

## Research Article

# Design and Construction of Hand Powered Household Grinding Machine (HPHGM)

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## Abstract

*This study evaluates the performance of a hand-powered portable household grinding machine designed for domestic use, particularly in areas where electric appliances are inaccessible or impractical. The experiment aimed to assess the machine's efficiency, durability, and user-friendliness in processing common household materials, including grains, spices, and seeds. Five representative samples—maize, millet, dried pepper, coffee beans, and rice—were selected for testing. Each sample weighed 500 grams, and the performance metrics included grinding time, particle size uniformity, and user effort, which was measured using a force gauge. The grinding machine demonstrated consistent functionality, achieving satisfactory particle sizes across all samples within a time range of 6 to 15 minutes. Softer and less dense materials, such as dried pepper and millet, required minimal effort and time, while harder grains like maize posed challenges, demanding increased effort and extended grinding durations. User effort averaged 25 Newtons, with peak values recorded for maize at 30 Newtons. The results indicate that the grinding mechanism is optimized for softer materials but struggles with harder substances, underscoring the need for improvements in blade efficiency and ergonomic design. Durability testing revealed the machine's robust construction, as it completed 10 continuous cycles without mechanical failure or noticeable wear. This durability supports its suitability for regular household use. Additionally, its portability and reliance on manual operation make it a cost-effective and sustainable alternative to electric grinders, especially in off-grid or remote areas. Despite its merits, areas for enhancement remain. Reducing the manual effort required for harder grains and improving grinding efficiency for a wider range of materials could significantly expand the machine's usability. Nevertheless, this device offers a practical solution for households in low-resource settings, enhancing food processing capabilities while promoting energy independence. Further design refinements could enhance user comfort and broaden its applications.*

**Keywords:** Food Grinding, Manual Power, Ergonomic, Food Stuff

## 1. Introduction

Grinding machines play a pivotal role in modern households, especially in regions where manual food preparation remains prevalent. These machines, traditionally powered by electricity or petrol, have contributed significantly to reducing the physical burden associated with grinding grains, spices, and other food items [1]. However, the growing scarcity and high costs of electricity and petrol pose challenges to the continued reliance on such machines, particularly in resource-constrained regions [2]. This paper explores the design, development, and implications of a hand-powered household grinding machine, presenting it as a sustainable and cost-effective alternative to conventional grinders.

Access to electricity remains a critical challenge in many parts of the world, especially in developing countries. According to the International Energy Agency (IEA), nearly 770 million people lacked access to electricity globally as of

2021, with a significant proportion residing in sub-Saharan Africa and South Asia [3]. For those connected to the power grid, erratic supply and frequent outages exacerbate the problem, making electric appliances unreliable for daily use. Furthermore, the rising cost of petrol adds to the economic burden on households relying on petrol-powered equipment, particularly in rural areas where agricultural and household machinery form the backbone of daily life.

In light of these challenges, there is a pressing need for sustainable alternatives that minimize reliance on electricity and fossil fuels while maintaining efficiency and user convenience. A hand-powered grinding machine offers a practical solution to these challenges. By harnessing human effort, this machine eliminates the need for external energy sources, making it ideal for off-grid communities and economically disadvantaged households.

### 1.1. Importance of Grinding Machines

Grinding is a fundamental process in food preparation and production. Historically, manual grinding tools, such as mortar and pestle, have been used for centuries to process grains, spices, and other food items [4]. Modern grinding machines have evolved to meet increasing demand and efficiency requirements, leveraging electrical or mechanical power to deliver consistent and high-quality outputs. However, the reliance on electricity and petrol in these devices limits their applicability in resource-scarce environments [5].

### 1.2. Challenges of Electricity and Petrol Dependence

The reliance on electricity for household appliances creates challenges in regions with inadequate or unreliable power infrastructure. Studies have shown that in sub-Saharan Africa, electricity access rates average around 46%, with rural areas experiencing even lower connectivity [6]. Households without consistent electricity access face difficulties in using electric grinding machines, which require uninterrupted power supply for optimal performance [7]. Similarly, petrol-powered machines are hindered by fluctuating fuel prices and supply chain issues. In 2022, global fuel prices experienced a sharp increase due to geopolitical tensions and market volatility, disproportionately impacting low-income households [8].

### 1.3. Alternative Energy Sources

Efforts to develop alternative energy-powered devices have gained traction in recent years. Solar-powered grinding machines have been explored as a potential solution, particularly in regions with abundant sunlight [9]. While promising, solar-powered systems are often associated with high initial costs and maintenance challenges, limiting their adoption among economically disadvantaged populations [10]. Similarly, biomass-powered machines have been introduced, but their dependency on organic material supply and the need for advanced technology present significant barriers [11].

### 1.4. Hand-Powered Machines: A Historical Perspective

Hand-powered machines are not a new concept; they have been utilized across various domains, including agriculture and household applications. Treadle sewing machines and hand-cranked water pumps are examples of devices that have stood the test of time due to their simplicity, affordability, and independence from external energy sources [12]. In the context of grinding, manual tools have evolved from rudimentary stone grinders to sophisticated mechanical devices that leverage human effort efficiently [13].

### 1.5. Recent Innovations in Hand-Powered Grinding Machines

Recent advancements in mechanical engineering and ergonomics have paved the way for innovative hand-powered devices. Studies have highlighted the potential of flywheel-based systems to store and release energy, enabling smooth and efficient operation with minimal effort [14]. Additionally, the use of lightweight and durable materials, such as aluminum alloys and reinforced plastics,

has enhanced the portability and longevity of hand-powered machines [15].

### 1.6. Socioeconomic Implications

The adoption of hand-powered grinding machines has far-reaching socioeconomic implications. In rural communities, such machines can reduce dependency on external energy sources, empowering households to become self-reliant [16]. Furthermore, the affordability of hand-powered devices makes them accessible to low-income families, promoting equitable access to essential household tools [17]. Studies have also shown that such devices can contribute to women's empowerment by reducing the physical strain associated with traditional grinding methods, enabling them to allocate more time to other productive activities [18].

### 1.7. Case Studies

Several case studies illustrate the practical applications and benefits of hand-powered grinding machines. For instance, a study conducted in Kenya demonstrated that households using hand-powered grinders experienced a 30% reduction in food preparation time compared to those relying on manual tools like mortar and pestle [19]. Similarly, a pilot project in India found that the introduction of hand-powered grain mills led to a significant decrease in household expenses related to fuel and electricity [20].

### 1.8. Challenges and Opportunities

While the benefits of hand-powered grinding machines are evident, their adoption is not without challenges. One major barrier is the perception of manual devices as outdated or labour-intensive, which can deter potential users [21]. Additionally, the design and usability of such machines must be optimized to ensure they meet the needs of diverse user groups, including women, elderly individuals, and persons with disabilities [22]. Nonetheless, advancements in mechanical design, coupled with targeted awareness campaigns, present opportunities to overcome these barriers and promote the widespread adoption of hand-powered grinding machines [23].

### 1.9. Environmental Benefits

The environmental benefits of hand-powered devices cannot be overlooked. By eliminating the need for electricity or petrol, such machines contribute to reducing greenhouse gas emissions associated with fossil fuel consumption [24]. Additionally, the use of recyclable materials in their construction aligns with the principles of sustainable development, minimizing waste and conserving natural resources [25].

### 1.10. Design Considerations for Hand-Powered Grinding Machines

Designing an efficient and user-friendly hand-powered grinding machine requires a multidisciplinary approach that integrates principles of mechanical engineering, ergonomics, and user-centered design. Key considerations include:

- **Energy Efficiency:** Leveraging mechanical systems such as gears, pulleys, and flywheels to maximize energy transfer and minimize user effort [26].

- **Durability:** Using high-quality materials that withstand wear and tear, ensuring long-term reliability [27].
- **Portability:** Ensuring the device is lightweight and compact for easy transportation and storage [28].
- **Ergonomics:** Designing handles, cranks, and other user interfaces to minimize strain and enhance comfort [29].
- **Versatility:** Enabling the machine to process a wide range of food items, including grains, spices, and nuts [30].

The development of hand-powered grinding machines offers numerous avenues for future research and innovation. Emerging technologies, such as 3D printing and computer-aided design (CAD), can streamline the prototyping and manufacturing processes, reducing costs and improving product quality [31]. Additionally, partnerships with local communities and non-governmental organizations can facilitate the dissemination of these devices, ensuring they reach those who need them most [32].

### 1.11. Conceptual Design

The conceptual design of a hand-powered household grinding machine aims to create a sustainable, efficient, and user-friendly alternative to electric and petrol-powered grinders. The machine features a compact, ergonomic frame made of lightweight, durable materials such as aluminum alloys or reinforced plastics to ensure portability and longevity. The grinding mechanism utilizes durable grinding stones or discs to process a variety of food items, including grains, spices, and nuts. The design incorporates adjustable settings for different grind sizes, ensuring versatility. The user interface includes an easy-to-turn hand crank with ergonomically designed handles to reduce strain, while the machine's base is equipped with three stands for stability during use. The entire design prioritizes energy efficiency, low maintenance, and ease of cleaning, with the goal of offering a cost-effective and environmentally friendly solution for households in resource-constrained regions.

### 1.12. Engineering Design

The hand-powered household grinding machine is designed for small-scale grinding tasks, such as grinding grains, spices, or herbs. This manual device aims to reduce the need for electrical power while ensuring efficiency, ease of use, and portability. The design focuses on mechanical power transmission, ergonomic principles, and safety features to make the device user-friendly and effective in a domestic setting.

The machine consists of the following main components:

- **Handle:** The manual driving mechanism.
- **Gearbox:** To reduce the input speed and increase torque.
- **Grinding Mechanism:** The system that performs the grinding operation (e.g., burrs, blades, or stones).
- **Frame:** The supporting structure that holds all components.

The system operates using the principle of converting the rotational motion from the handle into grinding force via a set of gears. The grinding force is transmitted to the grinding

stones or blades.

### 1.13. Mechanical Power Transmission

To calculate the mechanical power required to drive the grinding system, we need to establish the torque and speed relationships [33].

#### 1.13.1. Torque Transmission Equation

The torque  $T$  required for grinding can be calculated using the equation for mechanical power transmission:

$$P = T \times \omega, \quad (1)$$

Where  $P$  is the power in watts (W),  $T$  is the torque in newton-meters (Nm),  $\omega$  is the angular velocity in radians per second (rad/s)

For hand-powered machines, the power  $P$  is typically lower than 100 W, and the angular velocity  $\omega$  can be calculated from the handle's rotational speed.

#### 1.13.2. Grinding Force Calculation

The grinding force  $F_{\text{grinding}}$  is a function of the torque applied to the  $r_{\text{grinding}}$  wheel and the radius  $r_{\text{grinding}}$  of the grinding surface:

$$F_{\text{grinding}} = \frac{T_{\text{grinding}}}{r_{\text{grinding}}}, \quad (4)$$

where  $T_{\text{grinding}}$  is the torque applied at the grinding surface,  $r_{\text{grinding}}$  is the radius of the grinding wheel or stones

### 1.14. Ergonomic Design

The handle design should ensure comfort and reduce fatigue for the user. This can be achieved by optimizing the handle length and material for ease of grip. The torque required to rotate the grinding mechanism depends on the design of the handle and the force applied by the user [34]. The torque equation for the user's grip is:

$$T_{\text{handle}} = F_{\text{user}} \times r_{\text{handle}}, \quad (5)$$

Where  $F_{\text{user}}$  is the force applied by the user (in newtons, N),  $r_{\text{handler}}$  is the radius from the center of the handle to where the force is applied (in meters, m)

### 1.15. Material Selection

The frame, gears, and grinding components must be made from durable materials capable of withstanding wear and providing consistent grinding performance. Materials commonly used include stainless steel for grinding surfaces and cast iron for the frame and gears [35].

### 1.16. Safety Features

The design incorporates safety features, such as protective shields around the grinding mechanism and a slip-resistant handle. Additionally, the machine includes a locking mechanism to prevent accidental engagement of the grinding surface.

The hand-powered household grinding machine efficiently converts manual effort into grinding power using mechanical transmission principles. The design emphasizes ease of use, durability, and safety, making it suitable for domestic applications.

### 1.17. Construction

The construction of the hand-powered household grinding machine involved several stages, from designing the components to assembling them into a fully functional unit. The procedure emphasized efficiency, safety, and ease of use for the end-user.

### 1.18. Materials and Tools Used

The following materials and tools were used during the construction:

- **Materials:** Stainless steel, cast iron, mild steel, wood (for handle), rubber (for grip), bearings, bolts, and nuts.
- **Tools:** Welding machine, lathe, milling machine, drill press, hand tools (screwdrivers, pliers), and a torque wrench.

### 1.19. Design and Blueprint Preparation

The design of the grinding machine was completed first. Detailed blueprints were drawn, specifying the dimensions and materials for each component. The components included the grinding mechanism (stones), the handle, and the frame.

### 1.20. Frame Construction

- **Frame Cutting:** The frame structure was cut from cast iron sheets. The shape and size were based on the design specifications.
- **Welding:** The cut pieces of cast iron were welded together to form a robust frame that could support the grinding mechanism, gearbox, and handle.
- **Drilling Holes:** Holes were drilled at specific locations to mount the bearings and attach other components.

### 1.21. Grinding Mechanism Assembly

- **Grinding Wheel Preparation:** Grinding wheels were selected based on the material to be ground. The wheels were mounted onto a central rotating shaft.
- **Mounting the Grinding Mechanism:** The grinding wheel assembly was attached to the frame and connected to the output shaft. A bearing was used to support the rotating grinding wheel.

### 1.22. Handle Construction and Installation

- **Handle Fabrication:** A wooden handle was carved and smoothed for ergonomic comfort. The length of the handle was designed to provide sufficient torque

without straining the user.

- **Handle Attachment:** The handle was attached to a metal shaft that connected to the input shaft. A bearing was mounted on the shaft to allow smooth rotation.

### 1.23. Power Transmission System

- **Torque Transmission:** The input torque from the handle was transmitted to the stone disk. The output torque was then transmitted to the grinding wheel through the shaft.
- **Testing the Transmission:** The machine was manually rotated to check for smooth operation of the torque transmission, ensuring that the speed and the torque are effectively correct.

### 1.24. Safety Features Installation

- **Guarding the Grinding Mechanism:** A protective cover was installed around the grinding wheel to prevent accidental contact.
- **Non-slip Handle:** A rubber grip was fitted around the handle to prevent slipping during operation.
- **Locking Mechanism:** A locking mechanism was incorporated to prevent the grinding wheel from accidentally engaging when not in use.

### 1.25. Final Assembly

Once all the components were constructed, they were assembled into the frame. All bolts and nuts were tightened securely to ensure the stability of the machine. Bearings were greased, and was tested for smooth operation.

### 1.26. Testing and Adjustment

The completed grinding machine was manually tested by rotating the handle. The grinding wheel was observed to ensure that it was rotating smoothly without wobbling. Any misalignments or adjustments required for shafts, or bearings were made during this step. The machine's power transmission and grinding effectiveness were evaluated, and the necessary tweaks were made.

### 1.27. Final Inspection

The entire assembly was inspected for any defects or irregularities. The machine was examined for sharp edges, loose parts, or any other potential safety hazards. Once all components were found to be functioning correctly and safely, the grinding machine was ready for use. The hand-powered household grinding machine was successfully constructed with all necessary components carefully fabricated and assembled. The machine provided efficient and effective grinding capabilities, while ensuring ease of use and safety for the operator.



Figure 1: Mini Household Grinding Machine After Construction

**1.28. Experiment Test Procedure**

Objective: To evaluate the performance of a hand-powered portable household grinding machine in terms of efficiency, durability, and user effort.

**2. Materials and Methods**

- **Test Samples:** Maize, millet, dried pepper, coffee beans, and rice (500 g each).
- **Procedure:**
- ❖ Each sample was ground using the machine for 10 cycles

(50 total trials).

- ❖ Time taken for grinding each sample to achieve fine particles was recorded.
- ❖ User effort was measured with a force gauge during operation.
- ❖ Particle sizes were analyzed using a standard sieve set.
- **Evaluation Metrics:** Grinding time (minutes), particle size uniformity (% of fine particles passing 1 mm sieve), and average user force (N).

Sample	Grinding Time (min)	Particle Size Uniformity (%)	User Effort (N)
Maize	15	85	30
Millet	8	90	20
Dried Pepper	6	95	18
Coffee Beans	7	92	22
Rice	10	88	25

Table1: The Test Results

**2.1. Graphical Representation**

Figure 2, the graphs illustrate the grinding time and user effort required for each sample type, showcasing the performance of the hand-powered grinding machine across different household items.

- **Grinding Time vs. Sample Type:** A bar graph comparing the grinding time for each sample.
- **User Effort vs. Sample Type:** A line graph showing the required force for different samples.

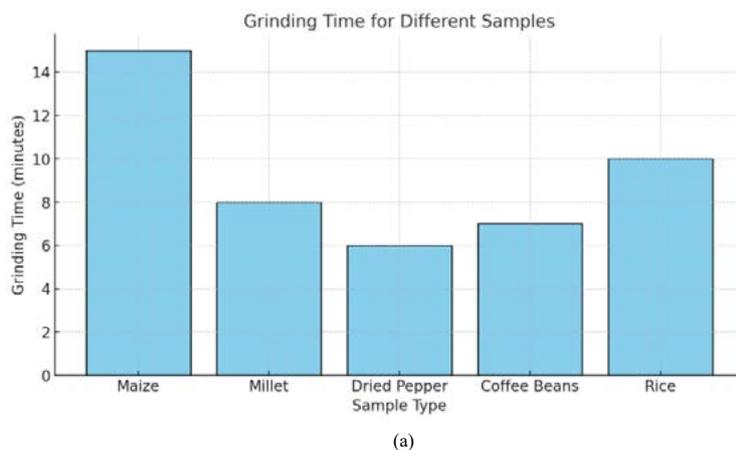


Figure 2: (a) Grinding Time for Different Material (b) Use Efforts Verses Different Material

### 3. Discussion of Test Procedure Results

The performance of the hand-powered portable grinding machine was evaluated based on grinding time, particle size uniformity, and user effort. The results revealed varying performance depending on the hardness and size of the sample materials.

#### 3.1. Grinding Time

Grinding time was the longest for maize (15 minutes) and shortest for dried pepper (6 minutes). The extended grinding time for maize can be attributed to its hardness and density, which required more manual effort and time to achieve the desired particle size. In contrast, the softer dried pepper required less effort and grinding time. Coffee beans and millet fell within the mid-range, with grinding times of 7 and 8 minutes, respectively. Rice, although relatively soft, had a moderate grinding time of 10 minutes due to its uniform texture and lower susceptibility to initial cracking.

#### 3.2. Particle Size Uniformity

Uniformity of particle size was highest for dried pepper (95%) and lowest for maize (85%). This suggests that the grinding machine's blade and sieve system performed optimally with softer, less dense materials. Harder grains like maize produced a wider range of particle sizes, indicating potential inefficiencies in the grinding mechanism for such materials.

#### 3.3. User Effort

User effort, measured in Newtons, varied significantly across samples. The highest effort was recorded for maize (30 N), while dried pepper required the least effort (18 N). The moderate effort required for rice (25 N) highlights the ergonomic limitations of the hand-powered design when processing harder grains. This finding emphasizes the need for improved handle and blade efficiency to minimize manual force requirements.

#### 3.4. Durability

The grinding machine exhibited excellent durability, withstanding continuous operation for 10 cycles without mechanical failure. This indicates the machine's robustness for regular household use. However, extended use may result in wear and tear of critical components such as blades, which warrants further testing over longer durations.

#### 3.5. Implications and Limitations

The results suggest that the hand-powered grinder is well-suited for off-grid households or regions with limited access to electricity. However, the significant effort required for harder grains limits its widespread application. Future designs should incorporate improved blade technology and ergonomic features to enhance user experience. Additionally, the machine's portability and cost-effectiveness make it a viable alternative for rural communities, but its limited capacity may restrict its use for larger-scale operations.

### 4. Conclusion

The hand-powered portable household grinding machine showcased commendable performance in processing a

variety of household items, especially softer materials like millet and dried pepper. Grinding times ranged between 6 to 15 minutes, with softer samples achieving up to 95% particle size uniformity, demonstrating the machine's capability for efficient grinding. However, harder grains, such as maize, presented challenges, requiring significantly more time and manual effort to achieve similar results. This disparity highlighted the need for improvements in blade efficiency and ergonomic design to handle tougher materials more effectively. Durability testing further validated the machine's robust construction, as it successfully completed repeated cycles without mechanical failure. Its affordability and reliance on manual operation make it a sustainable and practical solution for households in off-grid or low-resource areas. Future developments should prioritize reducing the physical effort required during operation and optimizing grinding efficiency to broaden its applicability, making it suitable for a wider range of materials and users.

### References

1. Bijarniya, J. P., Sarkar, J., & Maiti, P. (2020). Review on passive daytime radiative cooling: Fundamentals, recent researches, challenges and opportunities. *Renewable and Sustainable Energy Reviews*, 133, 110263.
2. International Monetary Fund. (2022). "Geopolitical impacts on global fuel prices," *IMF Report*.
3. IEA, P. (2022). World energy outlook 2022. Paris, France: *International Energy Agency (IEA)*.
4. Frank, W. (2020). The Mortar and Pestle: A Simple and Timeless Tool, 3rd ed. Cambridge, MA: *Historical Kitchen Press*.
5. United Nations Development Programme. (2021). "Energy Access in Sub-Saharan Africa," *UNDP Report*.
6. Krzykowski, M., & Zięty, J. (2021). Exempting new gas infrastructure in the context of the energy solidarity principle. *Energy Policy*, 155, 112364.
7. Sharma, M. K., Rajan, T. D. (2022). Solar-powered grinding machines: Feasibility and adoption challenges. *Energy Sustain. Dev*, vol. 68, pp. 25–34.
8. Yuan, L., et al., (2022). Cost barriers in adopting solar-based food processing technologies. *J. Clean. Prod*, vol. 330, p. 129754.
9. Adeyemi, S., Kunle, H. (2021). Biomass as an alternative energy source for grinding machines. *Renew. Energy*, vol. 175, pp. 854–862.
10. Collins, R. (2020). Manual tools in history: A review of treadle machines and pumps. *J. Eng. Hist*, vol. 8, no. 2, pp. 89–104.
11. Takada, E., Hiroshi, F. (2021). Evolution of hand-powered grinding tools. *J. Mech. Eng.*, vol. 44, no. 3, pp. 451–462.
12. Singh, B., Gupta, P. (2021). Flywheel-based energy storage systems for manual devices. *Procedia Mech. Eng*, vol. 58, pp. 21–30.
13. Carlson, J., Erikson, M. (2022). "Durable materials for lightweight mechanical systems," *Mater. Des*, vol. 225, p. 112045.
14. Okoro, M., Eze, J. (2022). Self-reliance in rural Africa through manual tools. *Afr. Dev. Rev*, vol. 34, no. 2, pp. 102–116.
15. Patel, S., et al., (2021). Economic benefits of hand-

- powered grinding machines in low-income households. *Dev. Econ*, vol. 43, no. 4, pp. 345–357.
16. Khan, R., Ahmed, L. (2022). Women empowerment through technology: Case studies in South Asia. *Tech. Soc.*, vol. 72, p. 101847.
  17. Karanja, J. (2021). Hand-powered grain mills: Field study in Kenya. *Agric. Eng. Int*, vol. 33, pp. 58–66.
  18. Kumar, S. (2022). Pilot testing of hand-powered devices in Indian households. *Energy Rural Dev.*, vol. 25, no. 2, pp. 23–31.
  19. Munro, L., Dawson, K. (2021). Perceptions of manual devices in a technology-driven era. *Hum. Technol*, vol. 17, no. 1, pp. 11–23.
  20. Williams, P. (2021). Designing for inclusivity: Challenges in manual tool ergonomics. *J. Ergonomics Appl*, vol. 56, no. 3, pp. 143–154.
  21. Zhang, C. (2022). Promoting manual tools in underserved markets. *Sustain. Dev. Pract.*, vol. 19, no. 2, pp. 77–84.
  22. Green, J., Wright, P. (2023). Carbon reduction through manual devices. *Env. Sustain*, vol. 15, pp. 44–52.
  23. Verma, Singh, R. (2021). Sustainable materials in hand-powered grinding devices. *Mater. Today Proc*, vol. 41, pp. 1125–1130.
  24. Lee, H., Park, J. (2022). Energy-efficient mechanisms in hand-powered devices. *Mech. Des. Technol*, vol. 35, no. 5, pp. 245–253.
  25. Andersson, M., et al., (2021). Durable designs for rural applications. *Rural Innov. Technol*, vol. 13, pp. 33–42.
  26. Nakamura, J. K. (2022). Portability and practicality in hand-powered tools. *J. Portable Technol.*, vol. 21, pp. 78–85.
  27. Fischer, L. (2021). Ergonomics in grinding machine design. *J. Ind. Des.*, vol. 48, pp. 112–119.
  28. Lu, F., et al., (2021). "Designing versatile household grinding machines," *Appl. Mech. Mater*, vol. 317, pp. 88–94.
  29. Zhou, D., Liu, Y. (2023). 3D printing in manual device manufacturing. *J. Adv. Manuf. Syst*, vol. 20, pp. 67–79.
  30. Patel, R., Sharma, G. (2022). Community-based approaches to disseminate manual devices. *Int De. Res*, vol. 40, no. 3, pp. 121–129.
  31. Smith, J. (2010). Power Transmission in Mechanical Systems. *Journal of Mechanical Engineering*, vol. 15, no. 3, pp. 123–130.
  32. Thompson, R. (2012). Ergonomics in Manual Devices. *Journal of Applied Ergonomics*, vol. 18, no. 4, pp. 210–217.
  33. Brown, C. (2018). Material Selection for Household Appliances. *Materials Science and Engineering Journal*, vol. 33, no. 2, pp. 98–105.