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Design and Fabrication of a Briquetting Machine

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Abstract

This research paper reports the design and fabrication of an appropriate, efficient and cost effective biomass briquetting machine that is suitable for local use both in terms of the briquetting press for local manufacture and the briquettes produced. The machine was designed to compress biomass materials (sawdust, rice husk and palm fruit shell) in the briquetting die easily. The developed machine was fabricated using 100% local content. The machine comprised of a hopper, compaction chamber, die/barrel, feed screw extruder, feed screw housing, bearings power transmission shaft and the frame. The developed machine was tested by using it to produce briquettes samples from sawdust, rice husk and palm fruit shell under the same condition of binder concentration. The compressive strengths of each samples were obtained. Results showed that the compressive strength of the briquettes samples ranged from 0.9kN/m^2 to 1.3kN/m^2 with palm fruit shell having the highest compressive strength of 1.3kN/m^2. The machine was found suitable to be used in producing briquettes from sawdust, rice husk and palm fruit shell for both local and industrial uses.

1. Introduction

The primary source of energy for such vital activities as cooking and space heating is burning wood and other agricultural products. An increasing population using limited resources of combustible materials will eventually result in the shortage of those materials unless urgent steps are taken to reverse the trend. Briquetting is one way of making efficient use of existing resources and it involves collecting combustible waste materials and compresses them into solid fuels of convenient shape that can burn like wood or charcoal [1].

Biomass briquetting is the densification of loose agro residues with or without a binding agent to produce compact solid composites of different sizes with the application of pressure. A briquette is formed from the physic-mechanical conversion of dry, loose and tiny particle size material with or without the addition of an additive into a solid regular shape. Briquettes are mainly used for heat applications and power generation through gasification of biomass briquettes and for domestic uses [2].

Obi *et al*., [3], reported that although the importance of biomass briquette as a substitute fuel for wood is widely recognized, the failures of briquetting machines in almost all developing countries have inhibited their extensive exploitation. The constraint in the advancement of biomass briquetting in developing nations generally, is the development of appropriate briquetting technology that suits the local condition; both in terms of the briquetting press for local manufacture and the briquettes. They attributed the failure of these machines to factors which include inappropriate or mismatched technology, technical difficulty and lack of knowledge to adapt the technology to suit local conditions, excessive initial and operating cost of the machines, and the low local prices of wood fuel and charcoal.

Hood [4] reported the existence of a number of developed machines for the production of biomass briquettes in developing countries. He noted that some of these machines in the rural areas are either gender unfriendly, have poor production capacity and briquette quality, and depends on direct human strength for densification. He also noted that there is a need to develop an appropriate briquetting machine suitable for the local communities in the developing nations. He however added that for biomass to make a significant impact as fuel for rural communities, it is imperative that an efficient, cost effective and easy to duplicate technology is developed specifically for rural communities.

Agidi *et al.*, [5] reported that developing countries are faced with the huge problem of waste management and agro residues. Agro wastes and sawmill residues are burnt on roadside or dump yards, which results in pollution they noted that there is a need to convert these residues into usable fuels. They observed that these residues are very difficult to handle, store and results in very poor thermal efficiency and create lots of air pollution when burnt directly. They however concluded that these problems could be avoided by briquetting the waste biomass into a usable energy generating fuel. This will make biomass briquettes an alternative for fossil fuels, improve waste management and reduced air pollution.

In this research paper, we reported the development of an appropriate, efficient, and cost effective biomass briquetting machine that suits local use; both in terms of the press itself for local manufacture and the briquettes produced. Briquettes were produced using rice husk, palm fruit chaff and sawdust with the developed briquetting machine.

2. Methodology

The methodology adopted in this research paper is to design the briquetting machine, fabricate the briquetting machine, produce the briquettes and determine the compressive strength of the briquettes produced using rice husk, palm fruits chaffs and sawdust.

2.1 Machine Description and Manufacturing Processes

1. *Feed Screw Extruder:* The feed screw extruder machined from a single mild steel shaft conveys the raw material and feed it through the barrel or die of the briquetting machine. The first and the second flights of the screw were hard-faced by welding after machining. It creates pressure and high temperature on the raw materials as it passes through the die to produce the briquettes. The feed screw extruder is as shown in Fig. 1.

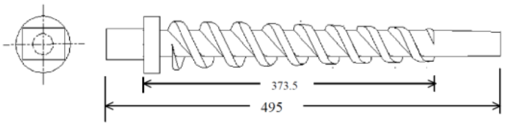


Fig. 1: Feed Screw Extruder

2. *Feed Screw Housing:* The feed screw housing was produced using various machining processes and it houses the feed screw extruder which converts the raw materials to briquette. It consists of the cylindrical housing and a tapered die attached to its end. The hopper positioned on top of the housing by bolts and nuts feeds the raw materials into the compression chamber and they are conveyed to the die by the feed screw were it is compressed and converted to briquettes. The feed screw housing is as shown in Fig. 2.

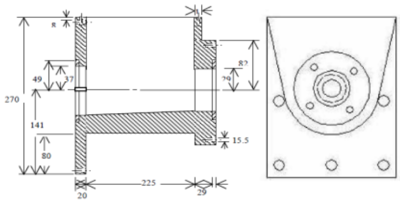


Fig. 2: Feed Screw Housing

3. *Bearing Housing:* The bearing housing protects the bearings from dust and other impurities. Bearings number 1162 and 1163, whose specifications given in Fig. 4 was used.

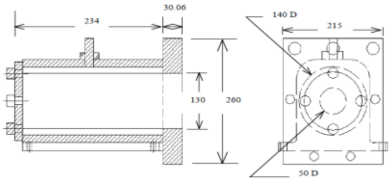


Fig 4: Bearing Housing

4. *Die/Barrel:* The die/barrel made of mild steel and machined on the lathe to its required dimensions had a die clearance and the taper angle of 45 mm and 2° respectively. The die clearance and the taper angle determine the performance of production rate of briquetting machine. The die/barrel is as shown in Fig. 5.

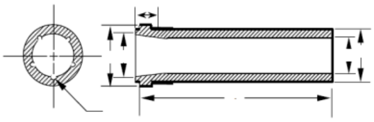


Fig. 5: Die/Barrel

5. *The Bearing:* Two pillow frictionless bearings were used to support the shaft on the frame.

6. *Power Transmission Shaft:* The power transmission shaft produced from mild steel has dimension 450mm long by 70mm diameter. The shaft produced using various machining processes carried the main pulley on one end and a coupling on the other end. It transmits power from the source (electrical motor) through a system of pulleys to the feed screw extruder.

7. *Hopper:* The hopper, made from 1.5mm mild steel sheet was constructed into a frustum and it is used to temporarily hold the raw material before they are fed into the compaction chamber.

8. *Frame:* Mild steel angle bars were used to produce the frame which supports the barrel housing, the hopper and the shaft". "The overall dimensions of the stand are 1000mm X 790mm X 500mm". The function of the frame is to hold all the other parts of the briquetting machine and to resists vibration while running.

2.2 Design Calculations

1. *The Hopper:* The hopper was designed as a frustum of a square pyramid. Using similar triangles, Fig. 7

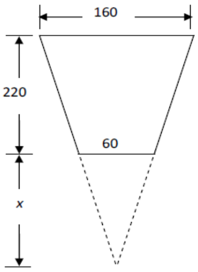


Fig 7: The Hopper

$$\frac{220+x}{160}=\frac{x}{60}. \quad (1)$$

$$x=132. \quad (2)$$

Volume of hopper = volume of the big cone – volume of the small cone. (3)

$$V=\frac{1}{3}\pi\left(R^2H-r^2h\right)=2.235\times10^{-3}m^3. \quad (4)$$

2. Die/Barrel Design

$$Weight = mass\ \times gravitational\ force. \quad (5)$$

$$Mass, m = \ \rho_{mild\ steel} = 7860\ kg/m^3\ [14] \quad (6)$$

$$Volume\ of\ the\ barrel = volume\ of\ cylinder + volume\ of\ the\ tapered\ end. \quad (7)$$

$$Volume\ of\ the\ cylinder = \frac{1}{4}\pi d^2 l. \quad (8)$$

$$where\ l = length\ of\ the\ cylinder = 530mm. \quad (9)$$

$$d = diameter\ of\ the\ cylinder = 120mm. \quad (10)$$

$$Volume\ of\ cylinder = \frac{\pi\times120^2\times530}{4} = 5.994\times10^{-3}m^3. \quad (11)$$

the die is a frustum of a cone and is designed, using similar triangles in Fig 8,

$$\frac{100+x}{120}=\frac{x}{50};\ x = 71.4mm. \quad (12)$$

$$volume\ of\ tapered\ die = volume\ of\ big\ cone = volume\ of\ small\ cone. \quad (13)$$

$$=\frac{1}{3}\pi(r_1^2h_1-r_2^2h_2)=\frac{1}{3}\pi\times(60^2\times171.4-25^2\times71.4)=5.99\times10^{-4}m^3. \quad (14)$$

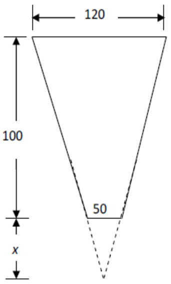


Fig. 8: tapered die

$Total\ volume\ of\ the\ barrel\ =\ volume\ of\ the\ cylinder\ +\ volume\ of\ the\ tapered\ die = 5.994 \times 10^{-3} m^3 + 5.99 \times 10^{-4} m^3 = 6.593 \times 10^{-3} m^3.$ (15)

3. Weight of Rice Husk

$weight\ of\ rice\ husk, W_r\ =\ mass\ of\ rice\ husk\ \times density\ of\ rice\ husk.$ (16)

$mass\ of\ rice\ husk = volume\ \times density.$ (17)

$density\ of\ rice\ husk\ =\ 114 kg/m^3$ [6]. (18)

$volume\ of\ rice\ husk\ =\ volume\ of\ hopper\ +\ volume\ of\ barel$

$= 2.235 \times 10^{-3} m^3 + 6.593 \times 10^{-3} m^3 = 8.828 \times 10^{-3} m^3.$ (19)

$The\ mass\ of\ rice\ husk\ =\ V_{rice\ husk} \times \rho_{rice\ husk} = 8.828 \times 10^{-3} m^3 \times 114\ kg/m^3 = 1.006392 kg.$ (20)

$therefore, weight\ of\ rice\ husk\ =\ m_{rice\ husk} \times g = 1.006392 \times 9.81 = 9.8727 N.$ (22)

4. Weight of Sawdust

$weight\ of\ sawdust, W_s\ =\ mass\ of\ sawdust\ \times density\ of\ sawdust.$ (23)

$mass\ of\ sawdust = volume\ \times density.$ (24)

$density\ of\ sawdust\ =\ 267 kg/m^3$ [7]. (25)

$volume\ of\ sawdust\ =\ volume\ of\ hopper\ +\ volume\ of\ barel$

$= 2.235 \times 10^{-3} m^3 + 6.593 \times 10^{-3} m^3 = 8.828 \times 10^{-3} m^3.$ (26)

$The\ mass\ of\ sawdust\ =\ V_{sawdust} \times \rho_{sawdust} = 8.828 \times 10^{-3} m^3 \times 267\ kg/m^3 = 2.357076 kg.$ (27)

$therefore, weight\ of\ sawdust\ =\ m_{sawdust} \times g = 2.357076 \times 9.81 = 23.1229 N.$ (28)

5. Weight of Palm Fruit Chaff

$weight\ of\ palm\ fruit\ chaff, W_p = mass\ of\ palm\ fruit\ chaff\ \times$
$density\ of\ palm\ fruit\ chaff.$ (29)

$mass\ of\ palm\ fruit\ chaff = volume\ \times density.$ (30)

$density\ of\ palm\ fruit\ chaff\ =\ 287 kg/m^3$ [8]. (31)

$volume\ of\ palm\ fruit\ chaff\ =\ volume\ of\ hopper\ +\ volume\ of\ barel = 2.235 \times 10^{-3} m^3 + 6.593 \times 10^{-3} m^3 = 8.828 \times 10^{-3} m^3.$ (32)

$The\ mass\ of\ palm\ fruit\ chaff\ =\ V_{palm\ fruit\ chaff} \times \rho_{palm\ fruit\ chaff} = 8.828 \times 10^{-3} m^3 \times 287\ kg/m^3 = 2.533636 kg.$ (33)

$therefore, weight\ of\ palm\ fruit\ chaff\ =\ m_{palm\ fruit\ chaff} \times g = 2.533636 \times 9.81 = 24.85496919 N.$ (34)

6. *Shaft:* The shaft is made of mild steel and the pulley was keyed to it. The yield strength in tension, S_{yt} = 770N/mm^2 and ultimate tensile strength = 580N/mm^2. Assuming the load is gradually applied, the combined shock and fatigue factor applied to bending moment, K_b = 1.5 and combined shock and fatigue factor applied to torsional moment, K_t = 1.0. The permissible shear stress, τ, is taken to be 30% of the yield strength or 18% of the ultimate tensile strength of the material or whichever is minimum [9].

$Therefore, \tau = 0.3 S_{yt} = 0.3(580) = 174 N/mm^2.$ (35)

$\tau = 0.18 S_{ut} = 0.18(770) = 138.6 N/mm^2.$ (36)

$\tau = 0.75 \times 138.6 = 103.95 N/mm^2.$ (37)

$let\ d\ =\ diameter\ of\ shaft,$

$M_t = torque\ transmitted\ by\ the\ shaft,$

$P = power\ tranmitted\ by\ the\ shaft\ (W),$

$N = rpm\ of\ the\ shaft,$

$\tau =\ permissible\ shearing\ stress, and$

$M_b = bending\ moment.$

The power transmitted by shaft and the torque in the shaft are related [9] as given in Eq. (38)

$P = M_t \omega.$ (38)

$\omega = \frac{2\pi N}{60}.$ (39)

$P = \frac{M_t \times 2\pi N}{60}.$ (40)

$$M_t = \frac{30P}{\pi N}. \quad (41)$$

The shear stress and transmitted torque are related Eqs. 42 and 43

$$\tau = \frac{16M_t \times 10^3}{\pi d^3}. \quad (42)$$

$$M_t = \frac{\pi \tau d^3}{16} \times 10^{-3} N/mm^2. \quad (43)$$

$$d = 36.5 \times \left(\frac{P}{\tau N}\right)^{0.33} mm = 36.5 \times \left(\frac{3000}{103.95 \times 480}\right)^{0.33} = 14.44mm. \quad (44)$$

also the diameter of the shaft can be calculated as follows,

$$\tau = \frac{16\sqrt{[(K_b M_b)^2 + (K_t M_t)^2]}}{\pi d^3}, \quad (45)$$

$$d^3 = \frac{16\sqrt{[(K_b M_b)^2 + (K_t M_t)^2]}}{\tau \pi}, \quad (46)$$

M_t the torque transmitted by the shaft is given by,

$$M_t = \frac{30P}{\pi N} = \frac{30 \times 3000}{480\pi} = 59.675Nm = 59675Nmm, \quad (47)$$

$$M_b = 127{,}306Nmm, \quad (48)$$

$$d = \frac{16\sqrt{[(1.5 \times 127306)^2 + (1.0 \times 59675)^2]}}{103.95\pi} = 21.34mm, use\ 25mm. \quad (49)$$

2.3 Biomass-binder Mixture.

Sawdust, Rice Husk and Palm Fruits Shell samples were mixed with cassava starch in proportions of 100:15 by weight in line with the works of [10, 11]. The starch and the biomass sample were properly mixed without forming a muddy mixture because the formation of muddy mixture due to excess addition of water reduces both the durability and density of the briquette [12]. The biomass-binder mixture was fed into the machine and briquettes were formed, after which they were sun dried.

2.4 The Principle of Operation of Briquetting Machine.

The briquette machine is a single extrusion die screw press that consists mainly of driving motor, speed reducer gearbox, feed screw, die, and the housing with a hopper. The motor transmits power directly to the screw through the speed reducer. As the machine is running raw materials are fed into the compaction chamber through the hopper; the raw materials are compressed in the barrel by the screw, and extruded through the die. The screw continuously forces the materials into the die. In an extrusion die screw press pressure is built up along the screw rather than in a single zone as in the piston type machines.

2.5 Compressive Test

Compressive test was carried out on samples of the briquettes using a compressive testing machine. The machine consists of a hydraulic jack, a load measuring gauge and a dial gauge. This was done to determine the compressive strength of the briquettes produced or the maximum load it can withstand.

The briquettes were placed in-between two jaw plates of the machine and pressure applied via the hydraulic jack to compress the briquettes plate until it starts to fail. The pressure displayed on the pressure gauge and dialed gauge were taken.

3. Results and Discussion

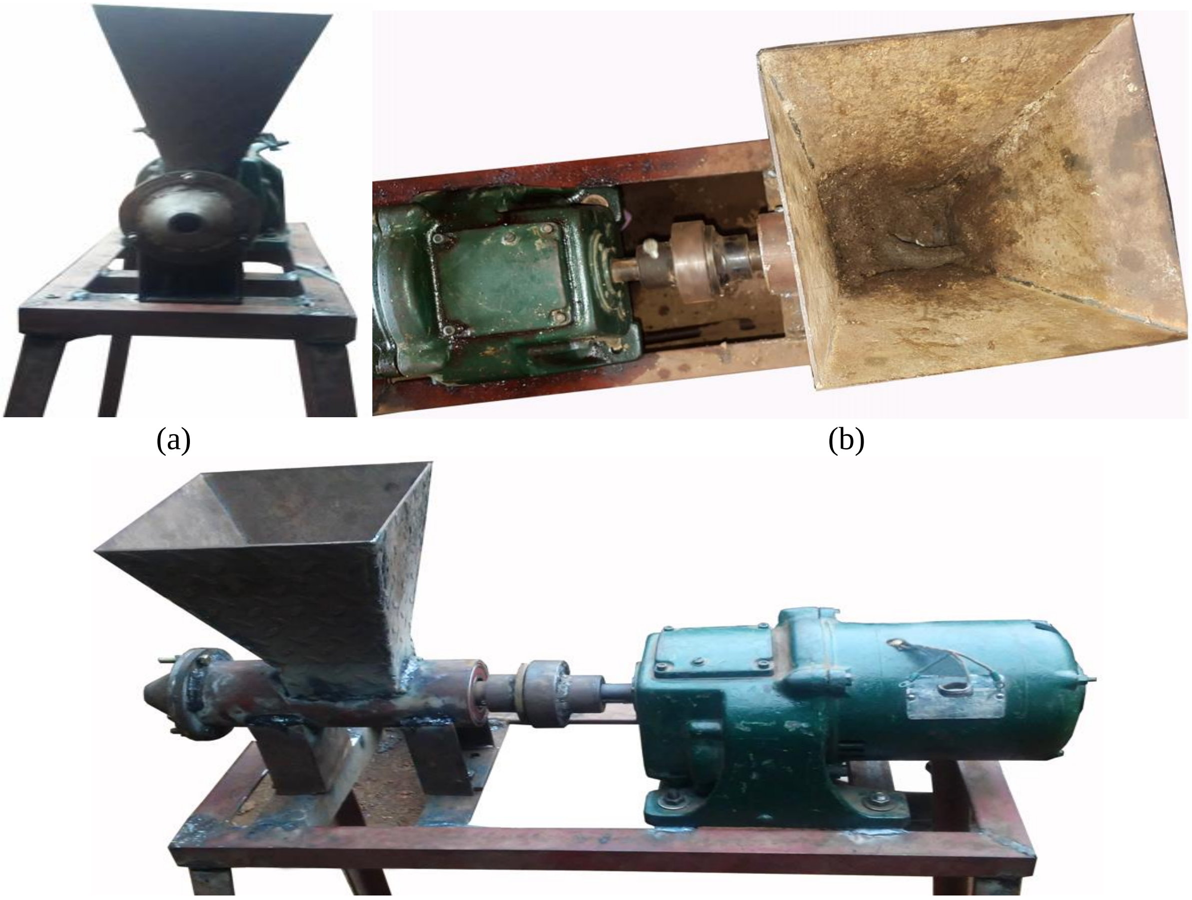
Producing briquettes from the machine developed a known quantity of sawdust, rice husk and palm fruit shell was sourced from a local sawmill, rice mill and an oil palm mill and pulverized in order to increase the surface area and to enhance binding efficiency. Briquettes were produced from sawdust, rice husk and palm fruit shell using the developed briquette machine. The compacting force of the rotating feed screw was able to gently push the mixture of the raw material inside the hopper into the die where compression took place. 5kg of the pulverized sawdust, rice husk and palm fruit shell were each mixed thoroughly with the binder. Briquettes produced were thereafter sundried.

The mean biomass loading time, compaction time, and ejection time for the briquetting machine are shown in Table 1. The developed briquetting machine is shown in Fig. 9 and Fig. 10 to 12 shows the respective briquettes produced using the developed briquetting machine.

Table 1: Production time components of the briquetting machine

Mean Production Time	Time [sec]		
	Sawdust	Rice Husk	Palm Fruits Shell
Biomass loading time	35	35	37
Biomass compaction time	45	42	45
Briquette ejection time	27	25	28

The developed briquetting machine is shown in Fig. 9



(a) (b)

(c)

Fig. 9(a), (b) and (c): The fabricated screw press briquetting machine.

Fig. 10 to 12 shows the respective briquettes produced using the developed briquetting machine.


Fig 10: Briquettes from Rice Husk

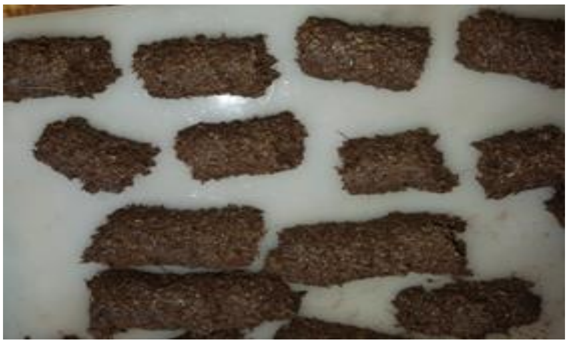


Fig 11: Briquettes from Sawdust


Fig 12: Briquettes from Palm Fruits Shell

The compressive strength of all the briquettes produced ranged from 0.9kN/m^2 to 1.30kN/m^2. The compressive strength of all the samples was determined and results are presented in Table 2 and Fig. 13. These results were compared with the Gbabo et al., [5] and it was observed that the machine was suitable to be used in producing briquettes from sawdust, rice husk and palm fruit shell for both local and industrial uses.

Table 2: Compressive strength for briquettes from different materials

Briquettes	Samples 1 (kN/m^2)	Samples 2 (kN/m^2)	Samples 3 (kN/m^2)
Saw Dust	0.90	1.10	1.00
Rice Husk	1.10	1.15	1.15
Palm Fruit Shell	1.25	1.20	1.30

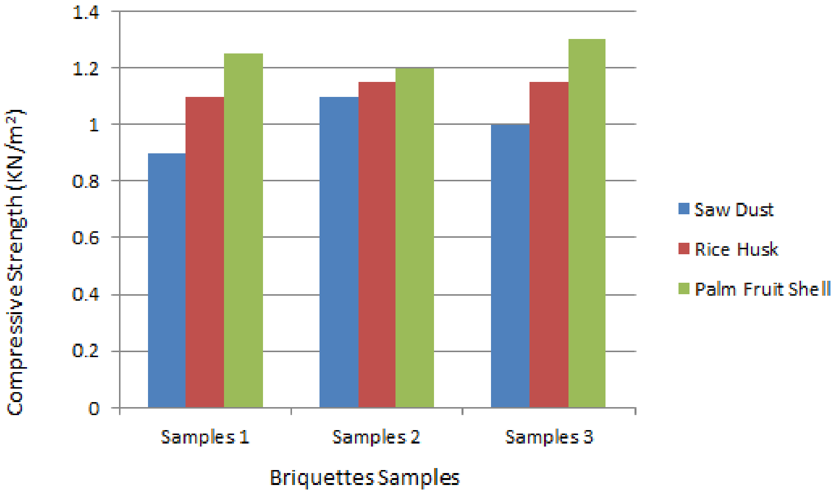


Fig.13: Compressive strength for briquettes from different materials

4. Conclusion

A briquetting machine was designed, manufactured and tested for its suitability for production of briquettes using saw dust, rice husk and palm fruit shell. The briquetting machine produced used a power screw to compress the raw materials to produce briquettes. Compressive test was carried out on samples of the briquettes using a compressive testing machine. Results showed that the compressive strength of all the briquettes produced ranged from 0.9KN/m^2 to 1.30KN/m^2. These results were compared with literature and it was observed that the machine was suitable to be used in producing briquettes from sawdust, rice husk and palm fruit shell for both local and industrial uses.

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