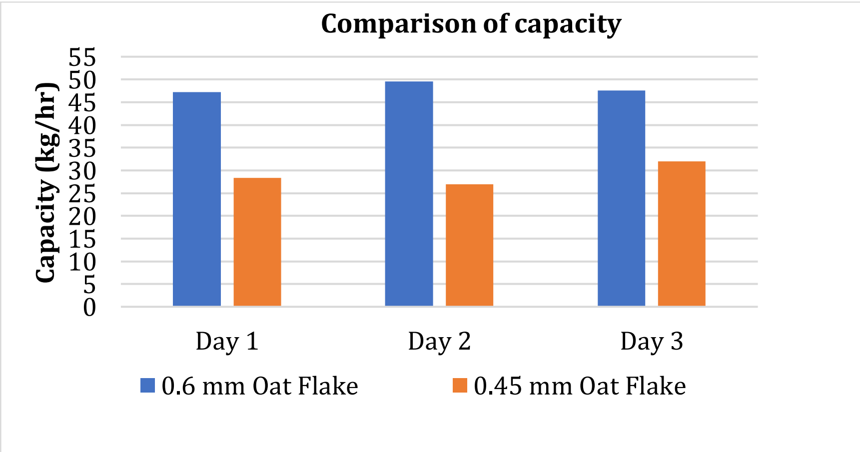

Figure 27. Comparison of Capacities for 0.45 mm and 0.6 mm Oat Flakes (Day 1–3)

The performance of the oat flake rolling machine with a 0.6 mm flake thickness over three days is presented in Tables 7, 8, and 9. On Day 1, the machine had an average capacity of 47.2722 kg/hr and an average efficiency of 99.694%. On Day 2, the capacity averaged 49.5915 kg/hr with an average efficiency of 99.746%. On Day 3, the machine showed a capacity of 47.5547 kg/hr, with an average efficiency of 99.75%. The average capacity for 0.6 mm oat flakes over Days 1, 2, and 3 is 48.1395 kg/hr, with an average efficiency of 99.73%.

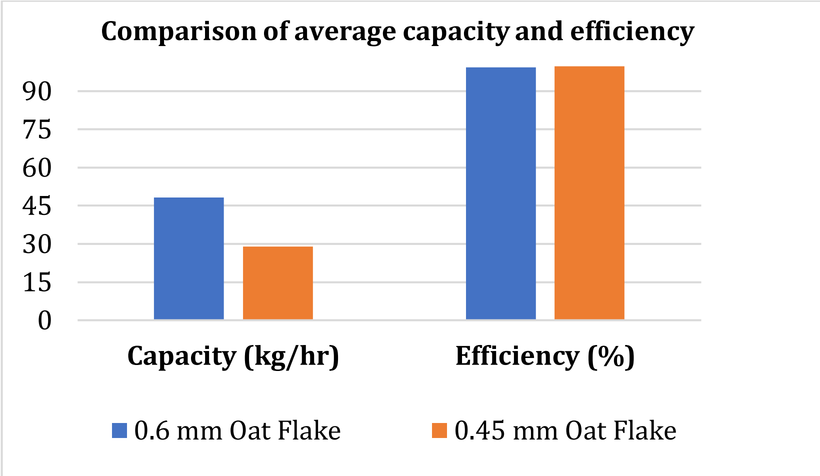

Figure 28. Comparison of Experimental Results for 0.45 mm and 0.6 mm Oat Flakes

The research results showed that the machine with a 0.6 mm flake thickness has a significantly higher average capacity (48.14 kg/hr) than the machine with a 0.45 mm flake thickness (28.99 kg/hr). However, both thickness settings demonstrated similar high efficiency, with the 0.6 mm flake machine achieving 99.73% efficiency and the 0.45 mm flake machine achieving 99.46%.

F. Conclusion

This paper presents the design and performance evaluation of spur gears and an oat flake rolling machine. The spur gear design was analyzed using the Hertzian contact stress equation, focusing on the structural behavior under different gear teeth configurations. A gear with 32 teeth was chosen, as it exhibited lower von Mises stress and effective strain compared to other gear designs.

In theoretical analysis, the von Mises stress for the spur gear was calculated to be 60.75 MPa, with an effective strain of 5.1309×10^{-4}. Numerical analysis using FEA showed a von Mises stress of 61.78 MPa and an effective strain of 6.1846×10^{-4}. The percentage errors between theoretical and FEA results were approximately 1.7% for stress and 17.1% for strain. Both theoretical and numerical results confirmed that the stress values were within safe limits, indicating that the 32-tooth gear design is suitable for operation.

The performance of the oat flake rolling machine was evaluated by measuring the capacity and efficiency over three days for two flake thicknesses: 0.45 mm and 0.6 mm. The machine was tested five times per day for each thickness. For the 0.45 mm flake thickness, the average capacity over three days was 28.99 kg/hr, with an efficiency of 99.46%. For the 0.6 mm flake thickness, the average capacity was 48.14 kg/hr, with an efficiency of 99.73%. Based on these results, the machine performed effectively, with higher capacities observed for the 0.6 mm flake thickness.

G. Acknowledgment

Firstly, the author would like to extend special thanks to Dr. War War Min Swe, Professor and Head of the Department of Mechanical Engineering at Mandalay Technological University, for her invaluable assistance throughout this research. The author is also deeply grateful to Dr. Htay Htay Win, Professor and Head of the Solid Mechanics Section in the Department of Mechanical Engineering at Mandalay

Technological University, for her kind guidance, valuable suggestions, and advice in preparing this research.

H. References

[1] R.S. Khurmij, K. Gupta, “A Text book of Machine Design”, 2005.
[2] Fred Gates, "Role of heat treatment in the processing and quality of oat flakes", 2007.
[3] Decker, Eric A.; Rose, Devin J.; and Stewart, Derek A., "Processing of oats and the impact of processing operations on nutrition and health benefits" (2014).
[4] Ram Krishna Rathore and Abhishek Tiwari, "Bending Stress Analysis & Optimization of Spur Gear" 2014.
[5] Saravanan Karuppanan and Santosh S. Patil, "Finite Element Analysis of stress variation along the depth of gear tooth", 2016.
[6] Sushovan Ghosh, Rohit Ghosh, Bhuwaneshwar Patel, Tanuj Srivastava, Dr. Rabindra Nath Barman, "Structural Analysis of Spur Gear using ANSYS WORKBENCH 14.5", 2016
[7] S. Prabhakaran, D. S. Balaji and R. Praveen Kumar, “Bending Stress analysis of a spur gear for material steel 15NI2CR1MO28”, 2017.
[8] Tey Wah-Yen, Yutaka Asako, Nor Azwadi Che Sidik, Goh Rui-Zher, "Governing Equations in Computational Fluid Dynamics: Derivations and A Recent Review", 2017.
[9] Ahmed kadhim zarzoor, Nabeel Almuramady and Eman Shaker Hussein, "Stress Analysis for Spur Gears using SOLID WORKS Simulation", 2018.