



ORIGINAL RESEARCH ARTICLE

TRIBOLOGICAL EVALUATION OF CANARIUM SHWEINFURTHI (AFRICAN ELIMI) OIL AS LUBRICANT IN METAL FORMING

P. M Kamtu^{1*}, N.S Gukop¹, A. Ashwe², D. T. Gundu², W.Y.T Albert³, A. Babawuya⁴ and C.A. Popoolao⁵

¹Department of Mechanical Engineering, University of Jos, Nigeria,

²Department of Mechanical Engineering, Fed. University of Agriculture, Makurdi

³HTTTC-Bambili, Mechanical Engineering Department, The University of Bamenda, Cameroon.

⁴Department of Mechatronics Engineering, Federal University of Technology, Minna.

⁵Department of Food Science and Technology, Federal University Wukari, Nigeria

*Corresponding Author: kamtup@unijos.edu.ng

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ABSTRACT

Reducing cost of production arising from high energy due to friction and tool failure using cheaper readily available and environment friendly lubricant is evaluated in this study. An experimental evaluation of tribological properties of Canarium Shweinfurthi (African Elimi) was carried out using Ring Compression Test. This was carried out using Boron Nitride as additive to determine the best quantity that can be added in vegetable oil lubricants. The formulated oils were applied to the die/ring surfaces as they were compressed in the California Bearing Ratio (CBR) using digital display Testometric Universal Testing Machine. The results show that friction factors for the developed lubricant range between $m = 0.3$ and 0.4 while the frictional coefficient results show $\mu = 0.07$ to 0.09 which compared favorably to referenced (mineral) oil which has $m = 0.4$ and $\mu = 0.12$. Additionally, frictional coefficient obtained from the developed lubricant are within the range for vegetable lubricants such as groundnut oil, palm oil, palm kernel and shear oil which range from 0.072 to 0.3 . Furthermore, it was observed that Canarium Shweinfurthi oil could be used as substitute to mineral based oils that are currently in use as lubricants in manufacturing process. Therefore, industrial organizations can take advantage of the benefits this natural, environmentally friendly, biodegradable and low toxicity oil lubricant presents.

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1.0 Introduction

Lubrication is the process or technique employed to reduce friction between, and wear of one or both, surfaces in close proximity and moving relative to each other, by interposing a substance called a lubricant between them. The lubricant can be a solid, solid/liquid dispersion, a liquid such as oil or water, a liquid-liquid dispersion (a grease) or a gas (Szkoda, 2014). Metal forming lubricants are applied to the tool work interface in many forming operations, so as to reduce friction and wear which generally affect the tool life, metal flow, energy consumption, heat evolution and surface finish. Lubricants used in metal forming processes such as metal drawing, extrusion, forging and rolling must develop a very thin adsorbed film, which does prevent metal to metal contact under high pressure. Metal forming lubricants in commercial use are classified as: aqueous dispersion (soap/water type, soap/fat emulsions, soluble oil emulsion etc); oil type fluids (mineral/fat oils, chemicals active oil, oil/wax fluids); solid lubricants and metallic solids (Szkoda, 2014). For over 100 years mineral oils have dominated metal forming lubrication. It has been estimated that 5-10 million tons of petroleum-based oleochemicals enter the biosphere every year and 40% of such come from spills, industrial and municipal waste where metal forming lubricants belong (Smith, 2020).

These mineral oils and synthetics are not readily biodegradable (depositing heavy metals to the ground which affect the ecosystem and human health). This may require washing of the work piece against chemical effect, high cost, and long chain of production process. Generally, the most available mineral oils in use are the

petroleum based which are carcinogenic and are further emphasized by the content of chlorine nitrides or metals (Syahrullail, et al 2011). These are also characterized by many kind of additives such as antioxidant agent, anti-wear agent, detergent, dispersants, antifoams, extreme pressure agent and viscosity improvers. Most of these additives are toxic and in the long run harmful to human, animal and plants.

Consequently, the negative impact of the mineral oils on the environment and human life has brought a renewed interest in natural fatty acid lubricants. These lubricants are derived from vegetables which are naturally biodegradable compared to mineral oils. Furthermore, the bio lubricants show excellent tribological qualities such as low frictional coefficient and good wear protection. This is achieved by ease of processing and regeneration through short rotation plantations, high flash point and low toxicity (Oseni, Gundu, & Enenta, 2012). It is noteworthy of the vegetable based lubricants caused by low thermo-oxidation stability primarily due to the presence of bis-allylic protons, hydrolytic stress and partly inferior cold flow properties. This can be corrected through the addition of some elements which are considered safe to the environment, (Syhrullail, M., S., & Ridzuan, 2011).

Most vegetable seed oils find wide applications in the production of soaps, paints, varnishes, lubricants, hydraulic fluids, printing inks, dyes, pesticide and insecticides (Uzoh, 2013). *Canarium Schweinfurthii* or otherwise call genus *canarium* is a perennial plant that is found in Africa. It is usually referred to as African olive or black olive. The tree has a lot of branches with an attendant height of 90-150ft tall and thrives well in the rocky and the flat lands of Plateau state of Nigeria (Orwa, 2009). There are many varieties of the plant producing fruits of different sizes ranging from 1.84-3.06 cm long, (Nyam & Wonang, 2004). The fruit has a sharp point at the apex and a persistent calyx at the base. The fruit contains a hard fluted stone which contains a seed inside; the seeds are edible. They are similar in structure and color to the well-known fruits of olive (*Olea europaea*) of the Isreal, though from different families (Nyam, Makut, Itelima, & Darriel, 2014).

The properties and qualities of the oils have been investigated to some extent. The oils have been shown to have potential industrial uses in production of pharmaceutical, personal products and as a thernal fluid among others. However, unlike some other oil-bearing plants such as groundnut, cotton seed, soybean, palm pulp and palm kernel are not being carried out at commercial level at present, despite their abundance in Nigeria and elsewhere in sub-Sahara Africa (Nyam, et al, 2014)

Canarium schweifurthii (African olive) oil is studied in this work with a view to determining its tribological properties in upset forging through the use of ring compression test. The study wished to provide in-depth analysis of lubricant formation, frictional factor and frictional coefficient determination. This is aimed at determining its characteristics and subsequent recommendation for use as metal forming lubricant.

The physiochemical properties of the fruit (Table I) and the prominate composition of the pulp was conducted by Nyam, et al 2014.

Table I: Approximate composition of *Canarium schweinfurthii* fruit(Nyam, Et al 2014)

Parameter	Whole seed	Pulp
Thickness (cm)	4.0	6.0
Fruit length (cm)	4.5	6.0
Shape	Oblong	Oblong
% free fatty acid	3.52	3.28
Melting point (°C)	32	30
% moisture impurity & volatile (miv)	1.72	1.70

The ring compression test (Alexandru, 2017) is commonly used to evaluate forging lubricants. The ring test consists of the deformation of a cylinder with a hole drilled through the center of the billet. The billet is compressed to various height reductions and the change in the inner diameter of the billet reflects the friction factor along the tool/work piece interface. The higher the friction the more the inner diameter of the test piece is reduced. In low friction environments, the inner diameter of the billet increases Figures 1-3. The frictional factor and coefficient are determined through the use of calibration curves shown in Figure 4-5.



Figure 1: Original ring before compression

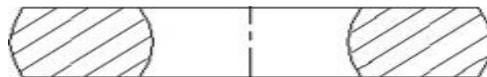


Figure 2: Ring after compression with high friction (poor lubrication)

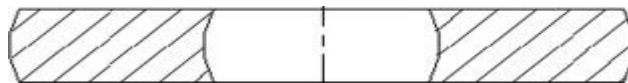


Figure 3: Ring after compression with low friction (Good lubrication)

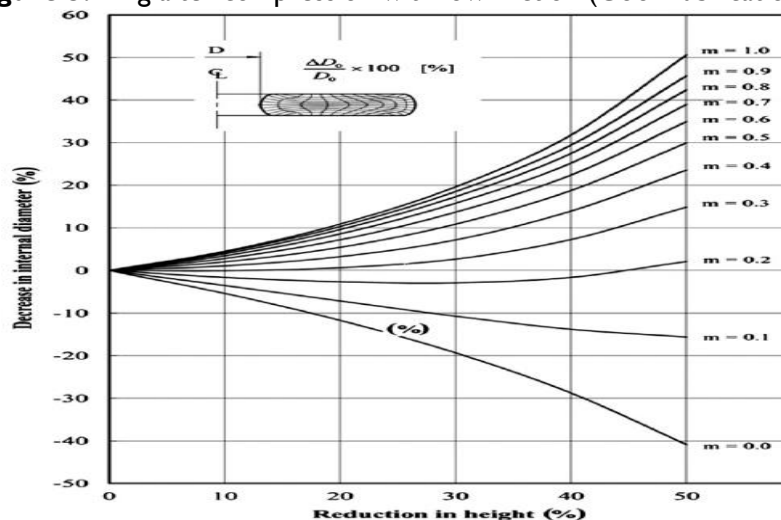


Figure 4: Typical calibration curves for ring compression test for frictional coefficient (μ)

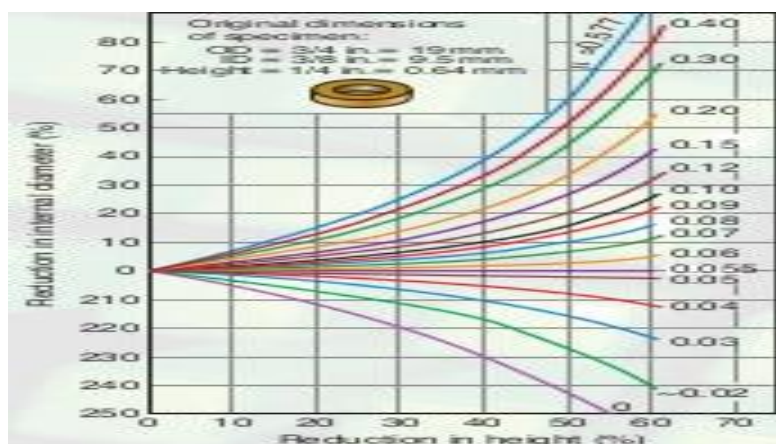


Figure 5: Typical calibration curves for ring compression test for shear factor (M)

2. Materials and Method

2.1 Materials Collection and Preparation

The ripe *Canarium shweinfurthi* fruits were purchased from the open market in Jos. They were first sorted to remove foreign materials, unripe and infected fruits. The fruits were then washed with clean water and dried (Table 2). Boron nitride was obtained from Burgoyne Burbidges and Company Mumbai, India. Aluminum alloy was obtained from the selected aluminum scraps in Farin Gada market in Jos, while acetone or propanone ($(\text{CH}_3)_2\text{CO}$) was obtained from JC Chemical laboratory in Jos.

2.2 Oil Extraction

Various components of the fruit (pulp, seed and oil) were separated using the traditional method as described by Nyam et al., (2014).

The foam and oil formed on top layer were skimmed and scooped out using sterile wooden spoon. The various components of the fruit after oil extraction were presented in Table 3.

Table 3: Elemental parts of fruit after extraction

S/No	Item	Weight (G)	Weight (Kg)	% of Total Weight
1	Oil	3,964	3.964	05.15
2	Seed	29,725	29.725	38.60
3	Pulp	19,464	19.464	25.28
4	Moisture	23,849	23.849	30.97
TOTAL		77,002	77.002	100

2.3 Design of Experiment

Design of experiment for this research was achieved using the software Design Expert (2010). It was used in complementing multivariate data analysis, such as development of empirical models, optimization of the process variables and statistical analysis. This was used to obtain the sample size and optimal Lubricant and coefficient of friction. There were three design factors and two levels for the experiment that were used. The design factors for the lubricant were *Canarium shweifurthei* oil, water substance in the oil and Boron Nitride which served as additive. Boron Nitride was added to the lubricants at two levels (low and high) of 0.02% and 0.4%. This gave rise to three combination (three elements for lubricant formulation) at two levels (low and high levels of boron nitride) for the lubricant formulation (3²). Run Order obtained in Table 4 gave rise to 8 experimental design order. Considering zero boron nitride, no lubricant condition and standard lubricant condition, the total number of experimental designs came to eleven. An additional sample number was added to make it twelve. Tables 4 and 5 shows the experimental layout in orthogonal array and addition of boron nitride to the lubricant.

Table 4: Experimental layout in orthogonal array

C1	C2	C3	C4	C5	C6	C7
StdOrder	RunOrder	CenterPt	Blocks	A	b	c
2	1	1	1	0.40	0	0
7	2	1	1	0.02	50	50
4	3	1	1	0.40	50	0
8	4	1	1	0.40	50	50
6	5	1	1	0.40	0	50
3	6	1	1	0.02	50	0
5	7	1	1	0.02	0	50
1	8	1	1	0.02	0	0

2.4 Addition of Boron Nitride to Lubricant

Maximum quantity by weight of boron nitride added to the lubricant ranged from 0.02% to 0.4% as recommended by Dehghan, Qods, and Gerdooei, (2013) and Frank, K., and Margaret, A., (2014). Each of the lubricant sample was shared into twelve sample bottles. The lubricants were weight into the sample bottles at 31.5g. Sample lubricants for Lub1, Lub2 and Lub3 were enriched with boron nitride as described in Table 7. The quantity of boron nitride to be added to every sample was determined (Equation 1-2).

$$\text{Number of classes} = \frac{\text{Range}(R)}{\text{Class interval } (h)} \quad (1)$$

where Range R = Highest - Lowest (2)

$$= 0.4\% - 0.02\%$$

$$= 0.38\%$$

Class interval h = 10

Number of class = $0.38\% / 0.04\% = 0.04\%$.

The calculated percentage of the boron nitride (0.04%) was added to the samples as shown in Table 5.

Table 5: Lubricant formulation with boron nitride

Sample	Addition of boron nitride to the lubricant
1	Standard Lubricant
2	No lubricant condition
3	Lub + 0.00 wt%BN
4	Sample3 + 0.02 wt%BN
5	Sample4 + 0.04 wt%BN (0.06 wt%BN)
6	Sample5 + 0.04 wt%BN (0.10 wt%BN)
7	Sample6 + 0.04 wt%BN (0.14 wt%BN)
8	Sample7 + 0.04 wt%BN (0.18 wt%BN)
9	Sample8 + 0.04 wt%BN (0.22 wt%BN)
10	Sample9 + 0.04 wt%BN (0.26 wt%BN)
11	Sample10 + 0.04 wt%BN (0.30 wt%BN)
12	Sample11 + 0.04 wt%BN (0.34 wt%BN)

2.5 Determination of Physical Properties of the Developed oil.

The developed oil, African elimi oil was analyzed. The Quality Assurance laboratory of Grand Cereals Company located at Zawan Roundabout, Bukuru in Jos South Local Government of Plateau State, Nigeria was used for the laboratory test as shown in Table 6.

2.6 Tribological Test

2.6.1 Preparation of test piece

Ring compression test according to Alexandru, Gheorghe and Lucian, (2017) was adopted for this work using the Californian Bearing Ratio (CBR). Aluminum alloy with properties shown in Table 7 was prepared and used to produce the test rings. XRF (X-Ray Fluorescence) NEX CG II series analyzer by Rigaku Technologies in National Metallurgical Development Center (NMDC), Jos was used to determine the detectable elements of the aluminum metal as shown in table 7 and according to AZO Materials (2005) established the aluminum grade as 6063A. This was arrived at by comparing the detected element with the standard grade. The aluminum alloy was prepared by gathering aluminum scraps from Farin Gada technical market in Jos. It was smelted to get billets that were machined using the local foundry. The metal was machined to CBR (Californian Bearing Ratio) 6:3:1 outside diameter (D_o) to inner diameter (D_i) to Height (H) (42: 21:7mm) respectively using four jaw chuck lathe machine shown in Plate 1.

Table 6: The determined parameters of the oils

S/N	PARAMETER	AFRICAN ELIMI OIL
1	% Moisture content	0.24
2	% Free Fatty Acid	1.84
3	Iodine Value (wij's)	89.44
4	Refractive Index	1.4619
5	Saponification Value (KOH/gm)	162.66
6	Peroxide Value (mEq/kg)	22.01
7	Soap Value (ppm)	0.00
8	Acid Value(mgKOH/g)	3.83
9	Flash point (°C)	98
10	Cloud point (°C)	9
11	Pour point (°C)	5
12	Specific gravity	0.98
13	Viscosity (cSt)	0.61

Table 7: The various elements of aluminum alloy 6063A as detected by XRF (x-ray fluorescence) analyzer process

Sample - Al-alloy		
S/No	Element	Values
1	Al	99.00
2	S	0.02
3	K	0.02
4	Ca	0.03
5	Ti	0.02
6	V	0.003
7	Cr	0.03
8	Mn	0.15
9	Fe	0.41
10	Ni	0.005
11	Cu	0.05
12	Zn	0.03
13	Ga	0.01
14	Ba	0.009
15	Pb	0.004


Plate 1: Cast aluminum billet with rings

2.6.2 Compression of Test Piece

The tribological test was carried out in two stages; firstly, it was to establish the similarities of the tribological properties of the lubricant developed from the various processes. This was with the view to selecting the best process for further development. The second stage was the determination of the tribological properties of the developed oil using machined aluminum rings. The tests rings were measured to establish similarities due to machining error. These were selected, grouped labeled in sample bags for ease of use. Three tests rings were used with the oil to carry out the compression test on a 300KN capacity QM-300MIF by Qualitest Testometric Universal Testing Machine in NMDC, Jos Plateau State Nigeria. Oil sample was applied on both sides of the ring and was placed between the compression platens of the Testometric machine Plate 2. A force of 270KN was applied on each of the ring at speed of 5 mm/min. Before the next oil was used for test the platens were cleaned with acetone (cleaning agent) using cotton wool. This was done in other to avoid mixture of oil samples at the cause of the experiment.

Various compression parameters such as test number, time of test, area of test piece, force at yield, stress at yield strain at yield, force at peak, stress at peak, strain at peak, young modulus and modulus of elasticity were chosen on the machine desktop and subsequently computed and tabulated by the machine.

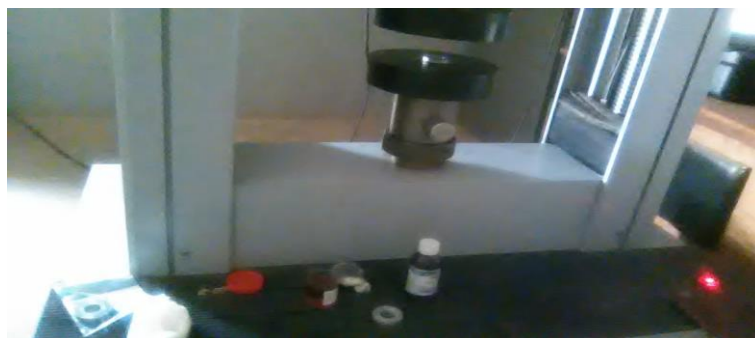


Plate 2: Test ring placed between upper and lower platen of testometric universal testing machine

3. Results and Discussion

Table 6 shows the properties of the oil which are related to those of mineral oil indicating that the oil can be used as lubricant in metal forming processes. The low quantity of acid value of 3.83 signifies its ability to prevent oxidation which ultimately prevent corrosion hazard, gum and sludge formation as suggested by (Kaia, A 2012). The moisture content falls within the agreed range of 25% of water present in vegetable lubricant as suggested by Mary and Doris 2001. That lubricant use in metal forming is a soap/fat paste with a formation of 5% soap, 25% oil, 25% water and 45 % solid. The quantity of Boron Nitride given in table 8, agrees with the standard quantity of additive for vegetable lubricants of 0.02% to 0.4% as suggested by (Frank, et al., 2014).

Table 8 shows the result of the lubricant sample and quantity of boron nitride to be added. The tables show the result of the sample weight in grams. The computed percentage by weight. Results for ring compression test using the developed lubricants are presented in Tables 9. The tables gave results of the computed percentage reduction in internal diameter and height. Table 10 showed result of the determination of frictional factor and frictional coefficient of the lubricant.

Table 8 is the result of the addition of boron nitride as given in Table 5. The table further shows the percentage by weight of the boron nitride as discussed by Dehghan, et al, (2013) and Frank, et al., (2014). It was suggested that the maximum quantity of boron nitride to be added to lubricant is from 0.02% to 0.4%. The quantity of boron nitride to be added to the lubricant was also measured in grams.

Table 9 shows the results of the calculation for the determination of percentage reduction in height and percentage reduction in internal diameter. The result obtained was referred to Figures 4 and 5 to determine frictional factor and frictional coefficient.

Table 8: Quantity of boron nitride in grams

S/N	Sample (g)	% By weight	BN (g)
1	Ref oil		
2	No oil		
3	28.93	0.00	0.00
4	30.96	0.02	0.008
5	33.53	0.06	0.017
6	32.59	0.10	0.034
7	32.02	0.14	0.042
8	32.47	0.18	0.051
9	28.60	0.22	0.067
10	28.90	0.26	0.083
11	32.13	0.30	0.100
12	25.95	0.34	0.108

Table 9: Determination of percentage reduction in internal diameter and height

S/N	BN (g)	do	D _{ave}	D _{Diff}	%Diff	H _{av}	H _{Diff}	%H _{Diff}
1	Ref oil	22	19.63	2.37	10.76	4.6	2.4	34.29
2	No lub	22	20.53	1.47	6.67	5.63	1.37	19.52
3	0	22	20.3	1.7	7.73	4.43	2.57	36.67
4	0.008	22	20.5	1.5	6.82	4.6	2.4	34.29
5	0.017	21.5	19	2.5	11.63	4.27	2.73	39.05
6	0.034	20.5	18.5	2	9.76	4.45	2.55	36.43
7	0.042	21	19.8	1.2	5.71	4.7	2.3	32.86
8	0.051	21.5	20.07	1.43	6.67	5	2	28.57
9	0.067	21	19.43	1.57	7.46	4.73	2.27	32.38
10	0.083	21.5	19.55	1.95	9.07	4.6	2.4	34.29
11	0.1	21	20.4	0.6	2.86	5.3	1.7	24.29
12	0.108	21.5	19.9	1.6	7.44	4.57	2.43	34.76

where; Do = Original internal diameter

$((do - avgd)/do)*100$ = Percentage reduction in internal diameter

Ho = Original height

$((HO - avGH)/HO)*100$ = Percentage reduction in height

Results for the determined frictional factor and frictional coefficient of reference oil, no oil condition and the developed lubricant is displayed in Table 10. The reference oil has frictional factor and frictional coefficient as 0.4 and 0.12 respectively. While the no oil conditional has 0.6 and 0.15 for frictional factor and frictional coefficient respectively. The best result for the developed lubricant is shown on serial number 3 on Table 10. The result shows a record of new vegetable lubricant of frictional factor 0.3 and frictional coefficient of 0.09 as established by this work. The result agrees to ring compression test by Alexandru, Gheorghe and Lucian, 2017 where greater inner diameter to the original ring indicates low friction. Furthermore, smaller inner diameter in comparism to the original ring indicates high friction. Consequently, with 0.1g of Boron Nitride

Corresponding author's email address: kamtup@unijos.edu.ng

added to the lubricant (32.11g) a better result of 0.3 frictional factor with 0.07 frictional coefficient record was established for metal forming. These results measured better than reference oil with 0.4 and 0.12 and dry condition with 0.6 and 0.15 for frictional factor and frictional coefficient respectively.

Table 10: Determination of frictional factor and frictional coefficient

	Bn (G)	Reduction In Internal diameter (%)	Reduction in height (%)	Frictional (m) (From chart)	Factor	Frictional Coefficient (μ) (From chart)
1	Ref. Oil	10.76	34.29	0.4		0.12
2	No Oil	6.67	19.52	0.6		0.15
3	0.00	8.57	40.48	0.3		0.09
4	0.006	7.78	34.29	0.3		0.10
5	0.019	8.64	30	0.4		0.12
6	0.031	5.91	37.62	0.3		0.08
7	0.044	6.36	31.90	0.3		0.09
8	0.055	8.99	32.86	0.4		0.12
9	0.068	5.08	33.81	0.3		0.09
10	0.081	6.83	35.71	0.3		0.09
11	0.092	9.39	35.24	0.3		0.10
12	0.107	9.77	35.24	0.4		0.12

4. Conclusion

The African Elemi fruit oil has identical chemo physical properties with the reference oil. Following the result of tribological test, the African Elemi fruit oil gave satisfactory tribological performance in both ring compression. The results obtained as 0.3 and 0.09 in both frictional factor and frictional coefficient of the developed lubricant were satisfactory and better than the mineral oil 0.4 and 0.12 in frictional factor and frictional coefficient respectively. The Tribological performance was enhanced with Boron Nitride.

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