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ABSTRACT

This report describes a friction and wear testing of Pro-Long Metal Treatment for lubricants. A Block on Ring machine is used for the test. About 110 tests have been performed. The product was found to have a significant wear reducing effect - an interesting matter proposed for further testing.

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KEY TERMS SELECTED BY AUTHOR(S)	Wear testing	Slitasjetesting
	Tribology	Tribologi
	Oil additive	Additiv for olje

AUTHORIZED SIGN

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LIST OF CONTENT

SUMMARY

This report deals with a friction and wear study of the Pro-Long Anti-Friction Metal Treatment for lubricating oils. A Block on Ring Machine has been used for the test.

Typical test data have been selected to secure a boundary lubrication.

Material combinations like steel/steel and bronze/steel have been tested. Oils used for the test have been mineral engine oil, 2 different synthetic engine oils and gear oil.

Approximately 15% Pro-Long mixup in the oil is found to give the best result - in average about 50% wear reduction. Except for an increase in the steel to steel friction in gear oil and in the after all low friction in bronze/steel contact, a considerable reduction of friction and temperature was found.

Because of the positive results from this test, further work is proposed to study especially the effect on viscosity and the long term effect on real machines.

More details from the tests are presented as Appendix in a separate volume.

1. INTRODUCTION

SINTEF Division of Machine Design has been approached by Pro-Long Europe A/S for an independent friction and wear test of their product - an anti-friction product for lubricants.

The supplier claims that their product, when mixed in a specified proportion to any lubricating oil in the market, will reduce wear and increase the load carrying capacity of the lubricating film.

The purpose of the test has been to verify if the product would meet the supplier's statement and to estimate the optimum quantity of product in the oil.

For such a primary evaluation of the product we have found a standard type wear testing machine well suited. Depending on the results from this test and our client's needs and intensions, we can, however, foresee the need to perform more detailed wear studies or even real wear tests on engines, gears and hydraulic equipment.

For the present test we have applied a contact pressure somewhat above the normally acceptable pressure for a journal bearing of the similar material in order to obtain boundary lubrication and accellerate the wear. With the selected loading conditions, the pressure will be about 2 times higher than recommended for bearings at the stage when the width of the wear track is 0.5 mm.

One problem experienced during such tests is the increase in hydrodynamic effect caused by the increasing contact area as the wear is taking place. With this method we start out from and one has to carefully take this into consideration while comparing the results.

2. TEST PROCEDURE

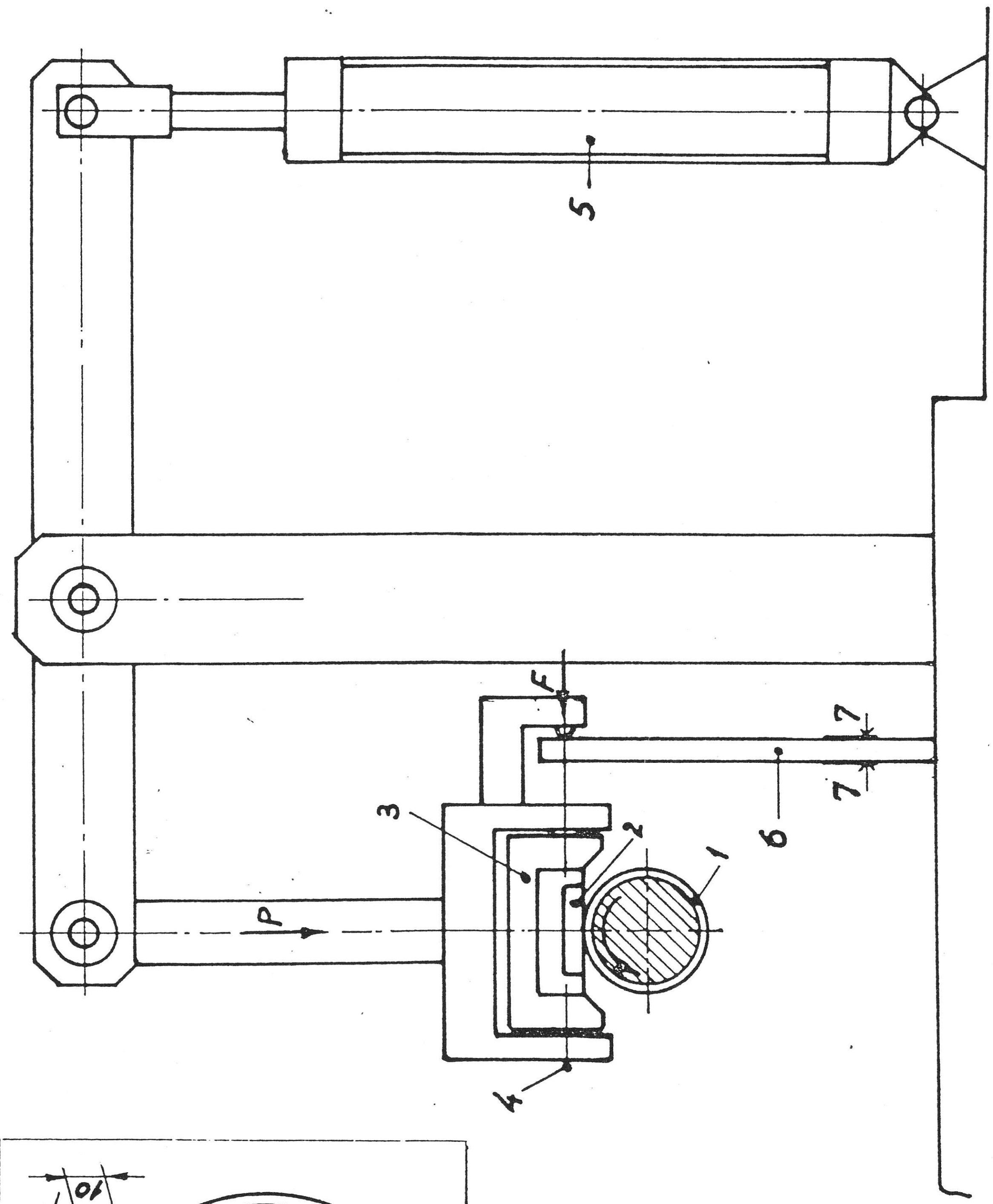
2.1 Rig descriptions

The test has been run on a Block on Ring Machine. The mechanism of this machine is briefly shown in Figure 2.1, page 3.

The ring (1) is a standard roller bearing inner ring with outer diameter 40 mm and width 20 mm. The ring is fixed on a very well balanced shaft rotating in journal bearings at a speed of up to 1700 rpm. For this test 800 rpm was selected for the final testing due to temperature build up at higher rpms. There is no cooling arrangement except for the lubricant.

The test specimen (2), in this case a block, is mounted in a specimen holder (3) which can rotate around its shaft (4). By this, line contact between ring and block is maintained. The specimen is pressed against the ring by a force P induced by a pneumatic cylinder (5) acting through an arm system. The force P can be increased stepwise or continuously from 0 up to a maximum of 110 N over an adjustable time period. Loading was selected depending on specimen material.

As the ring is rotating, the friction force F between the ring and the specimen will pull on the specimen holder that is held back by the arm (6) through a ball contact. The friction force will thus act directly on the arm and bend it. The moment in the arm is measured by help of strain gauges (7) and a strain gauge bridge, converted back to friction force and printed out on a strip chart recorder. Unwanted noise in the signal is filtered away.


P
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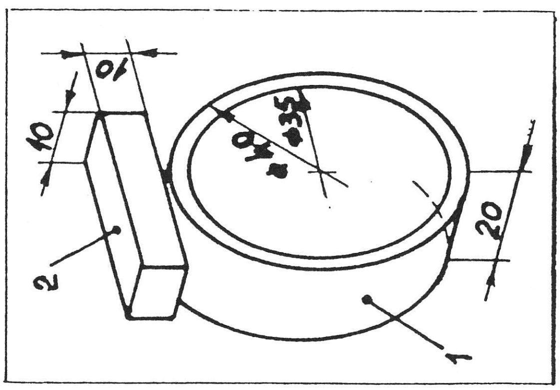
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20

The specimen temperature was measured with a thermo couple fixed between the specimen and its holder.

The different mixtures of lubricating oil were fed by natural fall through a pipe from a tank to the contact area between the specimen and the ring. The flow was kept constant at about 50 ml/min.

The material of the rotating ring is standard roller bearing steel AISI 52100 while the material of the mating test specimens have been white metal, bronze and steel C 0.9, Mn 1.2, Cr 0.5, W 0.5, V 0.1 (2510 AFNOR 90 MCW5 case hardened to 58HRC).

Load P applied to the block/ring has been for the different materials:

Steel/steel	P = 1075 N
Bronze/steel	P = 358 N
White metal/steel	P = 179 N

2.2 Test routine

The shaft was first speeded up and rpm adjusted. Next the flow of lubricant was connected and the block lowered. The load was then steadily increased to the maximum permitted value within 5 minutes. Each test was then run for half an hour.

From the printouts were found:

- maximum friction force
- mimimum friction force whenever a minimum occurred
- friction force after run-in period, stable curve at the end of the test
- maximum temperature

Width of the wear track was measured by help of a microscope and the volume of the worn material was calculated.

For some tests the roughness of the wear track was measured, and for some others Scanning Electron Microscopy was carried out.

3. THEORY

The ring and the block form an elementary plain bearing with hydrodynamic lubrication. The oil wedge formed in such a bearing is a function of speed N (rpm), load P and oil viscosity Z. Under fluid film conditions, an increase in oil viscosity or speed will increase the oil film thickness and the coefficient of friction, whereas an increase in load will decrease them.

The separate consideration of all these effects forms a rather complex picture. To simplify this picture, the viscosity Z, the speed N and the unit load P are normally combined into a single dimensionless factor called the ZN/P factor.

Although no simple equation exists that expresses the coefficient of friction or the friction force for any bearing in terms of ZN/P, the relationship can be shown by a curve as indicated by figure 3.1.

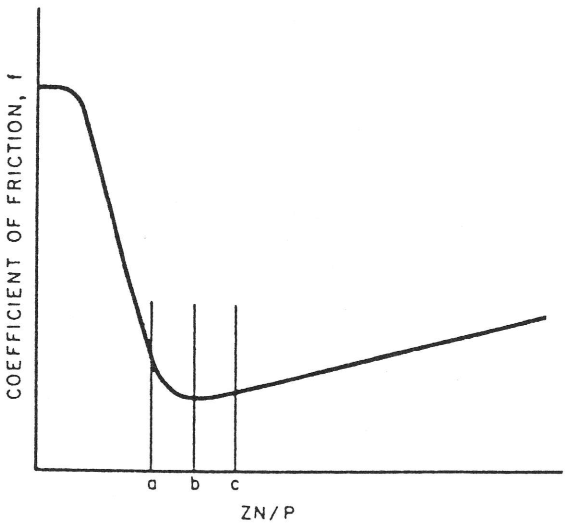

Fig. 3.1 Typical effect on bearing friction caused by viscosity (Z), speed (N) and load (P).

In this figure, boundary lubrication exists in the zone to the left of a, while full fluid film lubrication exists in the zone to the right of c. Boundary lubrication means that the conditions do not allow a full fluid film to be established. Some metallic contact will take place, causing friction and wear. Very high coefficients of friction may occur. In the following wear test we are operating in this boundary lubrication zone.

The zone between a and c is called the mixed lubrication zone. Minimum friction may be found in this area as indicated by b. For reduction of friction losses, it would be desirable to operate with a ZN/P value in the area a to c. However, in this area a minor disturbance of the conditions such as a speed reduction or a shock load may lead to film rupture. Bearings are therefore designed for an operating ZN/P value in the zone to the right of c. Normally the bearing is designed for a ZN/P value 5 times the minimum one at b. This factor is called the bearing safety factor.

A curve similar to the one in figure 3.1 may be developed experimentally for any fluid film bearing, so also for this "test bearing" formed by the ring and the block. The geometry of the block will, however, change rather fast during the running in period though N and P are kept constant and Z is changed only due to increased temperature. Because of increasing contact area, the surface pressure will decrease. Possible wear-resistance in Pro-Long Metall Pluss will try to slow down this process. The surface pressure may by this be difficult to control. Consequently a typical ZN/P curve should be drawn only after the geometry has been stabilized.

In this test we will concentrate on friction force and temperature measurements as well as wear track studies.

4. TEST RESULTS

4.1 Optimal Pro-Long mixup

Different mixup of Pro-Long in multigrade,commercial mineral engine oil was tested on material steel/steel. For each mixture the test was repeated once. Rotating speed was kept at 700 rpm. Results are plotted in figure 4.1.1. Friction coefficient is given at the end of each test after run-in. 0% Pro-Long mixup means pure engine oil without Pro-Long Metall Pluss. 100% Pro-Long mixup means pure Pro-Long.

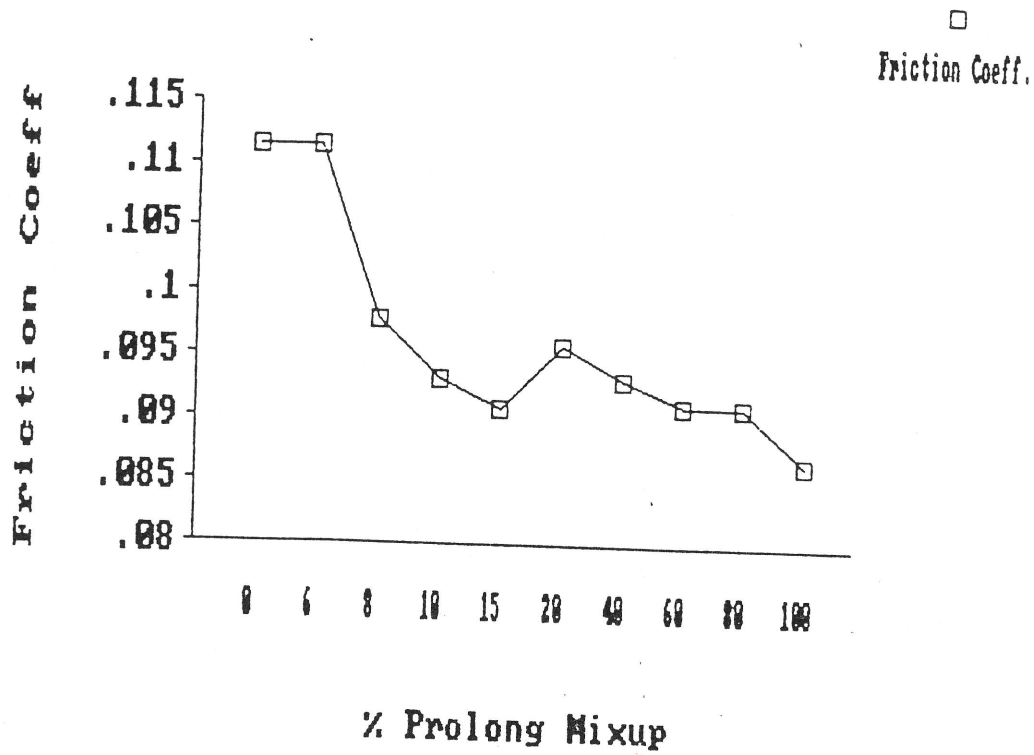

Figure 4.1.1 Friction coefficient related to Pro-Long mixup in mineral engine oil

Temperature was not measured during this test. The curve indicates 15% Pro-Long mixup as an optimal effect for mineral engine oil.

Surface roughness of the wear tracks is indicated in figure 4.1.2. Original roughness R_a of the specimens as prepared before testing is 0.5-0.6 um. This original roughness is not completely worn away for any of the specimens. Thus higher roughness value in the tracks indicates less wear as more of the original surface roughness is still present.

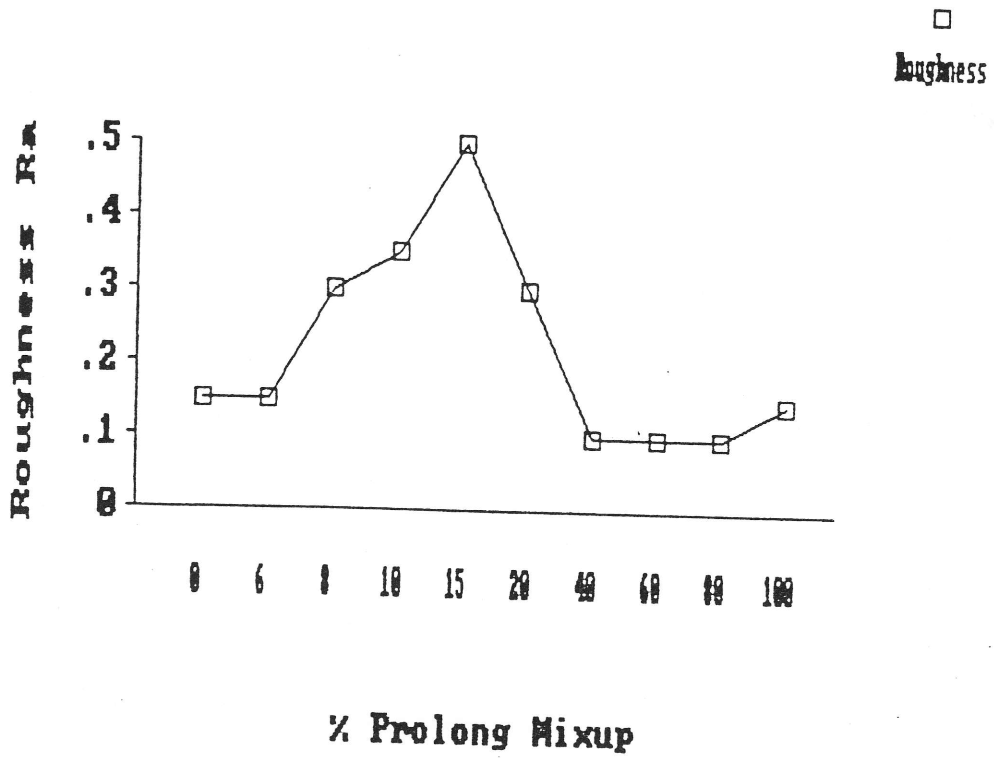

Figure 4.1.2 Surface roughness of wear track with different Pro-Long mixup in mineral engine oil. Material steel/steel

As can be seen from the figures, roughness as well as friction coefficient indicate an optimal effect at about 15% Pro-Long mixup. For higher mixups of Pro-Long the roughness value indicates a wear rate (or surface smoothening) of the same level as for pure oil while the friction coefficient at the end of the test is lower.

The optimal mixture may be different for other materials and/or other lubricating oils.

For the further testing 10% and 15% Pro-Long were selected in addition to pure oil.

4.2 Effect on steel

4.2.1 Measurements during testing

Pro-Long effect on steel was measured for 4 different lubricating oils. Specimen temperature was recorded in addition to friction force.

Rpm was increased to 800 for all the following tests.

As the same scale was suitable for both the temperature (degree Centigrades) and the friction force (Newton), the friction force was not converted into coefficient of friction. If this is done, the curve will remain the same, only the scale will change.

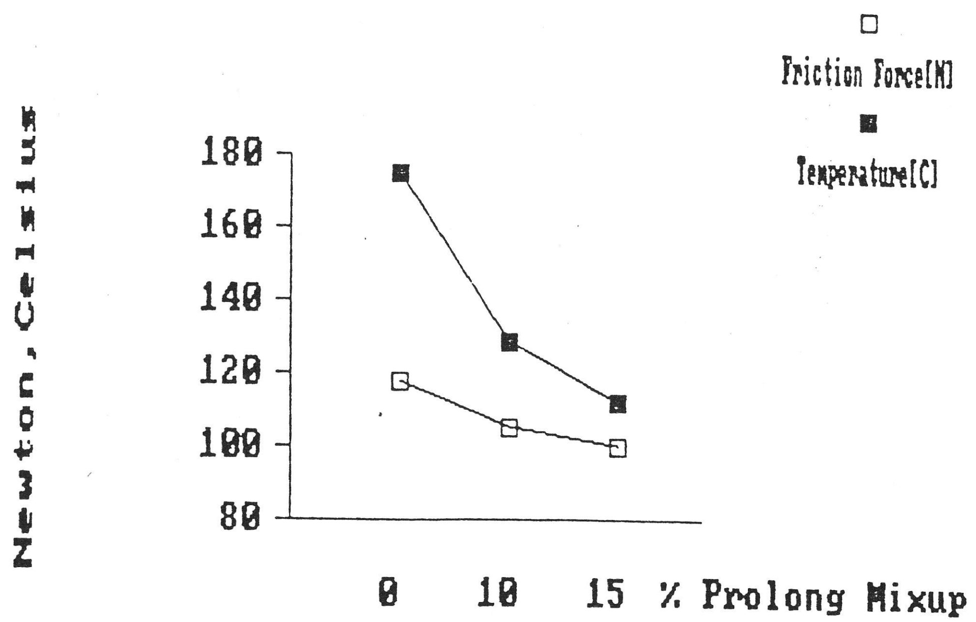

Figure 4.2.1 Friction force and temperature (same scale) related to Pro-Long mixup in mineral engine oil

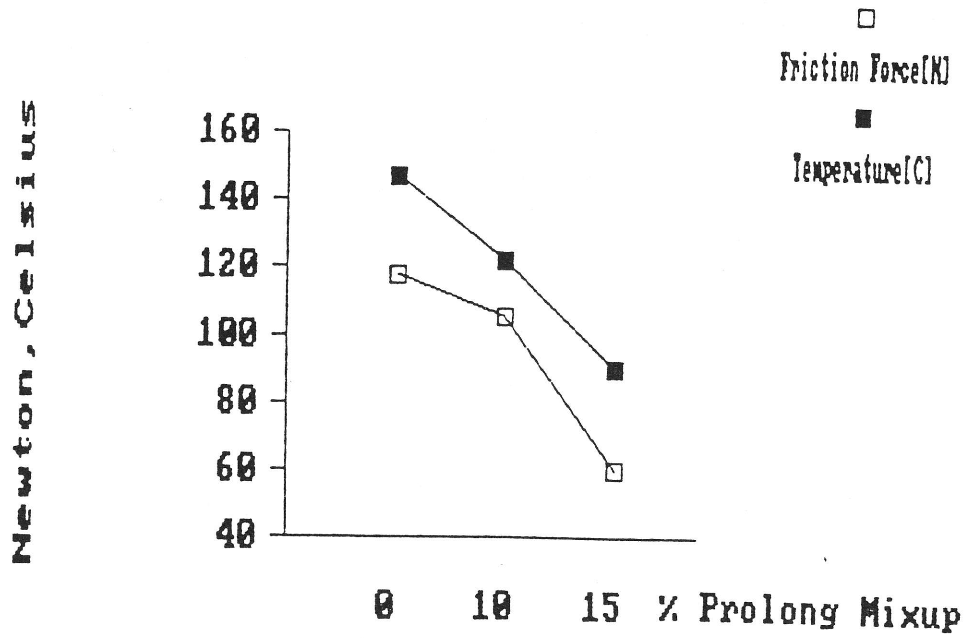

Figure 4.2.2 Friction force and temperature (same scale) related to Pro-Long mixup in commercial synthetic engine oil no. 1

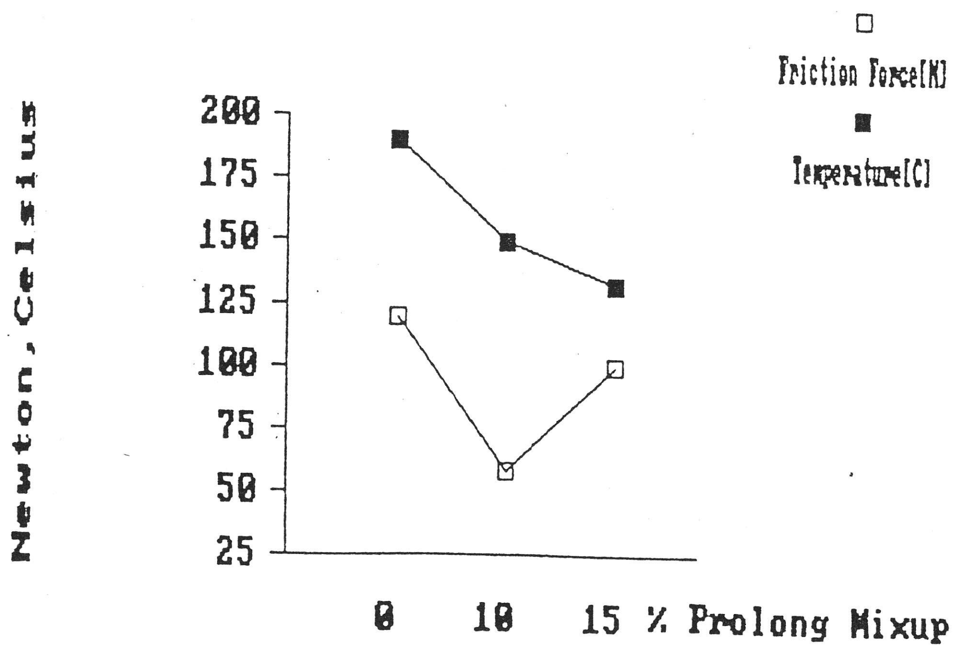

Figure 4.2.3 Friction force and temperature (same scale) related to Pro-Long mixup in commercial synthetic engine oil no. 2

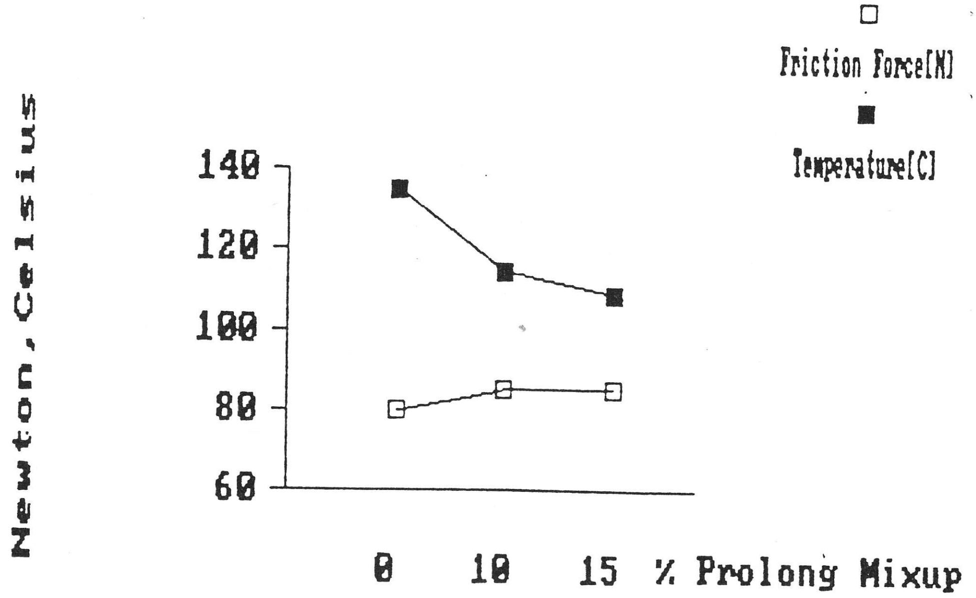

Figure 4.2.4 Friction force and temperature (same scale) related to Pro-Long mixup in commercial EP gear oil.

For commercial mineral engine oil and synthetic engine oil no. 1 there is a considerable decrease in friction as well as temperature by use of Pro-Long, and 15% mixup gives the best result. The effect in synthetic oil is best.

For commercial synthetic engine oil no. 2 the lowest friction tends to occur at about 10% Pro-Long mixup. However, the temperature is further reduced at the higher mixup.

For gear oil the temperature is reduced by mixing in Pro-Long, but a similar effect on the friction force did not occur. On the contrary, the friction force was slightly increased by mixing in Pro-Long. Due to this, the temperature decrease is not as big as for the engine oils.

It can be seen that the temperature does not exactly match the friction force as one would expect. We would therefore assume that this product has a cooling effect either by convection, by evaporation of some volatile matters or by local material melting because of entectic functioning of the product.

4.2.2 Wear measurements

The specimen wear represented by the width of the wear track was measured in microscope. Depth of the track is more difficult to measure, but is given by the width and the diameter of the ring. Worn off material may then be calculated for a unit length of the track as $w^3/32$ where w is the width of the track.

Worn off material from the steel to steel test is shown in figure 4.2.5 for all lubricating oils tested.

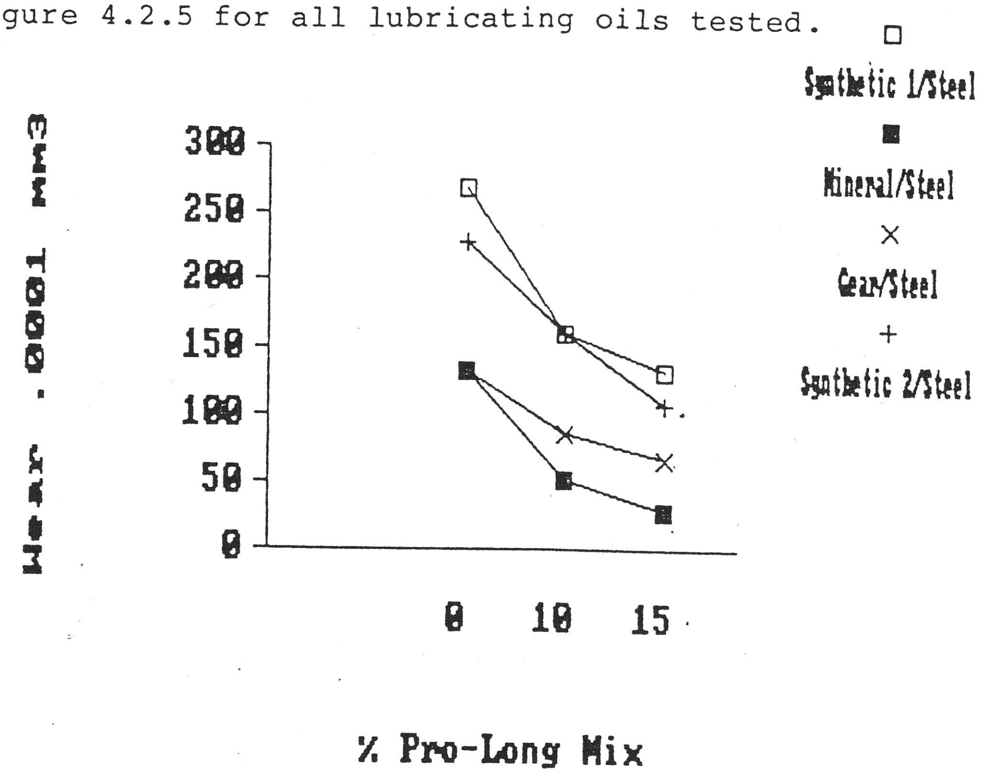

Fig. 4.2.5 Worn off material as a function of Pro-Long mixup

The mineral engine oil and the gear oil, also mineral, show the same amount of wear before Pro-Long is mixed in. The wear reduction effect is as high as 45% for 15% Pro-Long mixed in gear oil, for engine oils it is even more. Interesting to see is that synthetic oils show a very high degree of wear compared to mineral oils.

With 15% Pro-Long mixed in, the wear rate for the synthetic oils are brought down to the same level as for the mineral oils without Pro-Long.

Less Pro-Long effect in the gear oil may have some connection with the additive package already existing in EP oils.

4.2.3 Survey of test results

Table 1, next page, gives a general view of results from STEEL/STEEL tests. The table shows the amount of decrease or increase of friction, temperature and wear in percent values. The percent values are calculated from testdata with 10% and 15% Pro-Long mixup.

4.2.4 SEM studies

Studies were carried out in Scanning Electron Microscope for

- specimen material for reference purpose
- wear track from mineral oil test
- wear track from mineral oil with 6% Pro-Long
- deformed zone in wear track from 6% Pro-Long test

In the wear track from pure mineral oil an enrichment of Calsium, Copper, Zinc and Sulphur was found, compared to the reference material analysis.

Lub. oil	Friction		Temperature		Wear		% Pro-Long
	Mineral	Synthetic Multigrade	Mineral	Synthetic Multigrade	Mineral	Synthetic Multigrade	
	%	%	%	%	%	%	
Multigrade engine oil	- 10,6	- 10,6	- 26,5	- 17	- 60,6	- 40,3	10
	- 14,9	- 48,9	- 36	- 38,7	- 78,8	- 50,7	15
Multigrade Synthetic engine oil no. 2		- 51,6	-	- 21,3		- 29,8	10
		- 16,7		- 30,3		- 53,1	15
EP gear oil	+ 6,3		- 15,3		- 34,8		10
	+ 6,3		- 19,5		- 48,5		15
Average value from 65 STEEL/ STEEL tests	- 20		- 20		- 40		10
	- 20		- 20		- 55		15

Table 1 Results from STEEL/STEEL tests

The same oil with 6% Pro-Long mixup left a wear track with an enrichment of Nickel, while the contents of Copper and Zinc were reduced. Other elements were as for test with pure mineral oil.

In the deformed zone from the 6% Pro-Long mixup test, Cromium, Iron and Nickel contents were as for the wear track outside the zone, while Silisium, Manganese and Sulphur contents were reduced. In this zone the total percentage of elements also decreased to 80% compared to 88% otherwise.

Deformation zones in the wear track occurred only for oils with Pro-Long mixed in. Such zones tended to occur more frequently for low and high Pro-Long contents and less for 10-15% Pro-Long mixups.

The deformations look like cold welding, which means that local melting has taken place. One reason may be nonuniform material containing zones of another structure having a lower melting point than the surroundings. Provided Pro-Long has an eutectic function, it may reduce the melting point of the material enough to cause local melting of these zones at the load applied, which is unrealistically high for normal bearings. An explanation why these deformations do not normally occur at Pro-Long mixups of 10-15%, may be a better cooling effect from these mixtures.

Hardness measured in the wear track may indicate a slightly increased hardness due to Pro-Long.

The SEM studies were made in addition to the test agreed upon just for indication. For a final conclusion from this study, a larger number of SEM studies will be needed.

4.3 Effect on Bronze

4.3.1 Measurements during testing

Bronze was tested as for steel except for the load which was set to 358 N maximum. Three different lubricating oils were used. The following figures will show the friction force and temperatures recorded at the end of the tests, each of them of half an hour's duration.

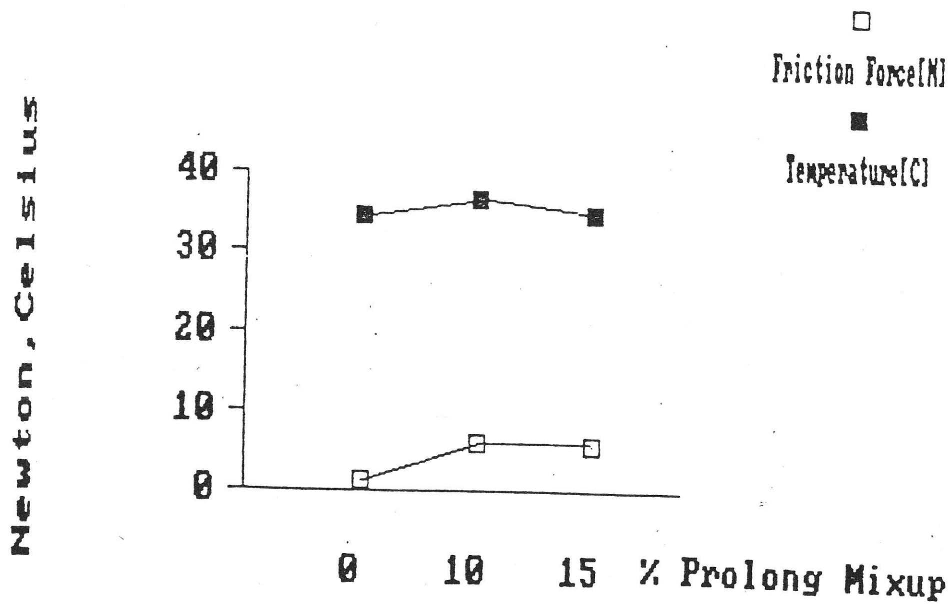

Figure 4.3.1 Friction force [N] and Temperature [°C] (same scale) related to Pro-Long mixup in commercial mineral engine oil

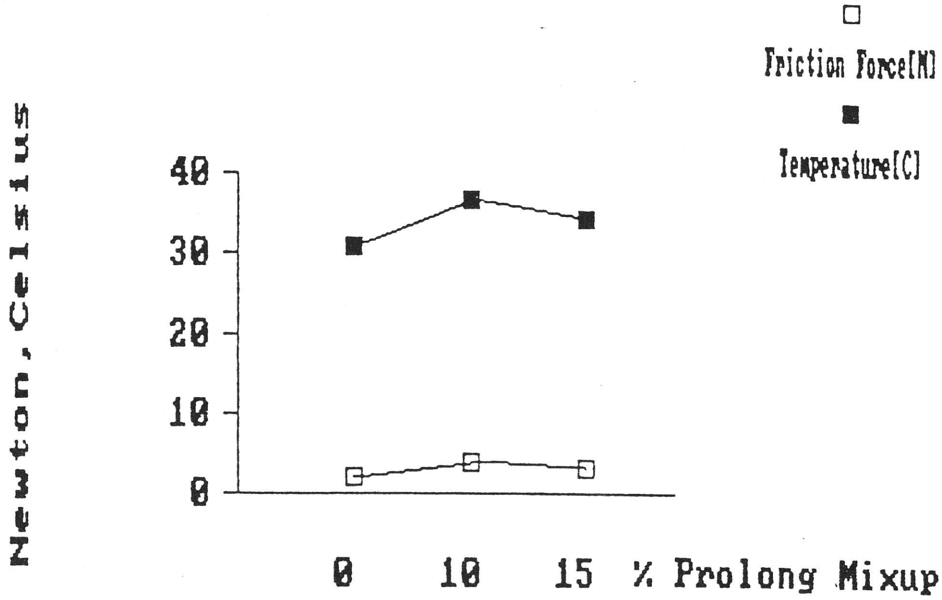

Figure 4.3.2 Friction force [N] and Temperature [°C] (same scale) related to Pro-Long mixup in commercial synthetic engine oil no. 1.

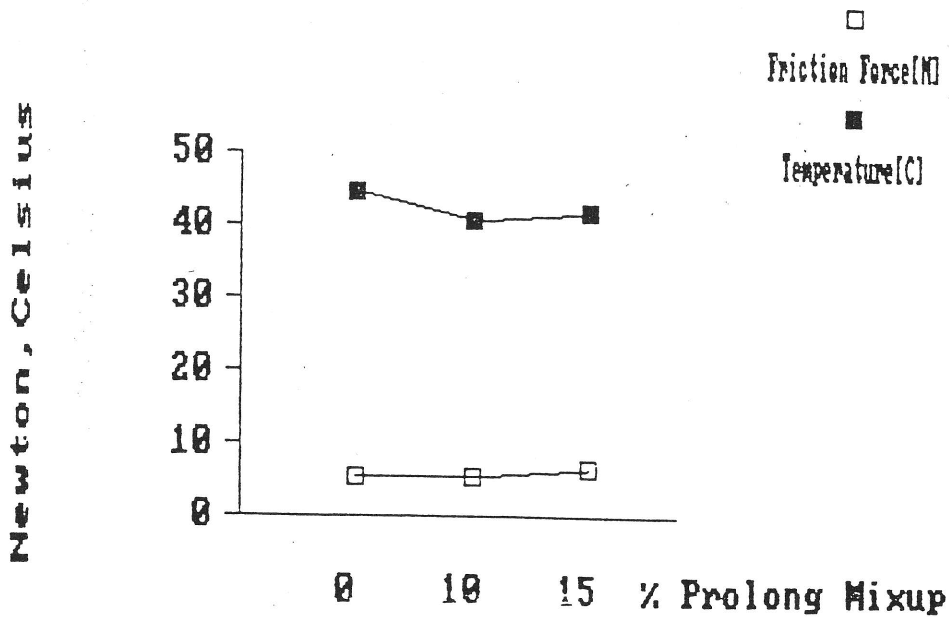

Figure 4.3.3 Friction force [N] and Temperature [°C] (same scale) related to Pro-Long mixup in commercial EP gear oil

It should be noticed that the friction and the temperature values from the bronze tests are rather low compared to the steel tests. Rigid conclusions cannot be drawn on smaller curve fluctuations as the accuracy for such measurements will also have to be taken into account.

As may however be seen from the figures, there is a slight increase in friction force for the bronze/steel contact for all the oils by use of Pro-Long.

The Pro-Long effect on the temperature tends to be different for engine oils and gear oils, maybe because of already existing additives in the two types of oil.

Another reason for these results may be the Pro-Long effect on the viscosity. Although viscosity has not been directly measured in this project, it has been observed that Pro-Long tends to reduce the viscosity. Keeping the rotation N and the load P constant, the viscosity Z is the only factor that can reduce the ZN/P value in figure 3.1 and increase the coefficient of friction in the boundary lubrication zone.

4.3.2 Wear measurements

An increase in friction force as was the fact for the bronze test, would normally result in a higher wear. However, in this case all the tests clearly indicated a considerable reduction of wear by using Pro-Long, ref. figure 4.3.4.

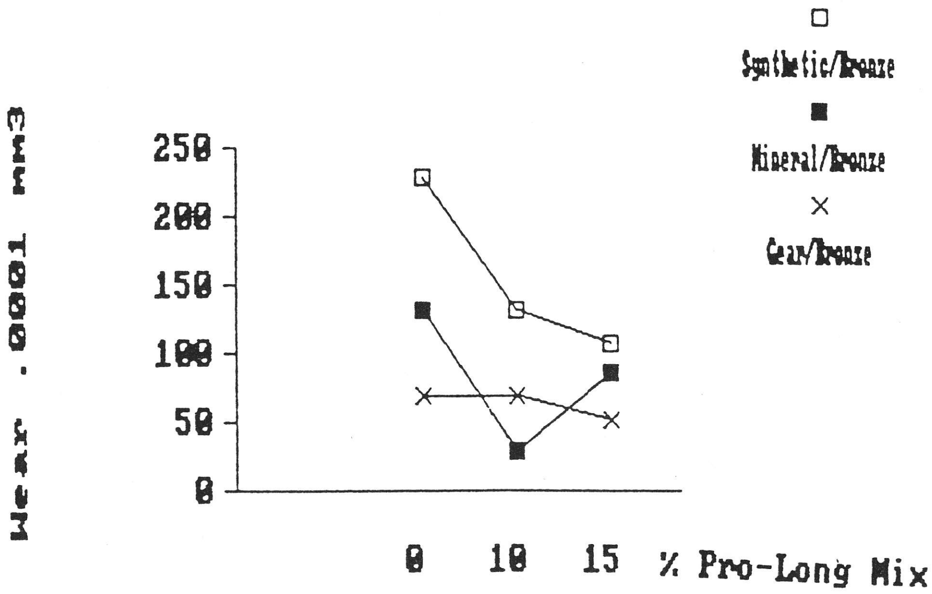

Figure 4.3.4 Worn off bronze material related to Pro-Long mixup in mineral and synthetic engine oils and in EP gear oil

For synthetic oil, 10% Pro-Long showed the biggest wear reduction.

Some structural changes in the material may be found as for steel, explaining this higher wear resistance. Being outside the agreement for this project, Scanning Electron Microscopy was not carried out on these specimens.

4.3.3 Survey of test results

Table 2, next page, gives a general view of results from BRONZE/STEEL tests. The table shows the amount of decrease or increase of friction, temperature and wear in percent values. The percent values are calculated from testdata with 10% and 15% Pro-Long mixup.

Lub. oil	Friction		Temperature		Wear		% Pro-Long
	Mineral	Synthetic Multigrade	Mineral	Synthetic Multigrade	Mineral	Synthetic Multigrade	
	%	%	%	%	%	%	
Multigrade engine oil	+ 321	+ 100	+ 6,4	+ 18,5	- 81,1	- 42,1	10
	+ 314	+ 50	+ 1,2	+ 11,4	- 41,9	- 53,1	15
EP gear oil	0		- 9,2		0		10
	+ 24,1		- 6,3		- 23,5		15
Average value from 45 BRONZE/STEEL tests	+ 75		0		- 45		10
	+ 75		0		- 45		15

Table 2 Result from BRONZE/STEEL tests

4.4 Effect on White Metal

As white metal is a rather soft material, the load had to be further decreased. At 180 N, which is about 2 times the acceptable load for such a bearing, there was a tendency of full hydrodynamic lubrication, ref. figure 4.1. As soon as the load was increased for bringing the ZN/P value into the boundary lubrication zone, some material was worn away with a bigger area and further hydrodynamic lubrication as a result.

With this low load, the specimen tended to float on the turbulent oil flow, and no comparative measurements could be done.

4.5 Other measurements and limitations

Density of Pro-Long Metall Pluss was measured to 1.15 g/ml which corresponds to the manufacturer's specifications. This is quite heavy compared to oils, and mixeability should be subject to further studies.

Contents of Sulphur was analysed, as a high contents of Sulphur is not recommendable for engines. The contents was found to be 0.48 gS/kg or 0.1% per volume, which is also according to the manufacturer's specification. The contents of Sulphur in the oil depends from where the crude has been taken, which is not under the control of the refineries. Crude from the Middle East may contain 1.5% Sulphur. The Sulphur mixed in from Pro-Long is therefore negligible.

Viscosity of Pro-Long was not measured during this test. It is, however, specified by the manufacturer to be far below the one for lubricating oils. As could be visually seen during this test, the viscosity is reduced by mixing in Pro-Long of large quantities. For this test the effect of a reduced viscosity is not critical as the test bearing operates in the boundary lubrication zone (see figure 3.1) anyhow. A lower viscosity will affect the ZN/P value, and hence one would expect even more reduction of the friction measured in the test provided the viscosity was maintained.

For a real machine, a correct viscosity is of more importance. Use of Pro-Long mixups of 10-15 % may therefore qualify for an increase in oil viscosity. Viscosity measurements for different mixtures should be carried through.

5. CONCLUSIONS

Results from this test should be used as an indication only. Measurements are taken from a specified laboratory test without simulation of any actual machinery situation. Real machines will have other and quite often variable temperature ranges and loading conditions which may result in other findings. Other material combinations than the tested ones will also exist. Especially one has to take care about the machinery manufacturer's recommendations or restrictions regarding lubricants during the guarantee period.

This test has revealed a significant wear reducing effect from the Pro-Long Metal treatment for lubricating oils.

Totally about 110 tests have been run. Average from these tests show that for steel to steel contacts friction, temperature and wear are reduced by approximately 20%, 30% and 55% respectively at a 15% Pro-Long mixup in the oil, ref. figure 5.1.

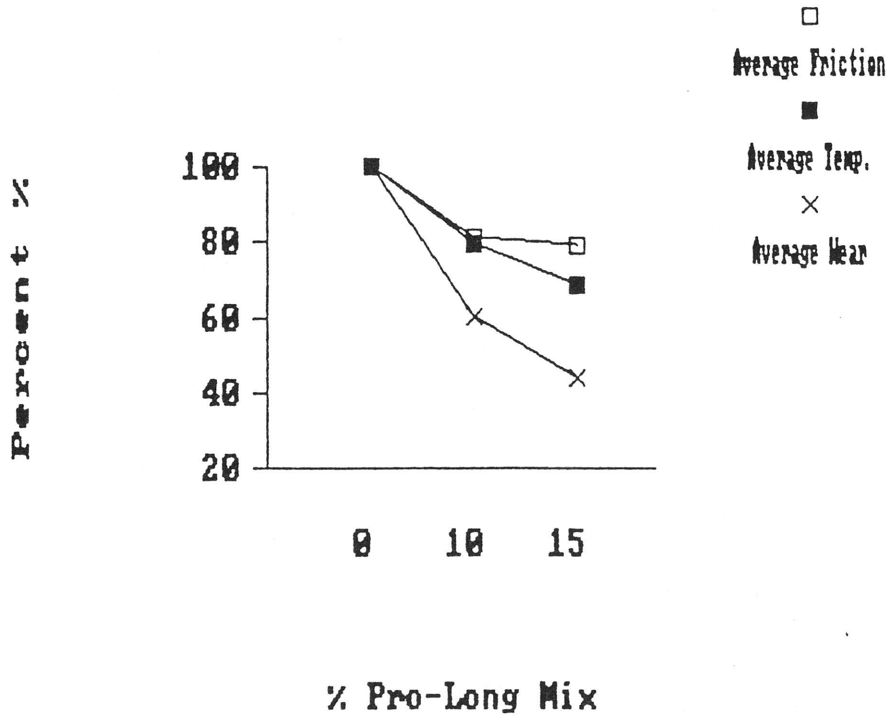

Figure 5.1 Average friction, temperature and wear from all steel/steel tests

For bronze to steel contacts average from the tests show that friction is increased by approximately 75%, temperature is almost unchanged and wear is reduced by approximately 45% with 15% Pro-Long mixed in the oil, ref. figure 5.2.

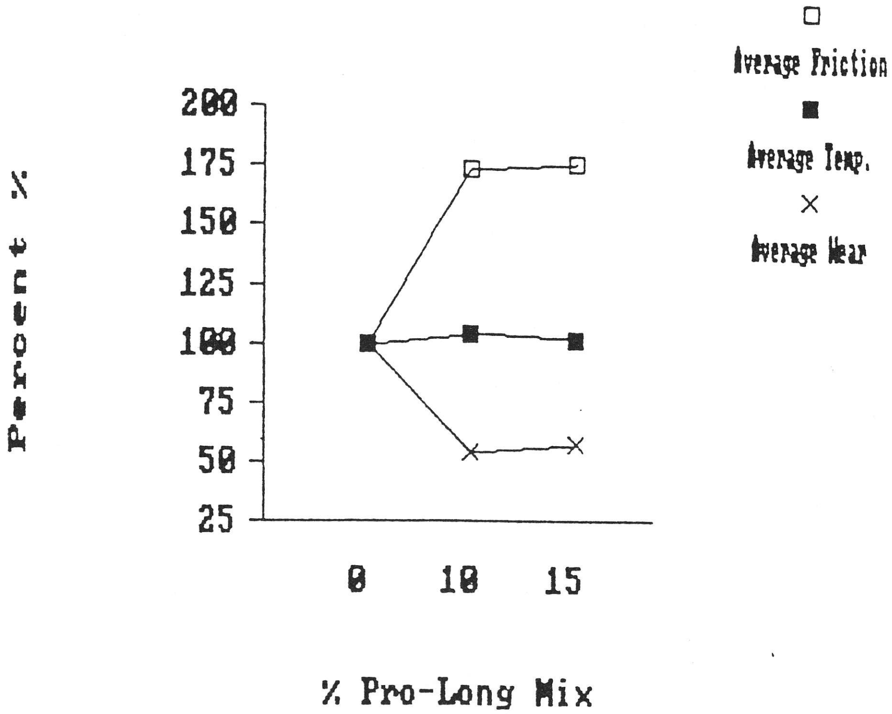

Figure 5.2 Average friction, temperature and wear from all bronze/steel tests

It should be noticed that although the friction is increased approximately 75% for bronze/steel contacts by use of Pro-Long, this friction is still low compared to the 25 times higher friction for steel/steel contacts, where Pro-Long showed a significant friction reducing effect.

Occasionally performed SEM analysis of the wear track on steel indicates a possible surface treatment and increase of hardness due to Pro-Long Metall Pluss. This will, however, need some further investigation.

Sulphur content and density were found to meet the manufacturer's specifications, 0.1% by volume and 1.15 g/ml respectively. No restrictions for use should be required due to contents of Sulphur.

Due to the significant results from this test, the product is proposed for further long term testing on real machines. Possible surface treatment effect and eventual long term effect on temperature due to possible evaporation of the mineral spirits contained, may be relevant for further studies.

Analysis of the affinity of the Pro-Long Metall Pluss to lubricating oils, especially regarding effect on viscosity and particle size distribution, is also proposed.

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/2/ Leif Lundby: Forbrenningsmotorer. Universitetsforlaget, 1975.

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/5/ TPC Skills - Training Program - Lubrication

LEB/4c/870213/tj/jkj

FACTS ABOUT THE SINTEF GROUP

The SINTEF Group is the largest technological contract research organization in northern Europe. About 90 % of the SINTEF Group's income comes from its project work.

The SINTEF Group is composed of 4 separate organizations which are constituted in different ways:

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EFI	The Norwegian Research Institute of Electricity Supply A/S (majority owner, SINTEF)
IKU	Continental Shelf and Petroleum Technology Research Institute A/S (wholly owned by SINTEF)
MARINTEK	Norwegian Marine Technology Research Institute A/S (majority owner, SINTEF)

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The SINTEF Group's motto is "Leading Technology". It follows that our objective is the provision of high professional standards in all aspects of our activities. We demand high quality project work and project management, quality control and good client relations. There is close interaction between the requirements of industry and the perspective of the research community into technological and scientific possibilities - an ideal relationship to nurture the innovations required to lead technology.

CLOSE COOPERATION WITH NTH

The SINTEF Group and The Norwegian Institute of Technology (NTH) work together in close, integrated cooperation. This primarily means the common use of laboratories, equipment and specialist staff. Consequently, research scientists from NTH participate in research projects in the SINTEF Group, whilst SINTEF Group staff often lecture at NTH. This association provides mutual benefits: it makes a significant contribution to the overall level of competence in the SINTEF Group, whilst simultaneously helping to ensure that teaching at NTH is directed towards pertinent social requirements.

The NTH and SINTEF community comprises a centre of technological R&D, which is only comparable on an international scale. The SINTEF/NTH model is recognized and acknowledged both at home and abroad as a unique solution to the problem of contact between society and a university environment.

KEY DATA 1986

No. of employees:		1820
- Research Scientists:	940	
- Research Scientists with Ph.D. or equivalent (%)	22 %	
Turnover 1986		NOK 890 million
- Industrial projects	NOK 660 million	
- Research Council projects	NOK 150 million	
- Grants from NTNF (The Royal Norwegian Council for Scientific and Industrial Research)	NOK 35 million	
- Other grants	NOK 10 million	

TURNOVER BY MAIN DISCIPLINARY AREAS:
(based on turnover in 1985)

Marine Technology and Fluid Dynamics	29 %
Petroleum Technology and Geosciences	20 %
Information Technology	16 %
Machine Design and Production Engineering	11 %
Chemistry, Metallurgy and Biotechnology	9 %
Civil and Structural Engineering	7 %
Electricity Supply	6 %
Social Research	2 %

QUALITY

The SINTEF Group is engaged in about 5000 projects anually. Our professionalism and quality assurance are ensured by the following project management and quality control systems developed by the SINTEF Group:

SAPO - The SINTEF Group's planning, and follow-up system for project administration
Quality assurance handbook
Project management handbook
Staff development program
Quality council

President	Johannes Moe
Senior Vice President	Eiliv Sødahl
Vice President, Technology,	Conrad Krohn
Company Secretary	Sverre Løvaas
Information Manager	Helge Amotsbakken
Vice President, Personnel,	Rolf Hjulstad
Operations Manager	Jostein Søvik
Vice President, Finance,	Terje Bisgaard
Business Development Manager	Jacob Hygen

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