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Testing lubricants by measuring wear.

Summary: An apparatus is described which makes it possible to carry out measurements of wear by reciprocating motion. A series of lubricants was investigated, in which the effects of duration of the test load, temperature, material and roughness of the friction surfaces were taken into consideration. Any variation in these experimentalconditions involves in many cases a simultaneous variation in the quality sequence of the lubricants, so that evaluation would would appear to be very difficult.

CONTENTS

A. Purpose of the experiments.

The most recent research in the field of testing lubricants has shown that the friction-reducing effect is not identical with a reduction of wear. It is therefore necessary to test the lubricants in respect of their wear behaviour. As the experiments in Report No. 478 have shown that the measurement of wear makes differentiation between various oils possible, these experiments were continued on a new, improved apparatus.

B. Experimental installation.

The construction of the new apparatus will be seen from Figures 1, 2 and 3. In principle there is no change from the machine described in Report No. 478. The new apparatus does, however, represent an extension and in certain respects an improvement of the old machine.

In place of a shaft with two drums, two shafts each with four drums have been provided. For these eight drums there are an equal number of load levers and containers for holding the oil to be tested. These containers, each of which contains 600 ccm oil, are housed in a common trough with heating fluid.

As distinct from the old system, the temperature of the oil to be tested is measured in each container with a separate thermoelement, all of which thermoelements are connected to a common millivoltmeter.

A further improvement resides in the device for measuring the wear. Whereas in the old apparatus the extent of the wear on the pin could only be ascertained after removing the drums, the new machine makes it possible to measure the amount of wear without any great trouble. Below the load levers is a slide bar, on which an encased gauge can be place. It is thus possible to ascertain without difficulty during the experiment to what extent the load levers have come closer to the slide bar. The distance thus measured is very approximately equal to the shortening of the worn pin,

As already mentioned in Report No. 478, the drums are fitted with hardened and polished steel bands and the surface of these bands is employed as wear surface. In the experiments described in the present report, two kinds of bands were used. Type 1 consists of the normal bands which are at present in stock in large quantities for these experiments. Type II differs from these by being somewhat rougher; they had to be used for part of the experiments to bridge over difficulties in supply. Bands of both types were normally used without alterations. For special experiments the roughness was increased by sand-blast treatment.

In order to be able to make use of the entire width of the band, if possible, the load levers are so placed that they can be moved axially in respect of the drums. In this manner three adjacent surfaces of wear are brought to bear on the width of the band so that the transition from one surface to the other can take place without effort. The surfaces of wear can be changed, as in the old machine, in the longitudinal direction of the bands by rotating the drums through 45°. Thus in the longitudinal direction four surfaces can be disposed one behind the other, so that twelve experiments are possible on one band.

C. Experimental Method.

For all the experiments herein described the speed chosen was 81 r.p.m.; this is rather lower than the speed in Report No. 478. This was done on the one hand so as to preserve the apparatus and on the other hand in order to make further progress in the domain of limiting friction and thus increase the wear per stroke. With the speed used here the number of strokes per minute was thus 162; with a length of slide of 32.5 mm, this corresponds to an average sliding speed of 22.3 cm/s and a maximum speed of 54 cm/s.

The friction pins used were not wedge shaped as in Report No.478 but cylindrical pins with a diameter of 3 mm. They possess the advantage that the specific load throughout the entire experiment remains the same, but they make it necessary to provide running-in in order to match the front surface of the pin to the curved surface of the steel band. Of the 12 friction surfaces provided by one steel band, one is used for running-in. This continued until the pin had been shortened by 1/10 to 2/10 mm. The experiment proper then commenced, with loads of 1,2 and 5 kg. With a lever transmission of 1 : 2, the specific loads for a diameter of the friction pin of 3 mm were 28.3, 56.6 and 141.5 kg/sq cm.

In so far as the nature of the lubricant permitted, the test was carried out at temperatures between 50 and 130°C. The time of the experiment was fixed for a large number of the tests at 4½ or 20 hours. When sandblasted bands were used, the wear was so great that the experiment had to be discontinued after a few minutes.

During the test the wear was measured by means of a gauge at certain intervals, when the machine was temporarily stopped to prevent undesirable vibration. After completing a test at the first temperature selected, the oil was warmed to the next temperature, a fresh friction surface was adjusted and the next experiment was commenced. As a rule five consecutive rising experimental temperatures were used, and the oil was not changed between the individual experiments. A certain ageing of the oil certainly occurs here, but it is unavoidable and of no consequence, as all the oils are uniformly stressed thermally.

The following oils were examined:-

Description of Oil	Remarks	Viscosity in cSt 38°	Viscosity in cSt 99°	Viscosity Index
Rotring No. 723	Aero-engine oil	272	21.5	100
" Calib. oil	"	257.7	19.04	89
Wehrmacht- Unit oil	Auto. oil	101.9	10.4	81
TZ 900/5	Synth. lubricant	742	53.7	95
TZ900/ 2	"	197	15.8	85
Aeroshell med.	Aero-engine oil	276	18.2	75
Aero W	"	246.2	17.6	81
P 174	Synth. do.	207	21.7	120
SS 902 FM 25	" "	121.8	15.5	125
Wifo Unit oil	Auto oil	120	11.5	81
Essolub running in oil	"	62.8	8.9	112
LK 2200	(Synth. lubricant (sol. in water	116.8	13.9	117
Rape oil refined	-	44.8	10	156
Refrigerator oil, red	-	16.3	3.2	- 50
H 8	Synth. hydrocarbon oil	60	8.55	110
H 425	Synth ester oil	50.7	6.57	63
E 515	do.	15.5	3.48	20

D. Results of the Experiments.

1. Wear of brass on steel.

a) Wear as a function of time.

Figures 4 to 7 show wear as a function of time for four lubricants at four different temperatures.

The behaviour of the four oils varies considerably. At the lowest temperature of 53° C (Fig. 4) TZ 900/2 and Rotring show to begin with very little wear, but after an hour this increases very rapidly and reaches high values, especially in the case of TZ 900/2. Wear curves of a hyperboloid character are obtained. It may be assumed that this peculiar curve is to be attributed to a change in the surface of the steel band. As investigation has shown, the bearing surface gradually becomes coated with brass dust. This coating of metal reaches a definite amount and then increases no further; this means that the wear curve approximately takes the form of a straight line, as may be observed particularly clearly in the case of TZ 900/2. In the case of Essolub running-in oil and Rotring the wear is indeed less, but the character of the curve remains the same. Quite different conditions are produced with LK 2200. With this oil, the wear after the first half hour is the greatest of all the four oils, but after 1½ hours the shortening of the pin has reached its peak. During the further stages of the experiment the wear is approximately 0 and a curve is obtained that is parallel to the base line. On the friction surface there was no brass dust and only slight traces of wear were ascertained on the band. It may be assumed that the roughness is eliminated by the great initial wear, and this brings about a total cessation in the formation of metal dust.

If the course of the wear curves of these four oils is followed at higher temperatures (see Figs. 5, 6 and 7), it will be seen that in the case of TZ 900/2 and Rotring, an increase in temperature from 53 to 70°C brings about a decrease in wear, while the curve character is maintained. A further increase in temperature causes, especially in the case of TZ 900/2 (Fig. 6) a further drop in wear. Both oils show here an approximately straight line relation. At 130°C the wear rises again in the case of Rotring. Both with this oil and with TZ900 /2 the time/wear curve is convex upwards (Fig. 7). Essolub running-in oil at this temperature passes through a very rapid rising straight line wear. The wear curve of LK 2200 at 70° C has the same characteristic as at 53°C, but at higher temperatures a curve cannot be plotted, as the wear is extremely small and is therefore scarcely capable of measurement.

These examples should show that the periodic variation of wear furnishes valuable data as to the behaviour of a lubricating oil. If in the following paragraphs less reference is made to the time course and only the final result after a definite time is taken into consideration, the reason for this is the necessary limitation of the illustrations.

(b) Effect of various loads..

In these experiments brass pins were also used. The curves shown in Figs. 8 and 9 with Rotring and Wehrmacht-Unit Oil are to a very large extent identical in character, and only in one case (Fig. 9) is there an exception with 142 kg/sq.cm. The reason for this peculiar course has not yet been found; this case will be omitted from further discussions. As already ascertained in Report 478, there is a minimum between 50 and 100°C. The temperature pertaining to this minimum value is the higher, the smaller the specific load on the pin. On this side of the minimum, i.e. at low temperatures, the wear increases very rapidly and surface pressure is of no consequence. On the other side of the minimum the curves for the same specific load diverge appreciably with rising wear. The occurence of this minimum, as was ascertained subsequently, is a material property of the brass. In spite of this peculiar wear /temperature course contradicting practical experience, the brass pins for these experiments were at first retained, as the conditions for repeating this experiment with such material were satisfactory.

c) Testing various lubricants

In Figs. 10 and 11 the results are collated for those oils who by virtue of their viscosity belong to the class of aero-engine oils. Among these lubricants, the behaviour of TZ900/5 isstriking, which has a very high rate of wear at a low temperature and very low wear at a high temperature. A very flat course is shown by Aeroshell medium and P 174. Rotring produces a somewhat large amount of dust at both low and high temperatues and the intermediate minimum with this oil is particularly strongly marked. The synthetic lubricating oil SS 902 F 25 is remarkable for very low wear at a high temperature.

Further experimental results will be found in Fig, 12; these are lubricants of the viscosity of automobile oils. TZ 900/2 behaves very similarly to the above-mentioned more viscous TZ 900/ 5. The wear curves for the previously mentioned oils LK 2200 and Essolube-running-in oil are shown here as a function of the temperature. In the case of LK 2200 only at a low temperature could measurable wear be ascertained, as at a high temperature scarcely any dust could be observed. Very striking was the behaviour of Essolube running-in oil, which with rising temperature gave evidence of great increase in wear. Similar results were obtained with the two esters E 515 and H 426 (Fig. 13). It will be seen from the case of the refrigerator oil that even a thin oil can produce very little wear at a high temperature. Rape-oil gives, compared with the hydrocarbon oils H 3 and refrigerator oil, a very much lower degree of wear, especially in the range of the lower and medium temperatures.

d) Action of various admixtures.

Since oleic acid in certain concentrations has a powerful anti-friction action in the domain of limiting lubrication, this admixture was examined from the point of view of wear. As Fig, 14 shows, oleic acid both in the proportion of 2% and in that of 10% contributes to an appreciable decrease in wear at low temperatures when added to Tz 900/5. Similar conditions also apply to Rotring (Fig. 15). Experiments with oxidised oil are also of interest. This method of treatment, compared with the original oil, led at a low temperature to a decrease and at a high temperature to an increase in the amount of dust (Fig. 16). A further diminution in the wear figure was secured by adding 0.01% sulphur to the oxidised oil. The action of various additions of sulphur may be seen very clearly from Figs. 17 and 18. Particularly remarkable is the fact that even quantities of 0.1% can be demonstrated by wear measurements. At low temperatures a decrease and at high temperatures an increase in wear is observed. With rising temperature it would appear that the processes are more of a chemical than a mechanical nature, and these chemical processes bring about a speedy removal of metal. In the low temperature range the quantity of added sulphur can be determined at which the wear reaches a minimum.

The experiments so far conducted were all carried out with brass pins. The results are remarkable for their ~~excellent~~ repeatability and for the frequent appearance of minima. As already ascertained in Report No. 473, the position of this minimum is, inter alia, particularly dependent on the temperature and in connection therewith, on the viscosity. The more viscous the lubricant, the more the minimum will be found in the higher temperature range. It would appear that two types of wear processes must be distinguished here. The Minimum probably represents a transition stage from one form of wear to the other. At a low temperature, where wear assumes particularly high values, brass dust adhering to the friction surfaces could be observed again and again. A metal deposit is thus produced, the consequence of which is that after a relatively brief duration of the experiment the same metals slide on each other. Wear under these circumstances should however bear some relation to the phenomenon of corrosion. This would account for the large quantity of dust. In this state the lubricants offer to some extent appreciable discrepancies For instance, Aeroshell medium occupies a more favourable position than Rotring (Fig. 10). Furthermore, oleic acid and especially sulphur have an anti-wear action (Figs. 14-18). Certain relationships in regard to practice may therefore be established here.

At high temperatures, where the second type of wear is particularly marked, the wear is mutual; it is found both on the brass pin and on the steel band, but the dust on the steel band is small in quantity and shows a tendency to disappear. It might now be assumed that wear at high temperatures, e.g. wear on piston rings, comes nearest to practical cases. Unfortunately, under these conditions no relationship with practical cases can be found. A comparative experiment with Aeroshell medium and Rotring at 190°C shows that Rotring is superior, but this contradicts experience.

Although these wear experiments make a useful classification of lubricants possible, it is scarcely possible to judge an oil in regard to its practical behaviour. It will now be attempted to introduce some improvement here, by the use of other materials.

2. Wear of various materials.

Figs. 19 and 20 show the wear results with pins made of aluminium. Nida bronze and soft iron (obtained from iron carbonyl), compared with brass pins. While carbonyl iron and Nida bronze behave in much the same way, aluminium shows wear that rises with the temperature and hereAeroshell is inferior to Rotring reference oil. A similar result was obtained with piston material obtained from melted down aero-engine pistons (not heat treated). Fig 21.

When soft iron pins were used, made from welding rod Aeroshell gave a better performance than Rotring reference oil (Fig. 22). A drawback however is the fact that the low degree of wear involves a lengthy experiment and moreover a considerable amount of dispersion. In addition, a minimum would appear to occur here too. Experiments with cast iron pins have hitherto been unsuccessful, as the ensuing wear was far too slight. In subsequent experiments soft iorn pins were used, made from welding rod 6 mm thick.

3) Effect of roughness of the friction surfaces

Of special interest was the effect of roughness. As rough surfaces possess the advantage of producing measurable wear in a relatively short space of time, the steel bands were sandblasted with fine sand. In order to obtain the necessary uniformity, 8 bands were stretched together on a drum and sprayed while being constantly rotated. The eight bands thus obtained possessed practically the same degree of roughness. With them the experiments were conducted in the same way as previously, but the time of the experiment was shortened to 5 minutes. The results (Fig. 23) are very remarkable. Aeroshell medium and SS 902 FM show a higher degree of wear than Wehrmacht Unit oil and Rotring reference oil, although the reverse must be expected from practical experience. By way of comparison, the same oils were tested with the same materials, but with polished bands and for the period of 20 hours. As will be seen from Fig. 24, results were obtained in this manner which contradict the previous results, but approximate more closely to practical conditions. One might perhaps be of the opinion that this divergent assessment of the four lubricants is to be attributed to the ageing of the oils, as the action of high temperature in the one case corresponding to the 5 experimenting lasts 5 x 5 minutes and in the other case 5 x 20 hours. If this were the case, the oil that has been in service for 5 x 20 hours would have a sequence as in Fig. 24, even with the use of sandblasted bands. In actual fact, however, the conditions are as in Fig. 23. The periodic variation of the oil therefore has no effect on the divergent behaviour that has been observed. It may therefore be assumed that the different degrees of roughness and the different durations of the experiment are the causes of this phenomenon.

4) Collation of the results.

With the experimental arrangement selected, brass pins produce on hardened and polished steel wear values that can be repeated satisfactorily, and permit of classifying lubricants. The relationship between these experimental results and the results obtained in practice can, however, scarcely be established. Brass, soft iron, aluminium, Nida bronze and piston material vary greatly in their wear behaviour; by varying the material, the assessment of the quality of the lubricants may be affected. Both the absolute wear and the effect of the temperature of the lubricant vary considerably with the materials tested. By increasing the roughness of the friction surface, not only is the wear increased, but a different assessment is given to the lubricant. The great dependence of wear on the material, the temperature and the roughness makes it difficult to assess thewear behaviour of the lubricants. It would be desirable to find a method of investigation permitting of drawing some practical conclusions, particularly in regard to the wear on piston rings in the engine. Soft iron pins on a smooth steel band seem to approximate most closely to practical conditions. To what extent this is the case must form the subject of future investigations. In many cases a more detailed explanation and reasons for the various pehenomena occurring here cannot be given. A knowledge of the physical anu chemical properties, the result of the usual measurement methods, is not sufficient here. It is indeed necessary to investigate further the behaviour of the lubricants on the metals, perhaps by measuring the friction with boundary lubrication, the surface tension, the heat of wetting, the corrosion etc. Information is also lacking about the stability of the material in various directions, e.g. tensile strength, shear strength. Only a knowledge of these lubricant and material properties can shed further light on the problem of wear.

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