Original scientific paper

An Evaluation of the Performance of Chainsaw Lubricants

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Abstract

Chainsaws require lubrication of the guide bar and saw chain to function properly. Many oils are commercially available to provide this lubrication. Economical and more recently environmental concerns are increasingly compelling consideration of the best type of oil to use. Several published scientific studies provide some guidance, but additional information is needed for operators to make informed and effective choices in lubricating oil selection. The work presented in this paper contributes to providing this guidance by comparing the performance of economy and premium versions of three commonly-used types of lubricating oils: petroleum-based bar-and-chain oil, biodegradable bar-and-chain oil, and petroleum-based motor oil. Testing was conducted on a laboratory chainsaw test apparatus used in prior published scientific studies of chainsaw performance. Testing consisted of free running (i.e. chain traveling about the bar at cutting speed but not cutting) for a prescribed time period, while lubricating oil was applied to the guide bar and saw chain in the usual manner and at typical flow rates. Based on the correlations between wear, friction, and temperature, the mean guide bar temperature was used as the measure of performance of each oil. Results showed that, while each oil type performed adequately, the petroleum-based bar-and-chain oil performed best and the biodegradable-based oil performed worst with the petroleum-based motor oil providing intermediate performance. No consistent correlation was found between either the unit cost of each oil and its performance or the perceived quality (economy versus premium) of each oil and its performance. Tribological properties of flash point, viscosity, and four-ball wear were measured. A weak correlation was found between flash point values and performance. A possible Stribeck relationship was found for viscosity implying a possible transition from mixed and hydrodynamic lubrication. No correlations were found between performance and four-ball wear test results. These results support chainsaw operator observations and other published scientific findings that a variety of oils can be effectively used as lubricants. The lack of correlation of performance with some commonly-measured tribological properties suggests lubricating-oil providers should consider the use of a dedicated saw chain testing apparatus in product development.

Keywords: chainsaw, guide bar, wear, temperature, friction, lubrication, oil, biodegradable, motor

1. Introduction

To perfom properly, chainsaws require lubrication of the saw chain both for articulation and for sliding along the guide bar. This lubrication has most commonly been provided by petroleum-based oils specifically marketed for chain saws and referred to as bar-and-chain oils. Other petroleum-based oils used are motor oil (both new and used), transmission fluid, and hydraulic oil. More recently, biodegradable oils derived from animal fats and plant oils have become available for chainsaw use. Regardless of type, lubrication in modern chainsaws occurs by drawing oil from a reservoir using a pumping system located in the powerhead, passing it through a port in the groove of the guide bar, and depositing it on the underside of the moving saw chain.

While this system is effective in providing the needed lubrication, it is inherently inefficient and causes pollution. There is no means of recovery and all of the oil is eventually dispersed into the surrounding environment. Specifically, 64% of oil is entrained in sawdust with the remainder adhering to the cut surfaces, falling to the ground, or becoming aerosolized (Skoupy et al. 1990). Increasingly the negative environmental impacts of this oil pollution are prompting regulatory responses. Specifically, Austria has banned the use of petroleum-based bar-and-chain oils; Germany, France and the UK have placed restrictions on forestry lubricants that affect chainsaw oil choice; and Scandinavian countries have employed tax exemptions to increase biodegradable oil use (Bart et al. 2013). However, biodegradable oils often have a higher unit cost which motivates non-compliance. For example, in Germany a two-million-liter annual deficit between approved lubricants purchased and lubricants consumed indicates widespread use of less-expensive illegal alternatives (Hartweg and Keilen 1989).

However, cost is not a consistent indicator of oil type. Some petroleum-based bar-and-chain oils marketed as »Premium« have a per-unit cost approaching or even exceeding some biodegradable oils. The per-unit cost of premium motor oils easily exceeds the cost of many biodegradable oils.

In addition to environmental concerns, regulations, and widely varying cost, lubricant choice is further complicated by a lack of consistent and comprehensive information from published scientific studies. Only a few publications focus specifically on the relative performance of the various chainsaw oils.

One such study is that of Rac and Vencl. They compared a sunflower-based oil to a petroleum-based oil using a block-on-ring tribometer (grey cast iron block on a steel ring). Based on a consideration of measured friction coefficient, block scar volume, and temperature increase, they concluded that the sunflower-based oil could be an effective lubricant for chain saws (Rac and Venci 2008).

A second is a study by De Caro et al. In their work, six different biodegradable chainsaw oils were evaluated using a petroleum-based oil as a standard. Their chainsaw oil study consisted of the performance of twenty chainsaws shared among six logging teams for several months. Evaluation criteria consisted of both operator-observed parameters of engine power, engine temperature, qualitative bar temperature, and chain retensioning frequency and scientifically-measured surface roughness of the lubricated interfaces. They concluded that the biodegradable oils they tested were effective substitutes for petroleum-based bar-and-chain oils (De Caro et al. 2001).

A third study is that of Stanovsky et al. This study evaluated a commercially-available biodegradable bar-and-chain oil (Stihl BioPlus) with a commercially-available synthetic motor oil (Shell Helix Ultra VX 5W-30). Testing was conducted using two commercially-available and commonly-used chainsaws: a Husqvarna 346XP and a Stihl MS440 performing typical bucking cuts on beech, spruce, and fir logs. Measured parameters were the time of chainsaw operation, the temperature of the chain and guide bar, diameter of the cut log, number of cuts made, and ambient temperature. The results showed no significant difference in chain and guide bar temperatures between the two oils. From this, it was concluded that within the limitations of the study, biodegradable oils do not cause excessive wear of chainsaw components (Stanovsky et al. 2013).

A fourth is the work of Stawicki and Sedlak. Their study compared three oils: a commercially-available petroleum-based oil, a commercially-available biodegradable oil (vegetable oil), and a modified Rapeseed oil. Testing consisted of typical bucking cuts on beech wood cylinders using a Husqvarna 357 XP chainsaw. Measured parameters were chainsaw fuel consumption and lubricating oil consumption. Results showed that the greatest fuel and oil consumption occurred with the petroluem-based oil. From this, it was concluded that the use of plant-based oils is justified (Stawicki and Sedlak 2016).

Finally, a fifth is a study conducted by Nordfjell et al. Their work evaluated two biodegradable oils (a rapeseed oil and a pine oil) and one petroleum-based oil. Testing was conducted using a custom-build apparatus in which a standard commercially-available guide bar using cutterless saw chain is pressed against a rotating rubber wheel to simulate cutting conditions. The primary evaluation criterion was guide bar temperature (measured by a thermocouple in the guide-bar). No clear trend was found in the results but the petroleum-based oil produced the highest temperature at high flow rate and the lowest at low flow rate (Nordfjell et al. 2007).

The work presented in this paper significantly adds to this body of research in several ways. It evaluates a total of six commercially-available lubricating oils: premium and economy petroleum-based bar-and-chain oil, premium and economy biodegradable bar-and-chain oil, and premium and economy motor oil. This selection allows not only a comparison among three oil types but also an evaluation of perceived quality and cost benefit within each type. Tribological properties are given for each oil enabling an exploration of trends between properties and lubricating performance. The evaluation is conducted using a sophisticated laboratory chain saw test apparatus. The use of this apparatus eliminates the inherent variability of using manually-operated chainsaws, while retaining the use of standard commercially-available components.

2. Materials and Methods

2.1 Test Apparatus

All testing was conducted using a custom-built precision saw-chain testing apparatus that replicates actual operating conditions. It has been used and described in detail in two prior published chainsaw studies (Otto and Parmigiani 2018, 2015). It uses standard commercially-available saw chains, guide bars, and drive sprockets. Drive power is provided by a 3.0 kW AC motor capable of speeds up to 12,000 RPM. Sensors measure shaft speed and drive torque. Lubricating oil is delivered to the guide bar port and deposited on the moving saw chain as in a typical chainsaw. A programmable peristaltic pump controls oil pressure. Chain tension is actively controlled by monitoring and varying the longitudinal position of the guide bar with respect to the drive sprocket. Cutting is performed on workpieces consisting of rectangular cross-section timbers. Forces generated during cutting are measured by sensors present in the workpiece supporting structure. Two linear slide tables control the horizontal and vertical motion of the guide bar allowing for both bucking and boring cuts of the workpiece. The apparatus was modified with a new feature specifically for this study: a FLIR A655sc infrared camera to measure guide bar temperature. This provides high resolution images of the guide bar temperature field.

2.2 Saw Chain and Guide Bars

A need for lubrication arises in four locations as the saw chain moves around the periphery of the guide bar. The first, and perhaps most obvious, is the sliding contact that occurs between the saw chain and the guide bar rails. Specifically, this contact occurs on the underside of the cutter links and tie straps. The second is the rotational contact that occurs at the rivets. A journal-bearing pair exists at each riveted joint. The third is the guide-bar nose sprocket. This sprocket engages the drive links and reduces the friction associated with the saw chain traversing about the guide-bar tip. It rotates about a bearing located inside the guide bar. The fourth and final is the saw chain drive sprocket.

This study deals with the lubrication of the sliding contact that occurs between the saw chain and the guide-bar rails. The saw chains used in this study are commercially-available Oregon 91PX with 54 drive links and driven by a six-tooth spur-style sprocket. The guide bars used are commercially-available Oregon 140SXEA041. To obtain accurate infrared-temperature measurements, one side of all guide bars used in the study were coated with a low-reflectivity black paint.

2.3 Lubricants

Table 1 lists the specific lubricating oils selected for this study. Three types were selected: petroleum-based bar-and-chain oil, biodegradable bar-and-chain oil, and petroleum-based motor oil. Within each type, a commonly-used commercially-available oil perceived by users as premium or economy was selected. Unit costs as of spring 2018 in the U.S. are given. Also listed is an abbreviated name used in this paper for each oil.

Each of the six lubricants were sent to a test laboratory for measurement of relevant tribological properties. These properties are: flash point, viscosity (at 40° C and 100° C), viscosity index, four-ball-wear coefficient of friction, and four-ball-wear coefficient of scar length. Flash point is defined as the lowest temperature at which an oil vapors will ignite if in the presence of a suitable ignition source. Viscosity quantifies the oil internal frictional resistance to flow. Viscosity Index quantifies the change in viscosity with temperature

Table 1 Description of lubricating oil used in this study

Type	Perceived quality	Product description	Unit cost, $/L	Short name
Petroleum-based bar and chain oil	Economy	A low-cost typical bar-and-chain oil	3.06	Petrol E bar
	Premium	A high-cost typical bar-and-chain oil	8.36	Petrol P bar
Biodegradable bar and chain oil	Economy	Canola oil	0.84	Bio E bar
	Premium	A high-cost typical biodegradable bar-and-chain oil	11.15	Bio P bar
Petroleum-based motor oil	Economy	A non-detergent SAE 30 motor oil	3.34	Petrol E motor
	Premium	A high-performance (racing) 5W-30 motor oil	10.56	Petrol P motor

Table 2 Measured Lubricant properties

Property	Test method	Units	Petrol E bar	Petrol P bar	Bio E bar	Bio P bar	Petrol E motor	Petrol P motor
Flash point Cleveland open cup	ASTM D92	°C	222	197	328	314	244	202
Viscosity 40° C	ASTM D445	cSt	63.86	67.59	31.22	95.18	127.9	56.99
Viscosity 100° C	ASTM D445	cSt	10.41	7.56	7.627	20.84	11.57	9.99
Viscosity index	ASTM D2270	–	154	63	228	248	70	161
Four ball wear coefficient of friction	ASTM D4172	–	0.103	0.125	0.125	0.07	0.096	0.097
Four ball wear coefficient of scar length	ASTM D4172	mm	0.49	0.47	0.47	0.7	0.84	0.49

(the lower the Viscosity Index, the more the viscosity is affected by temperature and vice versa). The Four Ball wear tests consist of holding three steel balls together, covering them with lubricant, pressing a fourth into the cavity formed between the three (resulting in point contact at three locations), and rotating the fourth causing sliding contact between it and the other three. Contact force, rotational speed, and duration are specified. The resulting friction and ball surface wear are quantified by the parameters of coefficient of friction and coefficient of scar length. All properties were determined using applicable ASTM testing standards. All results are given in Table 2.

2.4 Experimental Design

The test metric used for evaluating the performance of each lubricating oil is the mean guide bar temperature. This metric was selected based on the following progression:

⇒ better or poorer performing lubricating oils will respectively lead to lesser or greater friction at the guide bar / saw chain interface

⇒ lesser or greater friction will respectively produce lesser or greater heat input to the guide bar and saw chain

⇒ lesser or greater heat input will respectively lead to lesser or greater temperatures of the guide bar and saw chain.

One might consider using the actual physical wear of the guide bar rails and/or saw chain (the actual amount of metal removed) as a metric. However such measurements are difficult and time consuming and not feasible for the study of a number of lubricants. Additionally, one might consider using drive torque (the torque applied to the sprocket to move the saw chain) as a metric. The apparatus accurately measures drive torque. However, minor localized perturbations that impede the motion of the saw chain can have a significant effect on drive torque but have little or no correlation to lubricating oil effectiveness. These same perturbations will have little effect on mean guide bar temperature particularly given the thousands of temperature data points provided by the infrared camera system used in this study. Also, saw chain temperature might be considered in addition to guide bar temperature. However, for obtaining accurate temperatures using an infrared camera, the surface being measured must have a constant and known emissivity. The irregular and moving surface of the saw chain makes this difficult to achieve. The guide bar, in contrast, is stationary and can easily be painted a uniform black. Overall, the mean guide bar temperature was found to be an effective and robust metric for the evaluation of lubricating oil performance.

A second key consideration in defining the experimental design was whether to include cutting. Chainsaws are, of course, used to cut wood so it may seem obvious that one would certainly include cutting in the study. However the inclusion of cutting brings with it complications: variations in wood moisture content and density induce additional experimental uncertainty,

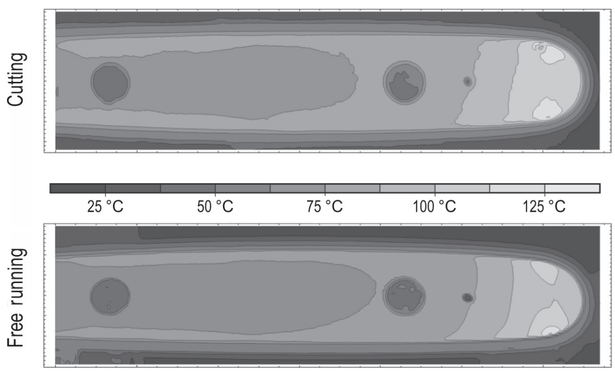

Fig. 1 Comparison between steady state temperature distributions of cutting and free running with the same operating parameters

chain tension (which greatly affects guide bar temperature) is less precisely controlled, and long-term steady state temperatures are difficult to obtain and identify. Given that the test metric is based on the guide bar temperature field, the inclusion of cutting brings these complications with little or no significant benefit as shown in Fig. 1 above. This figure shows an example of typical guide bar temperatures following cutting (down bucking) and following a corresponding period of »free running« (saw chain moving about the guide bar at cutting speed but not cutting). Operating parameters of chain speed, chain tension, oil flow rate, and oil between the two images are the same. The two temperature fields are highly similar and result in nearly identical mean temperatures. For these reasons, cutting was not included in the study and all results are based on free-running tests.

The testing procedure used for obtaining the mean guide bar temperature for each lubricating oil was as follows. Chain tension, drive-sprocket rotational velocity, and oil flow rate were set to values of 98 N, 940 r/sec, and 5 mL/min, respectively, and held constant for all testing. Testing began with a new guide bar and a new saw chain. The guide bar and saw chain were preconditioned by several hours of free-running to eliminate any variability or erratic behaviour due to their new condition. Specifically, the preconditioning was ended when the mean guide-bar temperature reached a steady-state value. Following preconditioning, the guide bar and saw chain were cooled to room temperature. Each test run consisted of the following steps:

⇒ free run for 15 minutes

⇒ stop until a temperature of 82 °C is reached at the lower nose of the bar

⇒ free run for 8 minutes

⇒ stop until the guide bar and saw chain reach room temperature.

Temperature values of the entire guide bar were measured each minute of both the fifteen-minute free run and the eight-minute free run. The mean guide bar temperature was calculated by averaging the measured temperature values of the entire guide bar. Data from the fifteen-minute free run was only used to confirm that no erratic behaviour was occurring and was not used in subsequent analysis. Data from the eight-minute free run produced steady-state mean guide bar temperature values and was used for subsequent analysis. The approach of free running, cooling until a specific temperature at a specific location was reached, and then free running a second time for data collection was found to give consistent values for mean guide bar temperature. A total of 18 test runs were conducted, three replicates of each of the six lubricating oils included in the study. Each of these runs consisted of the four steps listed above. The same guide bar was used for all testing. Test run order was fully randomized.

3. Results and Discussion

3.1 Lubricating Oil Type

The measured mean guide bar temperature for each of the lubricating oils included in the study is shown in Fig. 2. The value of the plotted data point is the calculated average of the three replicates performed for each lubricating oil type. The upper and lower error bar values are the maximum and minimum values, respectively, of the three replicates. The

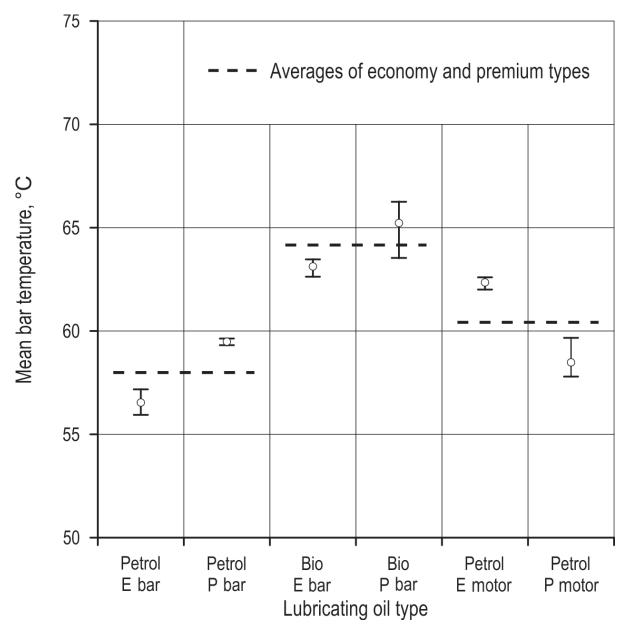

Fig. 2 Mean guide bar temperature for each of the six lubricating oils included in the study

data shows clear differences in performance among the six lubricating oils tested. Based on averages of the economy and premium oils (shown as dashed lines in the figure), the petroleum-based bar-and-chain oils performed best (i.e. had the lowest mean guide bar temperature), followed by the petroleum-based motor oils. The biodegradable bar-and-chain oils performed worst. Surprisingly, in two of three cases (petroleum-based bar-and-chain oil and biodegradable bar-and-chain oil), the oils marketed as economy outperformed those marketed as premium.

3.2 Lubricating Oil Cost

Fig. 3 illustrates the relationship between the measured mean guide bar temperature and the unit cost (U.S. dollars per liter) of the lubrication oil. As in Fig. 2 above, the upper and lower error-bar values are the maximum and minimum values, respectively, of the three replicates performed for each oil. No clear trend appears to exist between the measured performance of the lubricating oils and their unit cost. The best performing oil is the second least expensive and the worst performing is the most expensive.

3.3 Tribological Properties

The existence of a correlation between the value of the flash point and the mean guide-bar temperature was explored using a regression model. A relatively weak correlation was found (R-squared value of 0.6) between increased flash point and increased mean

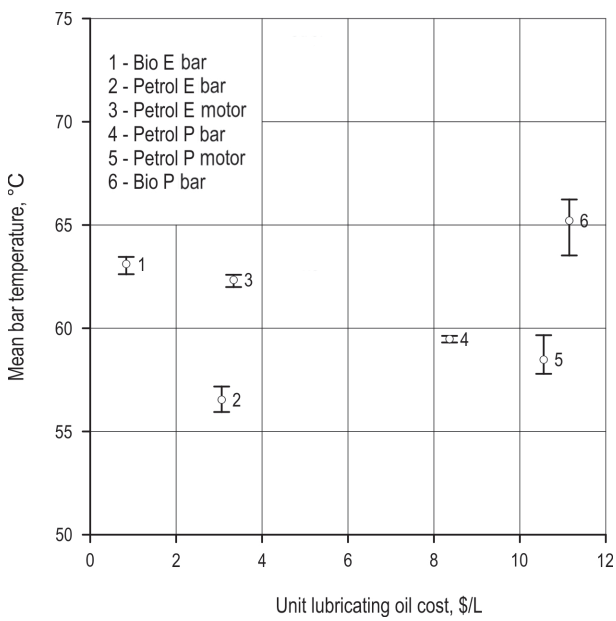

Fig. 3 Relationship between mean guide bar temperature and lubricating oil unit cost

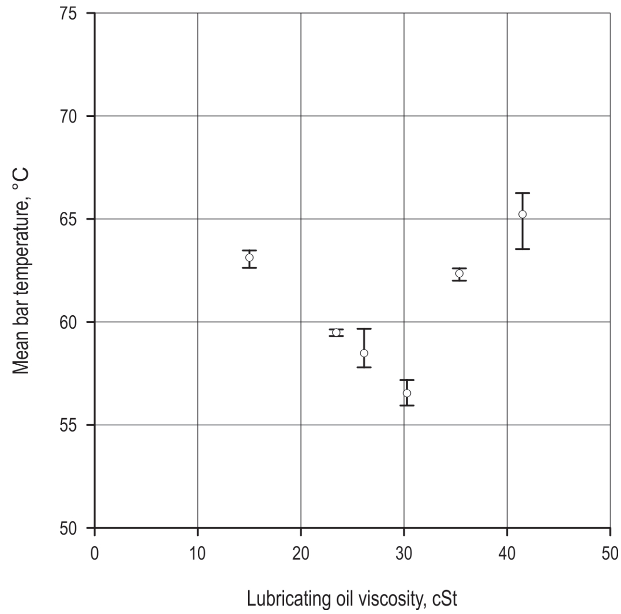

Fig. 4 Relationship between average bar temperature and viscosity

guide-bar temperature suggesting that greater flash point values correspond to lesser performance. However, given that the mean guide-bar temperature and even the maximum guide bar temperature are well below each oil flash point, no physical explanation is apparent for this correlation.

Using ASTM test standard D341-17 and the measured tribological viscosity parameters, viscosity values were calculated at the corresponding mean guide bar temperatures for each of the six lubricating oils included in the study. Results are shown in Fig. 4 above and show a clear minimum value of mean guide bar temperature at a viscosity value of near 30 cSt. The implication is that friction is minimized at this viscosity value. The trend of friction decreasing with increasing viscosity until a critical value is reached and then increasing is suggestive of the Stribeck curve in which the minimum value corresponds to a transition from mixed lubrication to hydrodynamic lubrication.

The existence of correlations between the values of coefficient of friction and mean guide-bar temperature and between the values of coefficient of scar length and mean guide-bar temperature were explored using regression models. No significant correlations were found (R-squared values were all less-than 0.3).

4. Conclusions

This paper had three primary goals: to compare the effectiveness of three types of lubricating oils, to evaluate the cost-benefit relationship within each type, and to explore how typically-measured tribological properties relate to lubricating performance. Each of these goals was met.

Using the metric of mean guide-bar temperature, it was shown that, among the lubricants included in this study, petroleum-based bar-and-chain oil performed the best, followed by petroleum-based motor oil, and biodegradable bar-and-chain oil performing poorest. However, the differences in performance were not large in magnitude, supporting prior work that found biodegradable oil to be an effective chainsaw lubricant. It is likely that this study, using highly controlled test conditions, was able to discern smaller differences in performance than prior studies.

Among the lubricants included in this study, oils marketed as premium had a higher per-unit cost than those marketed as economy. Only in the case of petroleum-based motor oils was this increased cost found to correspond to an increase in performance. For both petroleum-based and biodegradable bar-and-chain oils the economy oils performed better than the premium oils. Overall, no correlation was found between oil per-unit cost and performance.

The tribological properties of flash point, viscosity, and four-ball wear were measured for each oil included in this study. A weak trend of higher flash point corresponding to lower performance was found but no physical explanation was identified for it. A viscosity value near 30 cSt was found to correspond to the best performance with both lower and higher values consistently giving poorer performance. This may correspond to a transition between mixed and hydrodynamic lubrication. No correlations were found between performance and four-ball wear test results.

These results are significant in several ways. First, they indicate that unit cost is not a reliable indicator of the level of performance of chainsaw lubricating oils. Second, the results also indicate that a wide variety of oils, from canola to premium motor oil, can be effective chainsaw lubricants. Third, while biodegradable oils can be effective lubricants, they do not appear to perform quite as well as petroleum-based products. Finally, the lack of correlation with common tribological parameters indicate that these parameters alone should not be used for the evaluation of a given lubricant for saw chain applications. Lubricant manufacturers should base product development on actual saw chain testing ideally with both a test apparatus similar to that used in this study and actual field testing.

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