H K Trivedi
Sr Lecturer
Mechanical Engineering Department
Sir Bhavsinhji Polytechnic Institute
Bhavnagar, Guj
India

D V Bhatt
Professor
Mechanical engineering Department
S V National Institute of Technology
Surat, Guj
India

Effect of lubricants on the friction of cylinder liner and piston ring materials in a reciprocating bench test

A reciprocating bench test was used to evaluate the friction behaviour of cylinder liner and piston ring material for single cylinder four stroke petrol engines. The flat specimen of cylinder liner and actual piston ring segment has been used for this experimenalt work. Flat specimen prepared for this experimental work has been analysed for its composition. The lubricant was supplied into the inlet side of the contact zone. Commercial lubricants; SAE10W30, SAE20W40 and SAE20W50 are used to describe the behaviour of this test method. Variable load, variable speed, and variable temperature were taken to measure the friction coefficient. It has been concluded that the SAE10W30 offers highest friction coefficient among all lubricants for all operating parameters. The viscosity of lubricant plays a vital role to characterize the behaviour of friction.

Keywords:*Lubricants, Friction, Wear, Cylinder liner, Piston ring.*

1. INTRODUCTION

It is predicted that the number of automobiles in the world will be doubled by 2030. Since the automobile markets in developed countries have almost been filled up, half of this increase will be in Asia. Hence, environmental friendly automobile vehicles have been demanded; especially in Asian countries; for sustainable tomorrow. [1].

Both fuel consumption and emission increases in automobile components due to friction and wear. It was stated that 25% of the overall fuel consumption takes place due to frictional loss only [2,3]. The IC engine is the main mover of modern vehicles so we cannot cease or reduce the use of engine despite of awareness of wasted energy. However, slight modification of the surface to the component, geometry and selection of lubricant reduce the running costs of automobiles.

Cylinder and piston are primary link converting the chemical energy of combustion into torque,in internal combustion engine. The PRA system which contains contact at piston ring-cylinder liner, skirt-cylinder liner and that of the piston ring and ring groove. These contacts are responsible to mechanical friction, so PRA system is one of the highest contri–butors to mechanical friction. In IC engine, more than 30% of the energy consumption is caused by the PRA system [4].

Engine oils are used to lubricate the tribo pairs in IC engine [5-8]. A resistive force called friction is deve–loped due to relative motion between the cylinder liner and piston ring, which cause wear and tear of machine parts. A substance with low shear strength interposed between the two moving surfaces to minimize the friction.

This phenomenon is known as lubrication and the interposed substance is called a lubricant [8], [9], [10], 11]. The purposes of lubricants are protect against wear, reduce friction, separate moving parts, transfer heat and power, reduce noise and vibration, seal for gases, prevent corrosion and carry away contaminants and debris.

The quality of the lubricant directly influences the performance of engine. To obtain the optimum life of automotive component, drain interval is very important which depends on the usage time and degradation of lubricant. The quality and selection of the lubricant are directly linked with the overall performance of engine and fuel economy.

Farhanah A. N. et al. [12] performed an experiment to investigate engine oil from three different manu–facturers with the same SAE viscosity grade (SAE10W30). Experiments were performed by four ball wear tester for different temperatures (40°C, 70°C and 100°C) and varied speed from 100rpm to 2500rpm. It is observed that more viscous oil form a thick fluid film and create high separation distance result is decrease friction coefficient. Asrul M. et al. [13] have used CuO nanoparticles suspension in liquid paraffin to study the friction and wear performance by suing four-ball machine. 0.2, 0.25, 2 and 3% CuO was dispersed in liquid paraffin. The best friction coefficient obtained at 3%CuO nanoparticles and better result of wear scare diameter obtained at 0.2%Cu.

Truhan J. J. et al. [14] have studied on the reci–procating test rig to investigate the friction and wear behaviour for piston ring and cylinder liner materials in realistic engine oils. A flat grey cast iron cylinder liner material and actual piston ring segment was used. Different lubricants were used to evaluate the under–standing of lubricant condition. Weight loss measured for wear analysis and geometric model used to measure wear depth. The result shows that Jet A has higher wear & used 15W40 oil showed least wear. Thakre G. D. et al [15] performed an experiment to understand the physi–cal-chemical and tribological performance properties of

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Correspondence to: Ms H K Trivedi, Sr Lecturer
Mechanical Engineering Department, Sir Bhavsinhji Polytechnic Insititute, Bhavnagar, Guj, India – 364 001
E-mail: dnparekh@gmail.com
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commercial engine oils meeting the guideline of API standards. It is observed that the coefficient of friction and load have inverse correlation. This behavior of viscosity confirms virtual non-existence of hydro–dynamic or elastohydrodynamic conditions.

Riyadh et al. [16] has investigated of roughness on wear rate with sliding distance and velocity of casting alloy cylinder liner and piston ring on test rig. The result indicates that the coefficient of friction decreases as the load increases due to the temperature rise between the two sliding surfaces and it effect on the viscosity of lubrication. Friction coefficient is a function of wear rate. Many researchers had [17,18] performed expe–riment to understand the interactions between the surface tension of the liquid phase, the surface energy of the solid phase and their influence on the coefficient of friction. The shape of the curve at 40˚C looks different when compare to 90˚C and 120˚C. Over the three test parameters, the cof and the friction power (friction force × velocity) are the highest at 40˚C which results in a much thicker oil film.

Trivedi and Bhatt, (2017) [19] performed an expe–riment on pin-on-disc test rig to understand the tribological parameters for cylinder liner and piston ring segments. Incremental load condition has significant influence on friction coefficient and wear in terms of weight loss of cylinder liner. Viscosity of lubricant plays a vital role in tribological performance.

This paper presents the results on experimentally evaluation of tribological performance of commercial en–gine oils. The reciprocating test rig is used to conduct the experiment. The overall performance of engine has been linked with the quality of the lubricants. From the experimental results, best suitable lubricant is selected for single cylinder four stroke petrol engines.

2. EXPERIMENTAL SETUP

2.1 Lubricant selection

Three various types of lubricants were selected based on the popularity of the brand, market survey and available literature and the application domain (Petrol engine). Table 1 shows the properties of various lubricants.

2.2 Materials

Actual piston ring segment was used for the experimental work which used in Honda engine with capacity of 100CC as shown in figure 2. The specific ring used in this study has a chrome coating with 0.165μm surface roughness and 50mm diameter. The piston ring fixed in the upper holder, which consists of a segment of the matching piston in the ring groove area, which is, in turn, attached to the reciprocating arm of the tester.

A flat cast iron cylinder liner specimen is used instead of the circular cylinder sleeve to avoid issues of matching conformal curvatures of the ring and liner as shown in figure 3. The material used to manufacture a flat cylinder liner is similar to that used in the actual cylinder liner. The liner specimen manufactured Universal enterprise, Rajkot, Gujarat. The dimensions of specimens are 40mm × 40mm × 4mm with 270Hv hardness and 0.434±0.2μm surface roughness.

Table 1: Oil Properties

Name	Method	10W30	20W40	20W50
Density (g/ml)	ASTM D4052	0.876	0.882	0.884
Kinematic Viscosity (mm^2/s) at 40°C	ASTM D445	108	126	156.3
Kinematic Viscosity (mm^2/s) at 100°C	ASTM D445	11.51	14.3	19
Viscosity Index	ASTM D2270	102	114	126
Flash point (°C)	ASTM D93	211	216	220

Table 2 Material composition of prepared cylinder liner on X-met 5000-portable Analyzer

Elements	Fe	C	Si	Mn	Cr	Cu	P	S
Weight (%)	Rest	3.16	2.05	0.67	0.3	0.27	0.21	0.062

Figure 1. Reciprocating test

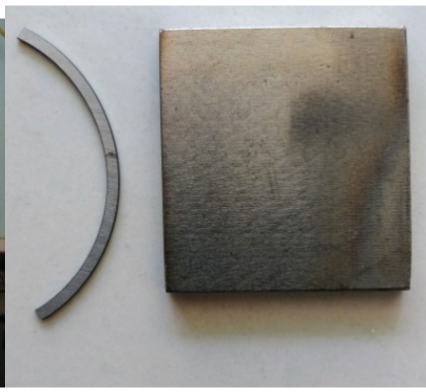

Figure 2. Specimen of cylinder

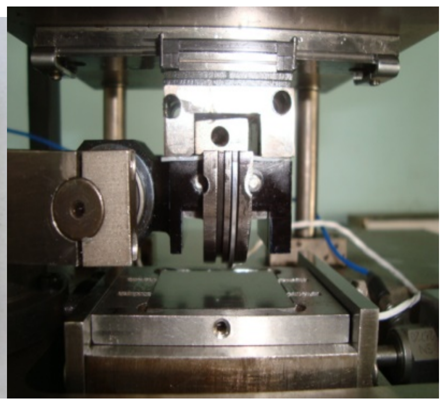

Figure 3. Attachment of liner and piston ring

2.3 Tribological test

The tribological tests were performed on a reciprocating friction and wear monitor test rig (TR-281M-M6) for a cylinder liner and piston ring as shown in figure 1. Piston ring is movable and slide on the surface of cylinder liner which is stationary. A bottom heating unit is used to heat the friction pair. Approximately 2drops of oil (each 5ml) was used in tray, immersing the liner flat. All tests were conducted with a 10mm stroke.

A series of experiments were carried out to study the effects of non-conformal contacts on friction behaviour. The experiments were accomplished with a various operating parameters like load, speed, temperature and lubricants. Here, 10mm stroke length is maintained throughout the experimental work. Prior to each test, the ring and liner were cleaned by acetone to remove metal fragments and oil from the surface. New samples were used for each experiment. All experiments have been performed under wet condition by using various lubricants. Frictional force and friction coefficient was measured from the controller. The above procedure is repeated for all tests. The Win Ducom software was used for data acquisition and display of results.

3. RESULTS AND DISCUSSION

Numerous series of friction experiments were carried out to analyze the tribological behaviour of cylinder liner and piston ring pair. The results are graphically represented for various engine speeds, applied load and various temperatures.

3.1 Effect of speed

To investigate the effect of frequency, 80N load and ambient temperature is maintained throughout the expe–rimental work. The frequency starts at 300rpm with 300rpm increments to a maximum value of 1800rpm, and average friction coefficient is measured at each frequency.

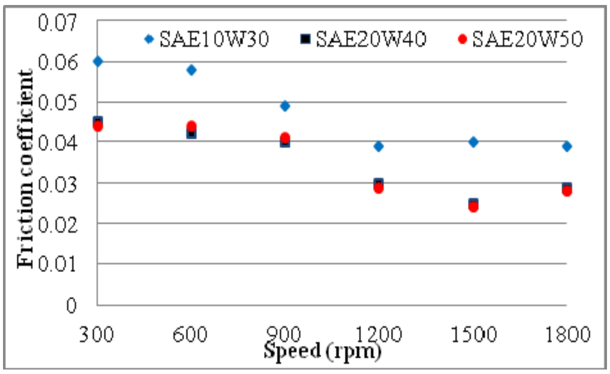

Figure 4. Effect of speed on friction coefficient

Figure 4 shows the effect of speed on coefficient of friction at 80N load and ambient temperature. It is ob–served that the range of friction coefficient is from about 0.035 to 0.06 at low speed and converge to about 0.023 to 0.06 at higher speed. At lower operating speed, hydro–dynamic action is not strong, so the film thickness may be thin [20]. Thinner film thickness leads to an increase in the asperity contact between the contacts surfaces due to boundary lubrication regime developed. This may be responsible to increase the friction coefficient.

With the increase of speed, stable fluid film may be formed due to the hydrodynamic pressure generated between the surfaces of the specimen. Here, mixed film plays the major role in decreasing the friction coefficient. Subsequently, the friction coefficient again rises with the increase of speed, due to the large amount of hydrodynamic pressure generated and negligible contact occurs between the surface of cylinder liner and piston ring. During this stage, Lubricant film is most responsible factor to separate the contacting surface and the friction is governed by the shearing of the lubricant fluid film dependent on the rheological properties of a lubricant. SAE10W30 offers maximum friction coefficient for all operating speeds.

3.2 Effect of speed

Figure 5 shows the effect of load on the friction coefficient at 600 rpm and ambient temperature for various lubricants. It is observed that the range of friction coefficient is from about 0.09 to 0.142 at low load and 0.078 to 0.118 at high load. The curve follows negative trend for all lubricants [15]. Here, irregularity of surface in the form of asperity plays a major role.

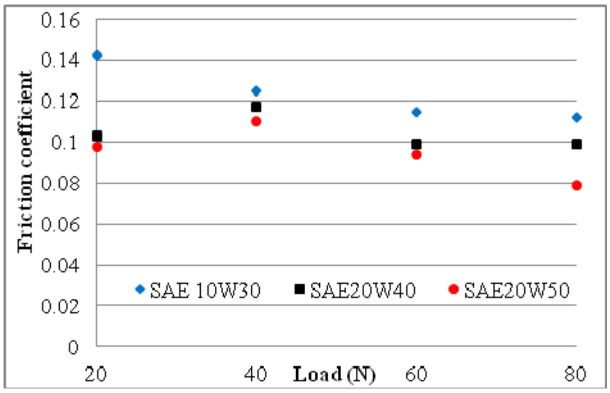

Figure 5. Effect of load on friction coefficient

Asperity contact generate during the small load con–dition which developed boundary lubrication regime. It increases the friction coefficient. With the increase of load, high wear rate occur which makes the surface smooth of the specimen. Hence, stable fluid film may be formed and reduce the friction coefficient. Elastohydro–dynamic effect is more evident for non-conformal con–tact [21].

3.3 Effect of Temperature

The temperature starts at 20°C with 20°C increments to a maximum value of 120°C. Tests are conducted at 80N load and 600rpm.

Figure 6 shows the effect of temperature on the friction coefficient at 600rpm and 80N load. The range of friction coefficient is 0.06 to 0.051 at low tem–perature and 0.062 to 0.06 at high temperature. Here, it is observed that there are no major changes in friction coefficient with various temperatures. It is observed from the figure 6 that little reduction takes place during the 40°C and then again rises in friction coefficient with increase of temperature till 120°C [14]. SAE10W30 offers stable performance as compare with the SAE20W40 and SAE20W50. The viscosity of the SAE20W40 and SAE20W50 lubricant is high as compare to SAE10W30 lubricant. With the increase of temperature, lubricant became thinner due to reduce its viscosity. The fluid film may be ruptured during the sliding motion and increase the asperity contact. It may increase the friction coefficient.

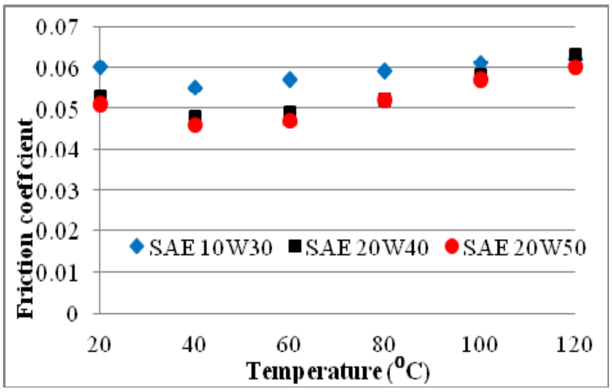

Fig.6. Effect of temperature on friction coefficient

Table 3: % increases in friction coefficient with SAE10W30 lubricants as compare to SAE20W40 and SAE20W50 lubricants

Operating parameters	Values	Lubricants	
		SAE20W40	SAE20W50
Effect of speed	300rpm	25	26.67
	1500rpm	37.5	40
Effect of Load	20N	27.97	31.58
	80N	11.83	29.46
Effect of Temp.	20°C	11.67	15
	120°C	1.61	3.23

Table 3 shows the values in % which shows the increment of friction coefficient with SAE10W30 lubricant. As compare to SAE20W40 and SAE20W50, SAE10W30 offers more friction coefficient for all operating parameters. It is observed that SAE20W40 and SAE20W50 have more or less equal performance.

SAE10W30 offers lower viscosity. The fluid film which is formed between the contact surfaces cannot withstand the desired operating parameters. Due to that reason, fluid film may be rupture during the motion of contact surfaces and results high friction coefficient. It shows that the quality of the lubricant plays the key role in tribological performance.

To analyse the behaviour of lubricants, friction tests were conducted with the same lubricants for 80N load, 1500rpm and 40C temperature. The duration for this test is 120min.

It is observed from the figure 7 that the nature of curve is similar for all lubricants. At the initial stage of sliding, the friction coefficient increased with increased sliding time and finally stabilized after certain period of time. The increases the friction coefficient at the initial stage occurred during the running-in-period of sliding. During the initial run, high asperity contact generates due to initial roughness between the sliding surfaces. The oil film formation may not develop sufficiently between the components during the initial run which results high friction coefficient [19].

When the rubbing process start, surface topography changes to a great extent, the asperity contacts gradually removed from the surface. Once it removes during the running in period, the surface becomes smooth and friction coefficient became almost stable. This may be due to the fluid film formed and mixed lubrication regime developed between the pair hence partial load carrying capacity increases up to certain extent.

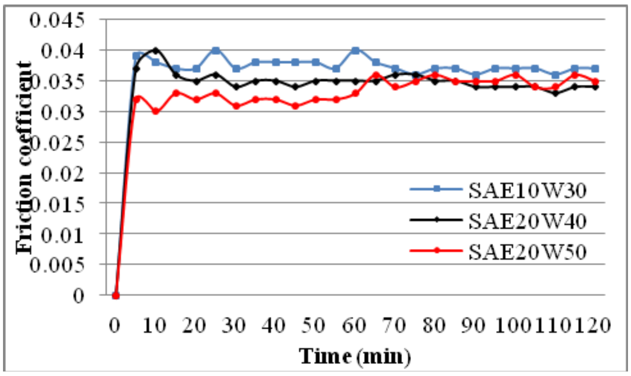

Figure 7 Variation in friction coefficient with time for various lubricants

By comparing the three lubricants, SAE10W30 offers the highest friction coefficient as compare to SAE20W40 and SAE20W50 which may be due to the lowest viscosity of lubricant. SAE20W50 has lower friction coefficient at the initial run because it has high viscosity which generate mixed lubricant regime bet–ween the two surfaces. After 65min, it is observed that there are no significant variations in friction coefficient for SAE20W40 and SAE20W50 lubricants.

During the running condition, SAE20W50 offers more wear loss on cylinder liner which generates rough surface. It is also verify with SEM analysis. Due to that, lubricant film cannot be formed properly and no any significant change may occur on the friction coefficient.

3.4 Correlation of friction coefficient with surface morphology of specimen for various lubricants

The friction coefficient results are correlated with SEM micrographs of the worn surface of cylinder liner as shown in figure 8. The morphologies of wear surfaces were studied to determine the various mechanisms responsible for the loss of material of cylinder liner.

With SAE10W30 lubricant, fluid film ruptured du–ring sliding due to its low viscosity hence it may shows the severe wear on the surface on the liner. Here, severe scratching and plastic deformation are noticed on the worn surface [22]. The severe plastic deformation indi–cates the boundary lubrication regime developed bet–ween the surfaces. There may be lots of corrosive pits and material dragging on the cylinder liner surface.

SAE20W50 is high viscous oil and it contains more viscosity improver, which will cause more sludge than the SAE20W40 during the operation. Due to the sludge between the contact surfaces, abrasion may occur which produced ploughing action and formed cracks and pits on the cylinder liner. SAE20W40 lubricant formed steady fluid film and developed mixed lubrication region hence only spalling and micro cracks developed on the surface Thus it can be consider SAE20W40 is a better lubricant due to wear volume is less among all lubricants.

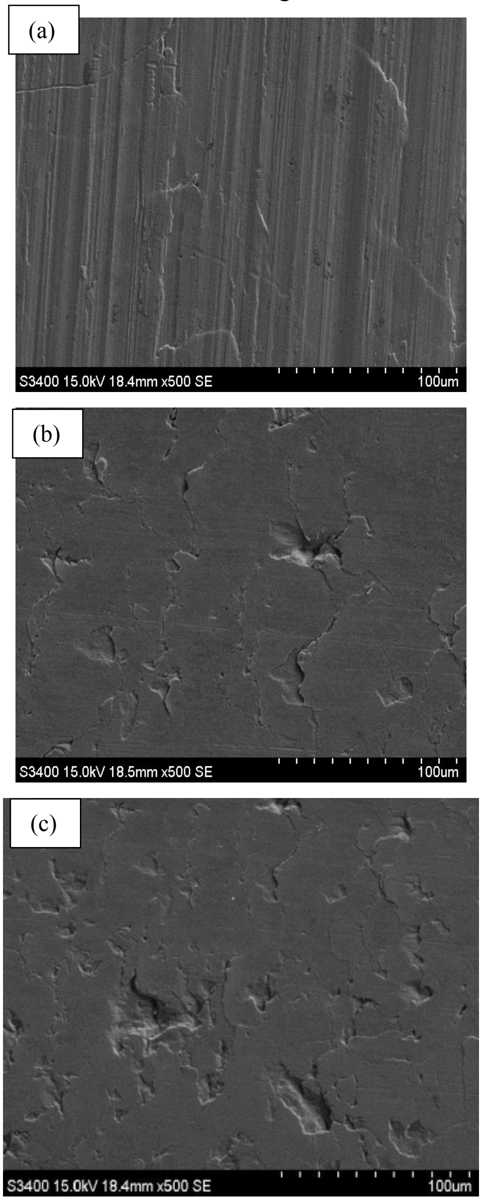

Figure 8 SEM analyses for (a) SAE20W40 (b) SAE20W50 (c) SAE10W30

4. CONCLUSION

In the present work, the tribological behaviour of cylinder liner and piston ring under lubricated con–ditions were studied as well, and several conclusions can be drawn as follows:

- Load, speed, temperature and selection of engine oil play a vital role and it's a key factor to analyze the tribological behaviour.
- Elastohydrodynamic influence is more evident with non-conformal contact.
- SAE10W30 offers higher friction coefficient as compared to SAE20W40 and SAE20W50 lubri–cants for all operating parameters. It shows that the quality of the lubricants plays a vital role in tribo–logical behaviour.
- SAE20W40 is a better lubricant due to wear volume is less among all lubricants.

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УТИЦАЈ МАЗИВА НА ТРЕЊЕ ИЗМЕЂУ КОШУЉИЦЕ ЦИЛИНДРА И КЛИПНОГ ПРСТЕНА КОД КЛИПНЕ МЕРНЕ ИНСТАЛАЦИЈЕ

Х.К. Триведи, Д.В. Бхат

Клипна мерна инсталација је коришћена у циљу евалуације трења између кошуљице цилиндра и клипног прстена код бензинског четворотактног мотора. Вршено је испитивање састава материјала од којих су ови делови израђени. Експеримент је извршен на пљоснатом узорку кошуљице цилиндра и делу клипног прстена. Довод мазива је обављен преко улазног дела контактне зоне. Комерцијална мазива SAE10W30, SAE20W40 и SAE20W50 су коришћена код испитивања описаног метода. Коефицијент трења је мерен следећим параметрима: променљиво оптерећење, променљива брзина и температура. Утврђено је да мазиво SAE10W30 има највећи коефицијент трења. Вискозитет мазива има најважнију улогу у карактеризацији понашања трења.