한국윤활학회지(1995), 제 11 권 제 5 호
Journal of KSTLE(1995) Vol. 11, No. 5, pp.162~171

Seizure Failure of Engine Crankshaft Bearings

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1. Introduction

The application of reciprocating engine crankshaft bearings is of particular importance and interest among the plain bearing, not only because the sheer volume of internal combustion engines now produced, but because the severe operating conditions they are subjected to. Demands for better performances of crankshaft bearings have provide an important impetus in the development of bearings and bearing materials.

As engine design progresses toward higher outpt and higher efficiency, crankshaft bearings must perform under more seveve operating conditions. Higher load, temperature, and speed as well as lower viscosity oil are applied to the bearing sysem, resulting in a smaller minimum oil film thickness. This means more solid-solid contact between the shaft and bearing, and the bearing is exposed to more danger of seizure. Some engines may experience bearing seizure problems. However, understanding about the seizure behavior and mechanism is far from being enough.

Seizure resistance of a bearing-shaft system will be affected by the properties of the shaft and bearing, especially their materials and surface texture. Commonly used engine bearing materials include Al-Pb-Si, Al-Sn-Si, Al-Sn, and Cu-Pb with Pb-Sn-Cu overlay. These materials have very different properties. They showed different behaviors dering seizure tests and seizure may occur with different mechanism for different bearing material. Shaft materials also affect the seizure resistance of the system. Surface texture of the bearing and shaft have apparent effects on the lubrication and solid-solid contact pattern, and therefore will affect the seizure behavior of the system.

Bearings and shafts which are made of different materials and have different surface textures have been tested and analyzed. Their effects on seizure resistance are discussed and possible seizure mechanisms for different bearings are presented in this paper.

2. Experimental

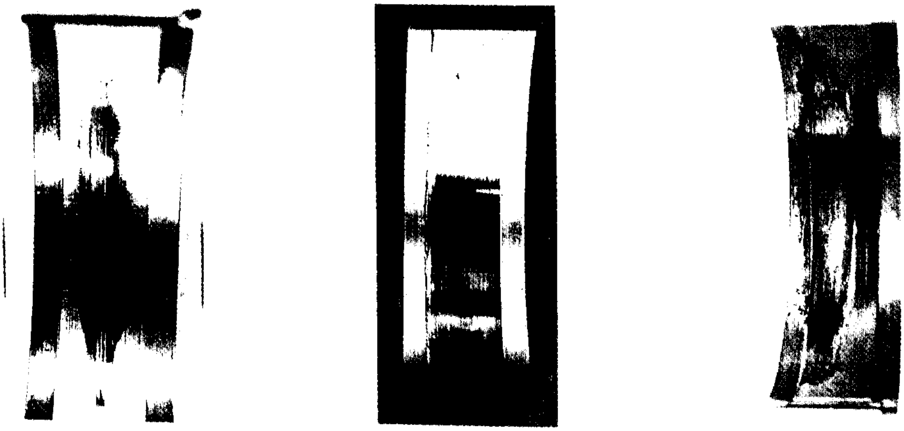
2-1. Apparatus

A crankshaft bearing test machine was constructed to test connecting rod big end bearings. The layout of the machine and is major features are shown in Fig. 1 The details about the machine and test procedures have been described elsewhere (Ni, 1995). The load applied to the test bearing is a static compression load. Load, friction force, and temperature on the back of the bearing are monitored by a three-pen chart recorder. An unsheathed fine gage thermocouple is used for temperature measurement. After running-in under a specific load of 8.9 MPa (1000 lbs) for 12 hours, the load was increased step by step until seizure occurred, with 4.5 MPa (500 lbs) for 0.5 hour per step. The final load is taken to be the seizure limit load for this bearing-shaft combination. The width of the test bearing was cut to 10 mm from its orignal width 18 mm to reduce the seizure load. The major parameters for our tests are listed in Table 1.

2-2. Test Bearings

Test bearing materials include aluminum-lead-silicon, aluminum-tin, aluminum-tin-silicon, copper-lead with lead-tin-copper overlay. Their chemical compositions are listed in Table 2.

AL1, AL2, and SAE 787 aluminum-lead-silicon bearings. The lead in the alloy provides the alloy with a soft phase and solid lubricant. Silicon exists in the bearing alloys as fine block-form particles. AL1 and AL2 share the composition. The major difference between them is the silicon particles. The size of silicon partices in AL 1 is around 1-3 μm



(a). an aluminum-lead-silicon bearing (b). an aluminum-tin bearing (c). a copper-lead with overlay bearing

Fig. 1. Seized bearings.

Table 1. Major test parameters

bearing dia:	50.025 mm	shaft speed:	3000 rpm
bearing width:	10.0 mm	inlet oil tempt:	135°C
dia. clearance:	0.042 mm	inlet oil pressure:	1.7 KPa
brng thickness:	1.5 mm	lubricant	10 W-30

with an average of about 1.5 μm. In AL2, the size is around 1-4 μm with an average of about 1.8 μm. The silicon particles of AL3 are more scattered. Most of them are around 1-2 μm, while some are around as big as 4-5 μm. The average is about 2 μm.

The final manufacturing method for the bearing inner surface can be boring or broaching, which results in different surface roughness orientation on the bearing surface. The surface roughness on a bored bearing is oriented in the circumferential direction, which is parallel to the moving direction, and this kind of surface texture is called as longitudinal surface roughness. On the other hand, the surface roughness on a broached bearing lays in the axial direction and is usually called as transverse surface roughness. AL1 bored and broached bearings, AL2 bored and broached, and AL3 bored bearings were tested. Surface roughness R_a of broached AL1 and AL2 bearings is about 0.2-0.3 μm in the axial direction and 0.35-0.45 μm in the circumferential direction. R_a of AL1 bored is around 0.1 μm in the axial direction and 0.08 μm in the circumferential direction. R_a of AL2 bored is around 0.4 μm in the axial direction and 0.09 μm in the circumferential direction. R_a of AL3 bored bearing is around 0.35 μm in the axial direction and 0.09 μm in the circumferential direction.

AS1 is the aluminum-20% tin (SAE 783) bearing. The bearing surface is bored and the average roughness R_a in the axial direction is around 0.35 μm and 0.06 μm in the circumferential direction. The tin in the alloy exists in the aluminum matrix as numerous islands which are interconnected along the trigonal grain boundaries of the aluminum to form a three-dimensional net of tin. Like lead, the tin in the alloy can work as a solid lubricant and provides the alloy a soft phase, and thus gives the alloy good embeddability, comformability, and compatibility.

However, as the aluminum-tin bearing alloy does not have hard phases in it, the bearing may have low seizure and wear resistance when it runs against a nodular cast iron shaft because iron caps would be formed above the geaphite nodules on the shaft surface during the manufacturing process and these iron caps may wear out the bearing like a file. Hard silicon particles were introduced into the aluminum-tin alloy to cope with the iron cas, and this idea lead to the application of SAE 788 aluminum-tin-silicon bearing alloy (Fukuoa, 1983).

AS2 is among the SAE 788 class, which is the aluminum-tin-silicon bearing. The size of the silicon particles in the AS2 alloy is around 5 to 10 μm. The bearing surface is manufactured by boring process; its surface roughness R_a is about 0.39 μm in the axial direction and 0.06 μm in the circumferential

Table 2. Chemical composition of tested bearing alloys (%)

Elements	Aluminum-based				Copper-based CLT	
	AL1&AL2	AL3	AS1	AS2	Lining	Overlay
Al	balance	balance	balance	balance	--	--
Sn	0.25-1.25	1.0-1.6	18.22	10-14	0.6-2.0	0.8-12.0
Pb	4.0-8.0	6.5-9.0	--	--	21.0-27.0	balance
Si	3.25-4.75	3.5-4.5	0.5	3.5-5.0	--	--
Cu	0.05-0.15	0.5-1.0	0.7-1.3	0.8-1.2	balance	1.0-3.0
Mn	0.2-0.4	--	0.1	--	--	--
Mg	0.05-0.15	--	--	--	--	--
Fe	--	--	0.5	--	0.7	--
Ni	--	--	0.1	--	0.5	--
Sb	--	--	--	--	0.5	--
Zn	--	--	--	--	0.5	--
P	--	--	--	--	0.1	--

direction.

Copper-based bearings, which usually have higher fatigue strength than aluminum-based alloys (Pratt, 1973), are often used in heavy-duty applications. One kind of copper-lead-tin with lead-tin-copper overlay bearings, designated as CLT bearing, has been tested. This bearing is among the most popular copper-lead bearings used in the automotive engines. The lining material is copper-lead-tin SAE 49. The copper-lead-tin lining layer was manufacturd by sintering process. The average size of copper grains is around 40 μm. The bearing surface is finished by broaching, but the manufacturing method is unimportant here because the manufacturing texture on the lining surface is covered by an electroplated overlay. The material of the overlay plate is lead-tin-copper SAE 192. Its thickness is around 10 to 12 μm A nickel interlayer is used between the lining layer and the overlay plate, and its thickness is about 1 μm.

2-3. Test Shafts.

Two kinds of nodular cast iron were used for the shafts, designated as NC1 and NC2. They have the same chemical composition but different metallurgical structures due to different amount of inoculation during casting process. NC1 iron has the typical bulls-eye structure. Graphite nodules are surrounded by a ring of white ferrite. There is about 30% ferrite in NC1. NC2 has less ferrite than NCl; no more than 10%. In NC2 there is no ferrite ring around the graphite nodule, though a small amount of ferrite can still be found adjacent to the graphite nodules. Brinell hardness of iron NC1 is about 220, and that of NC2 is about 250.

The shaft surface was finished with film polish. Two finishing methods, designated as F1 and F2, were used in the manufacturing of test shafts. F1 is a two-pass finishing method, i.e. the shaft is polished twice. F2 is a three-pass finishing method, with the third finishing done under a higher speed .with a finer grit film. The surface roughness R_a of NC1-F1 ranges from 0.08-0.12 μm with an average of 0.10 μm with an average of 0.10 μm, from 0.07-0.10 μm with an average of 0.09 μm for NCl-F2, from 0.06-0.10 μm with an average of 0.08 μm for NC2~F1, from 0.05~0.10 μm with average of 0.07 μm for NC2-F2.

3. Test Results and Discussions

Seizure failure of engine crankshaft bearings is the result of severe adhesion between the bearing and shaft and it is indicated by an abrupt increase of friction force and bearing temperature. Adhesion between the bearing and shaft can occur at micro, local, and failure scales. During the tests with aluminum-lead-silicon and aluminum-tin-silicon bearings, spikes of temperature and friction force could be observed even at a low load. These sudden increases of temperature and friction force indicate the occurrences of adhesion between the shaft and bearing. Most of the time no apparent seizure marks can be seen with naked eye vision. Seizure might occur at asperity scale and this phenomenon is therefore referred to as micro seizure. The important factors which may determine at what level of contact micro seizure may occur are the properties of the mating materials and the lubricant. Micro seizure does not affect the properties of the bearing. The bearing can still work normally and the surfaces will be modifed through the wear process

Localized seizure marks can be observed on the bearing surface sometimes after a large spike of temperature and friction force. There are always some local areas where solid-solid contacts are more severe than average because of the irregularity of the bearing and the shaft. Micro seizure may first start to develop at these areas. Development of seizure may most likely be promoted by the heat and wear debris generated during the process. Seizure develops more easily in the circumferential direction than in the axial direction because of the movement of the shaft. If the contact outside the local area is mild and seizure can not propagate all over the bearing surface, seizure will be limited within the local area. If seizure propagates across the bearing surface, final seizure failure occure. Therefore, final seizure load largely depends on the propagation mode.

Seizure is marked by a sharp and unrecoverable increase of temperature and friction force. Seizure failure totally destroys the bearing and severely damages the shaft. Large amount of heat and material transfer are produced during the failure process. Carbonization of oil and annealing of the bearing can happen under the high temperature. The bearing and shaft may appear like being welded togeter at the final stage of seizure failure; the shaft will be seized and the machine stopped. Fig. 1 shows some seized bearings.

3-1. Aluminum-Lead-Silicon Bearings

The overall test results of aluminum-lead-silicon bearings and nodular cast iron shafts are shown in Fig. 2. Each data in the figure is the average of 4 to 6 tests. Some comparisons can be made, based on the results.

Silicon is often used in aluminum-based bearing alloys. It disperses in the aluminum matrix as fine block-from particles. Hard silicon particles may break the continuity of aluminum matrix, and therefore block the propagation of aluminum adhesion and increase the seizure resistance of the bearing. They may also modify the shaft surface and remove aluminum adhesion on the shaft through micro polishing the shaft, and thus increase the seizure of the bearing-shaft system (Fukuoka, 1983). While the presence of hard silicon particles in the aluminum alloy plays such a significant role in bearing performance, the shape and size of silicon particles would certainly affect bearing performance.

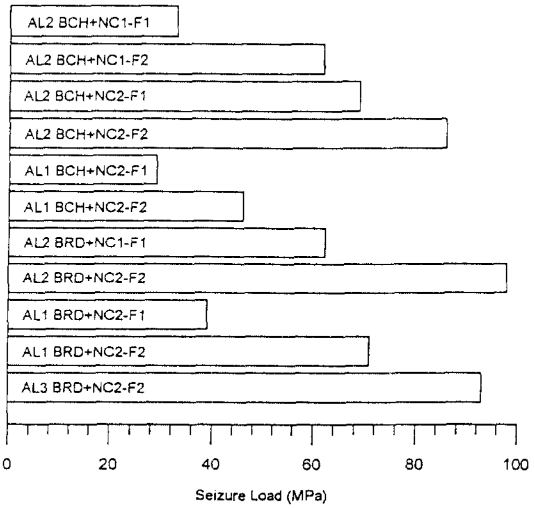


Fig. 2. Seizure test results of aluminum-lead-silicon bearings and nodular cast iron shafts.

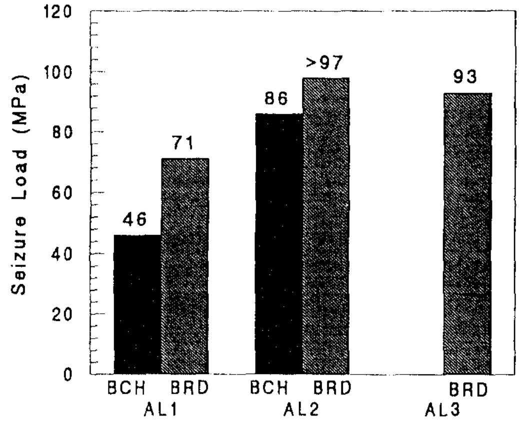


Fig. 3. Comparison of seizure loads of different bearing alloys with NC2-F2 shafts.

The comparison of seizure loads of AL1, AL2, and AL3 alloys is shown in Fig. 3 BCH means broached bearing and BRD is bored bearings. As it can be seen, AL2 has the highest seizure resistance, while AL1 has the least among these three different aluminum-lead-silicon bearing alloys. Comparing the sizes of silicon particles in these alloys, one can see that there is an optimum size for the silicon particle. It was observed in our tests that the alloy with larger silicon particles gave bigger temperature and friction (T & F) spikes during loading procedures. AL1 has the smallest silicon particles and it gave smallest spikes of T & F during the tests, but its tolerance for the spikes without seizure failure was also low. Seizure occurred therefore at lower loads with AL1 bearing. AL3 alloy has the largest silicon particles and the silicon particle size is more scatterd. Some silicon particles are as big as 5 μm. Large T & F spikes werre observed during the tests. However, the bearing could tolerate larger spikes without seizure failure and has higher final seizure load than AL1 bearing. The best one is the AL2 bearing. It showed just moderate T & F spikes during the tests and could recover from T & F spikes very well. It has the highest seizure resistance among three tested materials.

As it was mentioned above, silicon particles in the alloy break the continuity of the aluminum matrix. They may block the propagation of micro or local seizure. If the particles is too small, they may not have good blocking effect and they may be worn away easily during the contact with the shaft. Therefore, an alloy with too small silicon particles can not tolerate large T & F spikes and seizure occure at lower load. On the other hand, silicon is much harder than aluminum and it also has lower heat conductivity. Large silicon particles may create large spots with higher contact pressure and local temperature. Therefore, micro seizure may occur at a larger scale, which is indicated by large spikes of T & F, and may eventually trigger seizure failure earlier.

Based on the results we obtained with these different bearings, it can be concluded that there could be some optimum size and distribution of silicon particles for certain operating conditions. For our test conditions, the AL2 bearing has the highest seizure resistance.

3-2. Surface Roughness Orientation

Both broached and bored bearings were tested in order to investigate the effect of bearing surface roughness orientations. The comparison can also be seen in Fig. 3 As shown in the figure, bored AL1 bearings have a higher seizure load than broached AL1 bearings; bored AL2 bearings have a higher seizure load than broached AL2 bearings.

It is well known that surface roughness orientaion

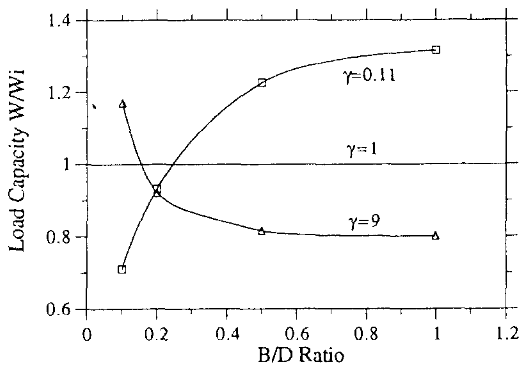
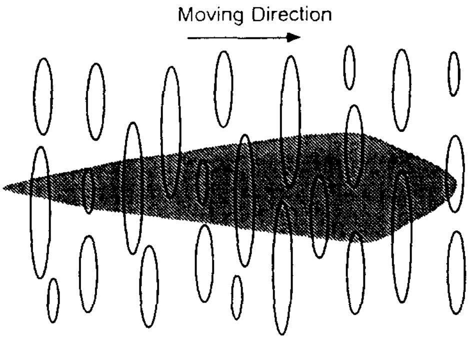
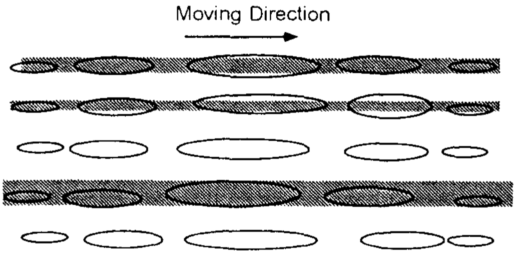


Fig. 4. Comparison of oil film load capacities of bearings with longitudinal (γ=9), transverse (γ=1/9), and isotropic (γ=1) roughenss.



(a). on a broached bearing surface



(b). on a bored bearing

Fig. 5. Schematic drawing of asperity contact foot prints and local seizure marks on a broached and a bored bearing. (a) on a broached bearing (b) on a bored bearing.

may affect bearing lubrication. Fig. 4 shows an example of lubrication analysis for our test conditions with Patir and Cheng's (1978, 1979) average flow model, comparing the load capacities of bearings with longitudinal ($\gamma=1/9$), and isotropic ($\gamma=1$) roughness at $\lambda=1$. As the width-to-diameter ratio of our test bearing is 0.2, the lubrication difference between our bored and broached are not significant in our test.

During the tests, broached bearings gave lower T & F spikes during loading procedures. However, their tolerance to these spikes was also low. Seizure to propagate into macro failure on broached bearings. On the other hand, bored bearings gave higher T & F spikes, and they can tolerate high spikes. Micro seizure on bored bearings is less likely to develop into macro seizure, and this conclusion was confirmed by the local seizure marks observed on the bored and broached bearing surfaces. Fig. 5 shows schematic drawings of asperity contact foot prints, which are modeled as ellipses, and local seizure marks, which are indicated with shaded areas, on the bored and broached bearing surfaces. The moving direction in the figure is from left to right. The local seizure propagated toward the down stream in the circumferential direction. The total width of a local seizure mark is usually within 1 to 3 mm.

On a broached bearing, local seizure also develops gradually in the axial direction. At the end of the seizure mark, smearing of the bearing material can be seen, and it created a white, shiny and smooth area. This smearing might be caused by the accumulation of wear debris which were produced at the upper seized area. On the other hand, local seizure on a bored bearing was constrained within narrow stripes. Seizure marks did not propagate in the axial direction. No accumulation and smearing of the bearing material was obsered.

When micro seizure occurs, wear debris will be created. One can assume that the shape of the debris is similar to its contact foot print. With the bored bearing, debris is short in the axial direction. It would be easier for this lind of particles to pass the contact area without being trapped, and micro oil grooves between asperities on a bored surface would have an effect to prevent micro seizure from propagating in the axial direction. Only the asperities in contact with the shaft were worn down and the bearing can still take higher load.

With the broached bearing, on the other hand, once micro seizure occurs and wear debris is created, the debris is more likely to be trapped within the contact area by next asperities and cause more seizure down stream. Because the asperity is long in the axial direction, it is easier for seizure to propagate in the axial direction than on the bored bearing, and seizure is very likey to propagate along the cirumferential direction because of the shaft motion. In this way, micro seizure is easier to propagate into macro failure on the broached bearing than on the bored bearing.

So bored bearings have higher final seizure loads than broached bearings.

3-3. Aluminum-Tin AS1 Bearings

AS1 bearings have been tested with NC2-F2

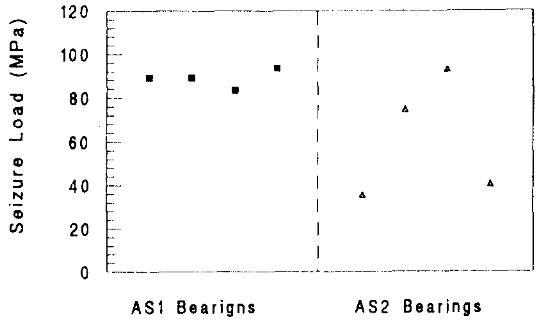


Fig. 6. Seizure test results of aluminum-20% tin AS1 and aluminum-tin-silicon AS2 bearings with NC2-F2 shafts.

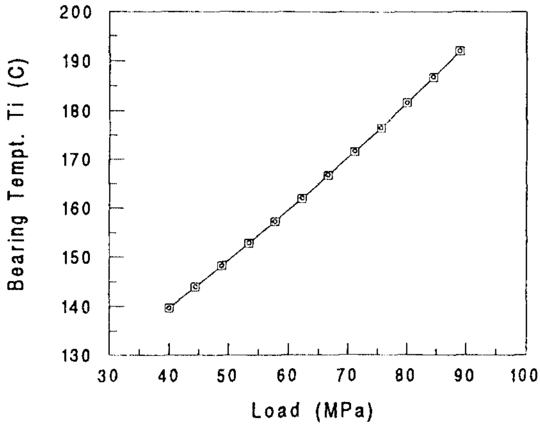
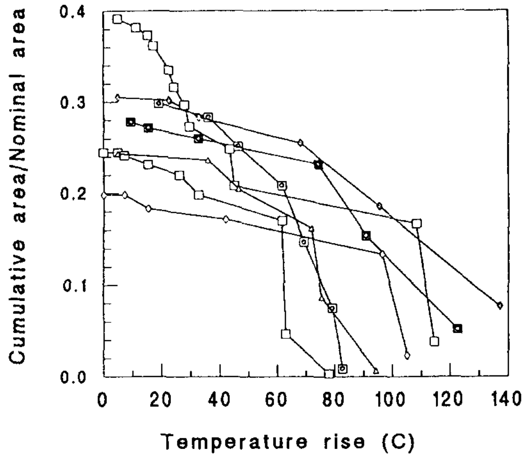
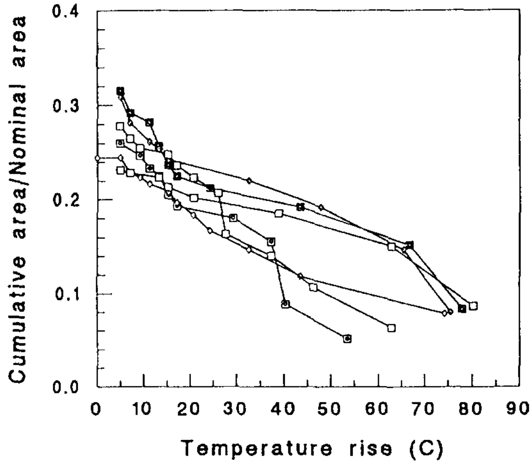


Fig. 7. Calculated bearing surface temperature with bearing load.

shafts. The results are shown in Fig. 6 The bearings showed very good seizure resistance. Seizure usually occurred at about 90 MPa. When the load was increased to certain level, the temperature and friction force to force began to fluctuate. If the load was further increased, the amplitude of the fluctuations became higher and higher. The bearing no loger functioned well and the load was taken to be the seizure limit load. After the tests, numerous small cavities and severe depletion of tin content at the contact zone were observed, while pure tin patches were just outside the contact zone in the down stream. It is concluded that tin at the contact area would be melted and quickly depleted when the bearing temperature is higher than the melting temperature of tin. Without enough protection of tin at the contact area, distress would occur on the bearing surface. Therefore, the melting temperature of tin, about 230°C (Neale, 1993), can be used as the failure parameter.



(a) case #1



(b) case #2

Fig. 8. Asperity temperature distribution on AS1 bearing surfaces before failure. (a) case #1 (b) case #2.

Bearing surface temperture is composed of bulk temperature and asperity temperature. Asperity temperature is the temperature increase caused by the contact between two relatively moving asperities. Because of the random distrbution of asperities, asperity temperature is also random and discrete. Both the bulk temperature and the asperity temperature distribution have to be determined to get the bearing surface temperature distribution.

Bearing surface bulk temperature was derived from temperature measurements on the back of the bearing and the housing, and the ambient temperature. Its relation with the bearing load is shown in Fig. 7 As it can be seen, when the bearing fails at 90 MPa, the bearing bulk temperature is about 192°C. Therfore, when the asperity temperature is higher than 38°C, the total temperature will be higher than the melting point.

Asperity temperature distribution was calcuated with Kuhlman-Wisdorf's (1987) model. Surface roughness profiles of both the bearing and shaft just before failure were used for the analysis. The results of two cases are shown in Fiure. 8 In case #1, the cumulated area where asperity temperature is higher than 38°C, i.e., the total temperature is higher than the melting temperature of tin, is about 24 percent; this area in case #2 is about 18 percent; the average is than about 22 percent. It is concluded based on the analysis that the aluminum-tin bearing may fail when the bearing temperature is higher than the melting point of tin at more than 22 percent of bearing area in the contact zone.

3-4. Aluminum-Tin-Silicon AS2 Bearings

Silicon was induced into aluminum-tin alloy to improve its strength, wear resistance, and compatibility with nodular cast iron. Fukuoka, Kamiya and Soda (1983, 1987) experimentally investigated the effects of hard particles in aluminum-based bearing alloy by introducing different hard particles into 10% tin-aluminum alloy. Their results showed that hard particles in the alloy can polish and modify the shaft surface, and remove aluminum adhesion on the shaft and thus can improve the seizure resistance. The aluminum-tin-silicon also has higher fatigue strength and wear resistance than the aluminum-tin because there is less soft tin content and there are hard particles (Fukuoka, 1983; Massey, 1990).

However, our tests with the aluminum-tin-silicon bearing AS2 and NC-F2 shaft did not show higher seizure loads than the AS1 bearing. The test results are shown in Fig. 6 In the tests with AS2 bearing, fluctuations of temperature and friction force during loading procedures, even at low loads, were always observed. The bearing could sometimes recover from a spike and take more load thereafter, but sometimes it could not recover and failed. Because it was unpredictable when the bearing could recover from a spike, the seizure load of AS2 bearing was more scattered; its average seizure limit load is lower than that of AS1 bearing.

As it was noticed in earlier tests with aluminum-lead-silicon bearings, larger hard parcticles in the alloy usualy give larger spikes of temperature and friction force. Excessively large particles may give too large spikes of temperature and friction force, and may trigger seizure earlier. Based on our observation and comparison with other tests, it is believed that the size of silicon particles in the AS2 alloy, 5 to 10 μm, is too large.Therefore, in order to increase the seizure resistance of aluminum-tin alloys, the size and distribution of silicon inclusion should be controlled.

3-5. Cooper-Lead with Lead Overlay CLT Bearings

In tests with CLT bearings, temperature and friction force increase smoothly step by stop as load is increased step by step during the loading process. No spikes of temperature and friction force were observed before failure. At some load level, the temperature and friction force would begin to fluctuate and seizure would usually occur within the next two steps. Fig. 9 shows the test results of CLT bearings and iron shafts.

After the seizure tests, energy dispersion X-ray spectroscopy analysis (EDX) was used to analyze the chemical composition of the bearing surfaces and shaft surfaces. Sulfur, phosphorus and zinc were always observed on shaft surfaces after tests, regardless whether sseizure occrred. These elements come from additives in the oil. On the shaft surface only a very small amount of lead was detected. Nickel, tin and copper were found in the seized area on the shaft, but not in the unseized area. These three elements always appear together on the shaft surface in the seized area. The ratio between nickel, tin and coppeer could be different from test to test, with nickel usually present in the largest amount.

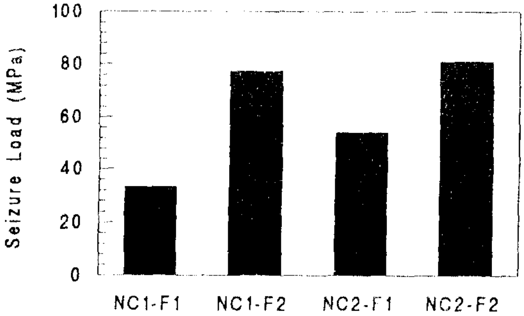


Fig. 9. Seizure test results of copper-lead CLT bearings and iron shafts.

While on the bearing surface, almost all the lead was gone. Major spectrum peaks are nickel, tin, copper and iron. Iron must come through material transfer from the shaft when seizure occurs. These results show that seizure occurred between the shaft and nickel-tin-copper compound layer after the lead-tin-copper overlay as removed by wear because the modified nickel layer has a poor seizure resistance (Bierlein, 1983; Milhra, 1991). Fluctuations of temperature and friction force during the step before final seizure may be an indication of localized of the lead-tin-copper overlay. Once these fluctuations appear, the bearing will soon seize.

As shown in Fig. 9 the NC2 shaft has a higher seizure limit load than the NC1 shaft. Three-pass finishing F2 has a higher seizure load than two-pass finishing F1. The seizure load of NC2-F2 shaft is 59% higher than that of NC2-F1 and NC1-F2 is 133% higher than NC1-F1, while NC2-F2 is only 5% higher than NC1-F2 and NC2-F1 is 64% higher than NC1-F1. It can be seen that the effect of surface finishing methods is more signficant than that of shaft materials when the shaft runs with copper-lead with overlay bearings.

When running with aluminum-lead-silicon bearings, however, shaft material has a significant effect on seizure load. With aluminum based alloy bearings, seizure is most likey to be caused by adhesion between the shaft and aluminum. So the resistance of the shaft material to adhesion with aluminum is very important to the seizure resistance of the bearing-shaft system. But in copper-lead with overlay bearings, the overlay has excellent seizure resistance and it supplies most of the seizure resistance for the bearing-shaft system. When there is a complete overlay on the bearing surface, seizure is very unlikely to occur with the cast iron shaft. So the shaft material has less effect on the seizure load for copper-lead with overlay bearings than for aluminum based bearings. When running with cast iron shafts, the seizure load of the CLT bearings is determined by the life of the overlay and the life of the overlay will be greatly affected by the surface quality of the shaft. If the surface quality of the shaft is worse, the overlay is worn away faster and seizure occurs earlier, When a CLT bearing runs with a F1 shaft, temperature and friction fluctuations appeared much earlier than with a F2 shaft. This indicated that the overlay was worn away earlier with a F1 shaft. Therefore seizure failure occurred earlier at lower load.

3-6. Effects of Shaft Materials and Surface Texture

Shaft with different materials and surface roughness, namely NC1-F1, NC1-F2, NC2-F1, and NC2-F2, were tested with aluminum-lead-sillicon bearings and CLT bearings. By comparing the results shown in Fig. 2 and Fig. 9, one can see that NC2 iron has a higher seizure resistance than NC1, and F 2 surface has a higher seizure load than F1.

As it was mentioned earlier, CLT bearing is more sensitive to the quality of shaft surface than to the material because of the wear of the soft overlay. However, aluminum-lead-silicon bearings are sensitive to shaft materials. The major difference between NC1 and NC2 is their ferrite contents. NC1 iron has more ferrite than NC2. There is almost no carbon in ferrite is softer and has lower seizure resistance than pearlite. Therefore, more ferrite reduces the seizure resistance of the NC1 shaft.

As the base material of aluminum-lead-silicon bearing alloys is aluminum, which is quite vulnerable to adhesion with iron, the seizure resistance of the shaft material has a significant influence on the seizure limit load of the bearing-shaft system.

F2 is the three-pass finished surface, and F1 is the two-pass finished. F2 shaft has a better surface quality than F1 shaft. So F2 shaft has a higher seizure load than F1 shaft.

4. Conclusions

Seizure behaviors and seizure mechanisms of four commonly used bearing materials, namely aluminum-lead-silicon, aluminum-tin, aluminum-tin-silicon, and copper-lead with lead overlay, were investigated. Effects of different shaft materials and surface texture were also studied. Some conclusions were obtained through experiments and analysis.

Hard silicon particles in aluminum-lead-silicon alloys may break the continuity of aluminum matrix, and therefore block the propagation of aluminum adhesion and thus increase the seizure resistance of the bearing. Size and distribution of silicon particles in an aluminum-lead-silicon alloy will effect the seizure resistance of the alloy. There might be an optimum size for the silicon particles to achieve their best effects. Too small particles may be worn easily and may not have enough effects of blocking adhesion development and micro polishing the shaft. Excessively large particles may create large high temperature spots, cause large micro seizure, trigger seizure failure earlier, and thus reduce the seizure load.

Because tin has melting temperature, the tin in the aluminum-tin bearing alloy will be melted and depleted quickly at high temperature. Without enough protection of tin when tin is quickly depleted, the bearing may fail. The melting temperature of tin, about 230°C, can be used as the critical parameter of failure. When the area where temperature is higher than the critical temperature is larger than a certain ratio on the beaing surface, 22 percent in our test cases, the bearing will fail.

Inclusion of silicon particles in the aluminum-tin alloy may not necessarily increase its seizure resistance. The size and distribution of the particles should be controlled. Excessively large silicon particles may reduce the seizure resistance of the alloy.

With copper-lead with lead overlay bearins, seizure will occur between the shaft and the nickel barrier after the overlay is removed by wear. Seizure load of this type of bearing is very sensitive to the surface quality of the shaft. If the shaft surface is rough and has a lot of burrs, the soft overlay will be away faster and seizure will occur earlier.

A bored bearing has longitudinal surface roughness, whicle a broached bearing has transverse roughness. Seizure propagates more easily on a broached bearing than on a bored bearing because micro grooves on a bored bearing can constrain seizure from propagating in the axial direction. Therefore, a bore bearing has a higher seizure load than a broached bearing.

Ferrite phase in shaft materials reduces seizure resistance of the shaft. More ferrite, ;ower seizure load.

Three-pass-finished shafts, which have smoother surfaces, have higher seizure loads than two-pass-finished shafts.

Acknowledgment

The authors are grateful for financial support from Ford Motor Company. The authors would like to thank Mr. C. L. Brower, Drs. R. S. Lo and Slike of Ford Motor Company, and late Dr. H. S. Lin of Federal-Mogul Corporation for their help in this work.

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