PLAIN BEARING FAILURES

BY

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Almost everything on earth that turns is supported either by balls or rollers or by a journal and plain bearing, frequently of the replaceable precision sleeve type widely used in gasoline and Diesel engines. The lubrication of plain bearings is by far the largest single application of lubricants, and is most commonly accomplished with a fluid lubricant like an oil.

Journal bearings may be as refined as those in aircraft and high speed Diesel engines, as delicate as those of a fine watch, as simple as on a child's toy wagon or as primitive as on an ox cart. In all cases these bearings turn more smoothly and with greater durability when lubricated, but their very multitude evokes the greatest number of inquiries or complaints arising from bearing malfunction or failure.

Although one cannot expect infinite bearing life, properly lubricated sleeve bearings often outlast other parts of the mechanism. Certain applications such as well-designed pedestal bearings in steam turbines with proper lubrication run for many years without change or adjustment. When bearings do experience premature failure, it is to the operator's benefit to be able to determine the reason for the malfunction so as to take proper safeguards against a recurrence.

Visual inspection of a damaged bearing frequently can reveal what happened; other instances may involve complex laboratory techniques to arrive at the probable cause of failure. Sometimes the damage has progressed so far that examination of the bearing itself is useless. When such is the situation in an enclosed system, such as a gearbox or engine crankcase, the nature of deposits in the bottom of the case or adhering to other components may shed light on the failure pattern. Physical characteristics of the bearing metal and other mineral constituents in the deposit sometimes reveal evidence of abrasion, seizure with the journal, overheating, melting, fatigue or corrosion.

This article has been compiled with the thought of describing and illustrating the more common causes of journal bearing failures in such a manner that a certain amount of diagnostic work can be done in place and before repair or replacement is undertaken. On-site diagnoses can thus speed the remedy without waiting for the laboratory to 'determine cause of failure'. Some causes of bearing damage like misalignment, erosion, defective bond or particle embedment can be recognized from viewing the bearing surface, perhaps with the aid of a simple hand magnifier; this makes for ready field handling. However, the confirmation of suspected defects like corrosion or porosity, and the identification of embedded material may need the support of microscopic examinations or complex laboratory techniques.

EXAMINATION PREPARATION

Examination of bearing surfaces frequently can be facilitated with some sort of hand magnifier, jeweller's loupe or low-power microscope: a magnification of five to ten diameters will often suffice. Higher magnifications—50 diameters or more—usually are not necessary for surface examinations and frequently are quite impractical due to the roughness of the unprepared surfaces. The

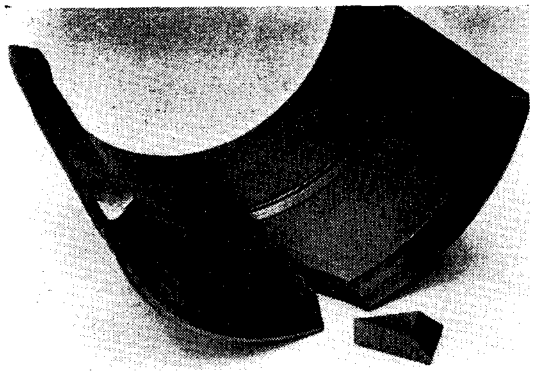

FIG. 1—A PRECISION TYPE PLAIN BEARING OR SLEEVE ENGINE BEARING WITH CROSS-SECTIONAL SAMPLE REMOVED IN PREPARATION FOR ROUGH GRINDING, MOUNTING, POLISHING, ETCHING AND MICROSCOPIC EXAMINATION

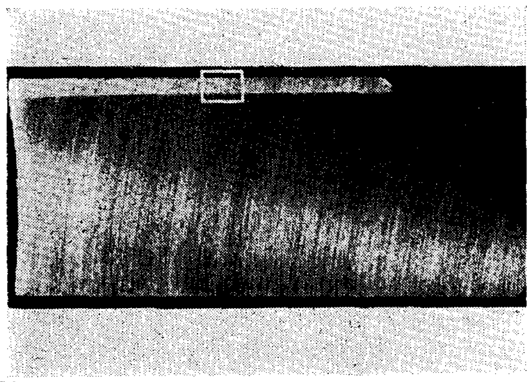

FIG. 2—SAMPLE SAWED FROM FIG. 1 AND ROUGH GROUND. NOTE 0·047 IN. LAYER OF BEARING ALLOY AT *TOP BONDED TO A* STEEL BACKING 0·5 IN. THICK ($\times 2\frac{1}{2}$)

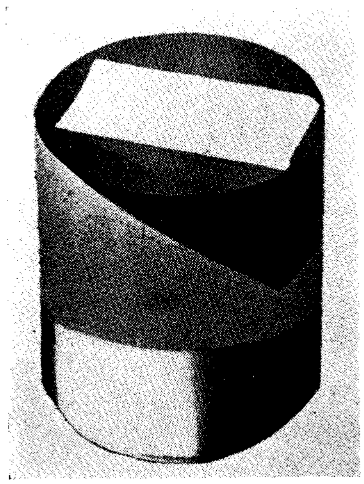

FIG. 3—SPECIMEN MOUNTED IN PLASTIC, POLISHED AND READY FOR FINAL ETCHING (APPROX. FULL SIZE)

magnifications listed under the photographs of various bearing surfaces indicates the detail that can be seen with relatively inexpensive equipment. Surface scratching, embedded particles, fatigue cracks, bond failures and wiped zones are among those forms of damage readily observed with relatively low magnification.

Microscopic examination of bearings at higher powers—usually of cross-sections—becomes necessary when observations must be made of the micro-structure, that is, of the crystal arrangements, grain structure, deformations, intergranular cracks, depth of corrosion penetration, phase changes, etc. A great volume of work can be done in the 100 to 500 diameters magnification range; however, at times, magnifications as high as 1500X may be necessary which requires a high-grade metallurgical microscope. Such work demands skilled laboratory sample preparation. To do this the bearing shell must be cut. rendering it unfit for any further service.

For example, to prepare a cross-section of a heavy-duty Diesel connecting rod bearing for microscopic examination, the desired portion is cut out as indicated in FIG. 1 with a saw or cutting wheel. Selection of the proper area is of paramount importance; defects are seldom evenly disbuted over a bearing and, when a particular kind is in question—for instance, shallow fatigue cracks—several sections from different locations may have to be examined to find views suitable for diagnosis.

FIG. 2 shows a specimen cross-section which has been lightly ground to reveal the bearing alloy layer 0·047 in. thick on a steel backing 0·5 in. thick. The specimen was then trimmed and moulded or cast into a round plastic mount. FIG. 3 shows a mounting which happens to be in lucite, however black or colored bakelites also make suitable mounts. The plastic mount provides the means of holding irregular specimens for polishing while a number inscribed on the base of the mount facilitates filing and retrieval.

After mounting, the specimen is polished with progressively finer abrasives

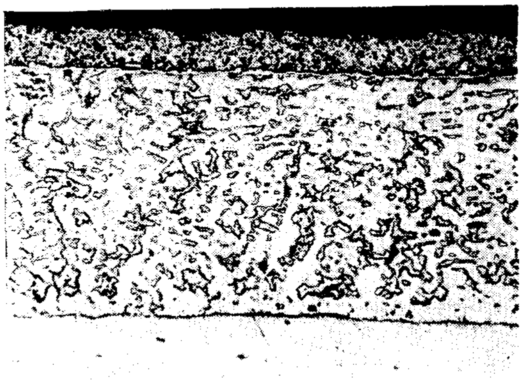

FIG. 4—PHOTOMICROGRAPH OF CROSS-SECTION OF BEARING SHOWN IN FIGS. 1, 2 AND 3. FROM TOP TO BOTTOM: (i) THE GREY-COLOURED LEAD-TIN BEARING SURFACE LAYER OR FLASHING, ABOUT 0·001IN. THICK; (ii) THE NARROW WHITE-COLOURED NICKEL 'DAM'; (iii) THE WHITE-COLOURED COPPER MATRIX WITH ITS INTERSTICES FILLED WITH GREY-COLOURED LEAD; (iv) A SMALL PORTION OF THE STEEL BACKING (× 200)

FIG. 5—PATCHY REMOVAL OF LEAD FLASHING ON A SILVER BEARING BY OIL-BORNE ABRASIVE. ALSO NOTE SCRATCHING OF BOTH LEAD AND SILVER BY HARD PARTICLES (X 4)

until a scratch-free mirror finish is obtained. This surface is then chemically etched by reagents specifically compounded to selectively attack one phase or grain type differently from the others and, in so doing, to create an optical differentiation between grains or microconstituents. FIG. 4 is a photomicrograph of a portion of the etched specimen ready for microscopic examination. The area shown represents the rectangle in FIG. 2, which includes the lead-tin bearing surface (10 per cent tin) approximately 0·001 in. thick, several thousandths of an inch of copper-lead substructure and a portion of the steel shell. Note the narrow, irregular white line between the copper-lead and lead-tin: this is electro-deposited nickel which serves as a diffusion barrier. It prevents the migration of tin from the surface layer into the underlying copper and thereby maintains the corrosion resistance of the surface layer. A structure such as this is frequently used in heavy duty Diesel bearings.

FAILURE TYPES

Following are descriptions and illustrations of sixteen types of failures which may occur in plain bearings. It will be noted that the lubricant can be justly blamed for very few of these, or that any lubricant could have prevented them. On the other hand, several types of failure indicate incorrect installation, improper operation, or contamination of the lubricant which must be corrected before satisfactory bearing life can be obtained.

Scratching

Hard solid particles entrained in the lubricant will, if they escape filtration, eventually be delivered to a bearing clearance space. Very fine particles which are smaller than the minimum bearing clearance of only a few ten-thousandths of an inch can circulate without causing serious bearing damage. The shaft may become lapped or slowly worn to a non-cylindrical shape while the bearing may develop a dull spot at the location of minimum clearance. A thin lead alloy overlay can become worn through with minor scratches as shown in FIG. 5. When the specimen is a copper-lead bearing with the conventional lead overlay, wear of only one thousandth of an inch can expose a narrow area of the bronze-coloured copper-lead which, alone, does not signify that the bearing had been worn beyond tolerances. Because of the colour difference between the overlay and the copper-lead, however, wear can appear more severe than it really is. Automotive bearings with copper-lead exposed by gentl:

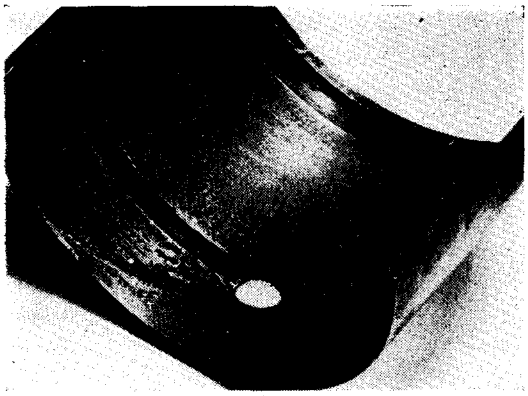

FIG. 6—SURFACE EROSION BY OIL-BORNE PARTICULATE MATTER FLOWING FROM BEARING'S OIL SUPPLY HOLE

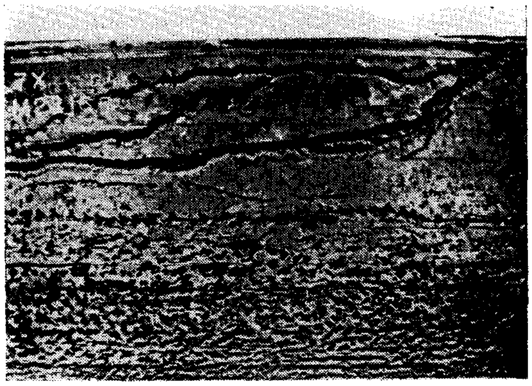

FIG. 7—GROOVING OR TRACKS MADE BY RELATIVELY LARGE HARD PARTICLES MIGRATING SLOWLY THROUGH THE BEARING CLEARANCE

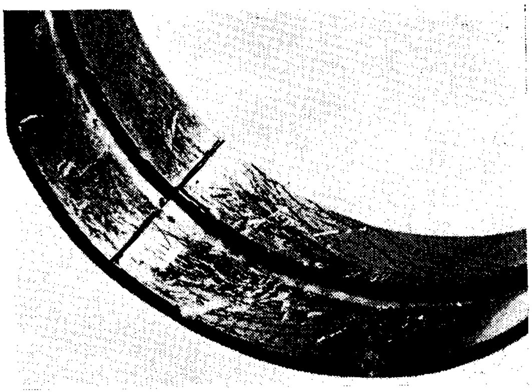

FIG. 8—PLOUGHING OR SURFACE SCORING OF BABBIT BEARING CAUSED BY OIL-BORNE HARD PARTICLES FLOWING OUTWARD DIAGONALLY FROM CENTRAL OIL SUPPLY GROOVE

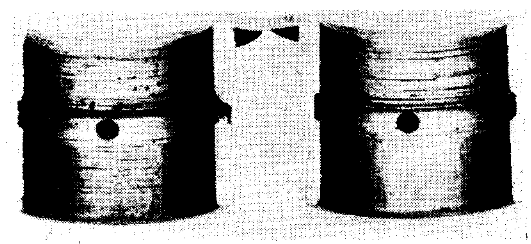

FIG. 9—SHALLOW EMBEDMENT AND GROOVING OF HARD METALLIC PARTICLES IN LEAD FLASHING OF SILVER BEARING

wear frequently can continue in service for an indefinite period provided that corrosion does not occur on the exposed areas. The degree and location of wear can often be evaluated with a micrometer calliper by measuring variations in bearing shell thickness.

Erosion

A high velocity oil flow with very fine hard particulate matter can locally wash out a gully in the bearing surface as illustrated in FIG. 6; this is sometimes called 'erosion'.

Grooving

Larger particles—in the range of a few thousandths of an inch or more—can get into the bearing clearance but not freely enough to squeeze through.

For example, large particles may migrate through the clearance space as conditions of load and speed permit; such action can be recognized on the bearing surface by a path of indentations of similar shape wandering more or less in the direction of journal motion. Several such tracks are shown on the bearing surface in FIG. 7.

Plowing

Large hard particles can be dragged along by shaft motion and oil flow, plowing grooves in the softer bearing alloy. FIG. 8 shows a babbitt bearing in which the lubricant delivered hard particles to a central oil groove; as the oil spread outward across the bearing surface, the particles moved with it, cutting diagonal, branched paths in both halves of the babbitt.

Shallow Embedments

FIGS. 9 and 10 show a lead-flashed silver bearing in which hard metallic particles plowed grooves for short distances and then became embedded in the thin lead overlay: the causative particles can be found at the ends of the score paths. The harder silver base, having poor 'embedability', prevented these particles from being depressed any further. Embedments such as these are especially

FIG. 10—ENLARGEMENT OF A PORTION OF FIG. 9 SHOWING THE CAUSATIVE PARTICLES AT THE RIGHT END OF THEIR GROOVES AND PROJECTING ABOVE THE BEARING SURFACE

FIG. 11—A HARDENED STEEL JOURNAL SCRATCHED BY ABRASIVE PARTICLES

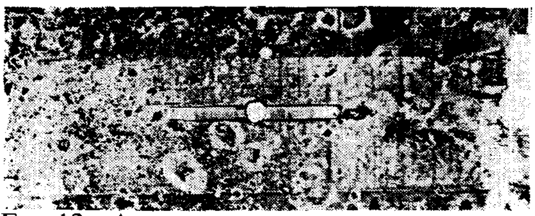

FIG. 12—A SEMI-CIRCULAR BEARING SHELL WHICH HAS BEEN 'OPTICALLY UNWRAPPED' TO SHOW INDENTATIONS MADE IN ITS BABBIT BY CARBONACEOUS AGGLOMERATES IN ENGINE SLUDGE

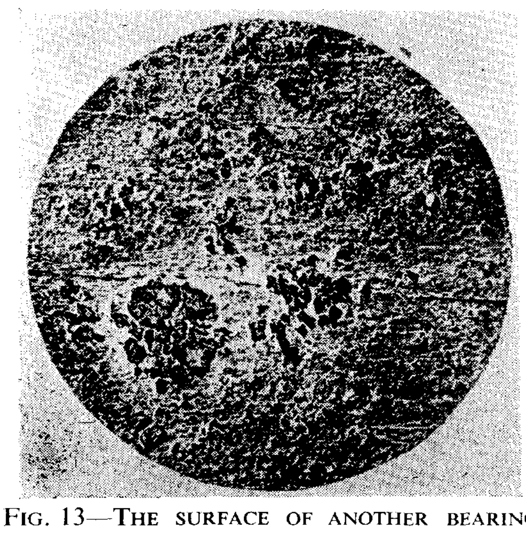

FIG. 13—THE SURFACE OF ANOTHER BEARING WHICH HAS BEEN INDENTED BY CLUMPS OF SLUDGE PARTICLES (x 40)

bad as they project slightly above the surface and are in perfect position to heavily score the shaft. FIG. 11 shows a hardened steel journal scratched by abrasive particles.

On the other hand, soft-bearing metals can be damaged by relatively *soft* particulate matter; for example, carbonaceous agglomerates can indent a bearing surface as illustrated in FIG. 12. These markings show how compressed lumps of common sludge produced shallow cavities with raised edges. Cavities appear as circular dark spots and the raised edges are bright and shiny from direct contact with the journal. Sometimes the surface is only indented as in FIG. 13.

Plowing produced by moving chips and particles raises the bearing metal on either side of the path; the elevation results from displacement of bearing alloy from the centre of the groove. High spots or raised regions on a bearing surface often have light shiny faces from direct contact with the shaft. Shiny rubbing spots are evident at the ends of two paths in FIG. 10—two white crescents, one surrounding a cavity caused by a metallic chip and the other surrounding a particle in place. Abrasion such as this causes hot spots which can destroy fluid lubrication and possibly result in bearing seizure.

Deep Embedments

Hard particulate matter can become completely embedded in the bearing alloy and, in effect, be taken out of circulation. This requires a comparatively soft-bearing metal such as lead or babbitt. FIG. 14 shows a cross-section through a babbitt-impregnated, sintered bearing with many hard metallic chips embedded in the babbitt. When thus buried in the alloy their tendency to damage the shaft is less than if they protrude as in FIG. 10.

Insert-Housing Contamination

Hard foreign matter also causes trouble if it becomes trapped behind a shell. i.e., between the steel backing of the bearing insert and its housing. Grit is particularly troublesome when

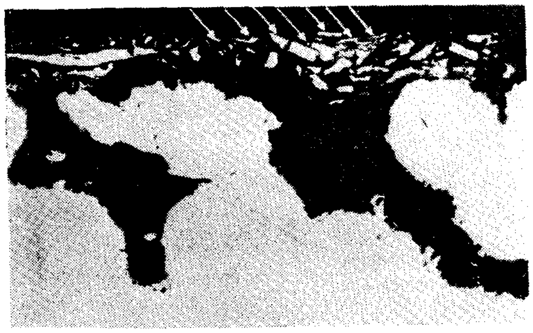

FIG. 14—PHOTOMICROGRAPH OF CROSS-SECTION OF A BABBIT-IMPREGNATED SINTERED BEARING WHICH HAS EMBEDDED AND LARGELY NEUTRALIZED THE HARD STEEL CHIPS INDICATED BY THE ARROWS (X 100)

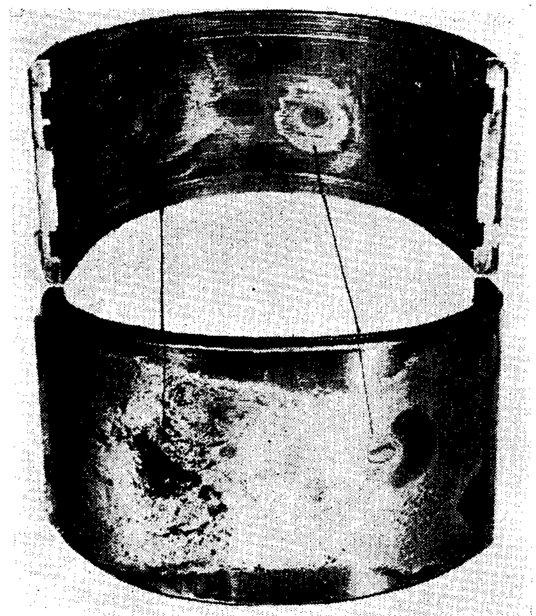

FIG. 15—THE BEARING SURFACE (TOP) AND CORRESPONDING BACKING SURFACE (BOTTOM) OF A RAILWAY DIESEL CONNECTING ROD BEARING SHOWING DISTORTION, EXCESSIVE WEAR AND INCIPIENT FAILURES ON THE BEARING SURFACE CAUSED BY TWO HARD FOREIGN PARTICLES BETWEEN THE BEARING BACKING AND ITS CONNECTING ROD

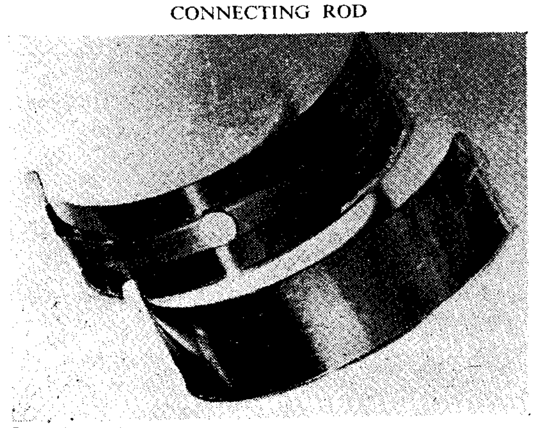

FIG. 16—A MATED SET OF MAIN BEARING INSERTS, ONLY THE UPPER LIGHTLY-LOADED HALF BEING PROVIDED WITH A CENTRAL OIL GROOVE

overhaul of automotive engines is carried out in dirty surroundings. A metallic chip or grain on the back of the bearing shell or on its housing can easily escape notice during installation; however, even normal bearing loads are sufficiently great to deform the steel shell around that particle, dent the back, and create a high spot on the bearing face. The high spot will run excessively hot in wearing down and may lead to seizure or fatigue breakouts. Dents or nicks on either the back of the bearing insert or its housing will cause similar failures. The lower part of FIG. 15 shows the back of a Diesel connecting rod bearing shell which was installed on two hard particles; even though the steel back was a quarter of an inch thick. it was deformed and created matching wear spots on the bearing face as shown in the upper part of the figure. Relatively thin steel backings common to automotive service are even more sensitive to this type of damage. Therefore, when inspecting any damaged bearing shell, one should always look for marks on the steel back to determine if dirty seating is associated with disfigurations on the bearing surface.

Journal Ridging

Abrasive shaft wear occurring at a slow rate can be offset by corresponding bearing wear so that no gross misfit occurs, even though the journal may wear to a barrel or hourglass profile. For example, a shaft riding on a bearing shell having a central oil groove can become worn on the load-bearing areas so that the shaft develops a 'non-wear' ridge or band corresponding to the oil groove. If the groove is contained in only one half-shell of a full bearing as in FIG. 16, a ridge can still form on the shaft; however, the non-grooved half-shell will wear at the same time along a band matching the ridge, so that an even distribution of load continues. Such a bearing shell will show a narrow circumferential

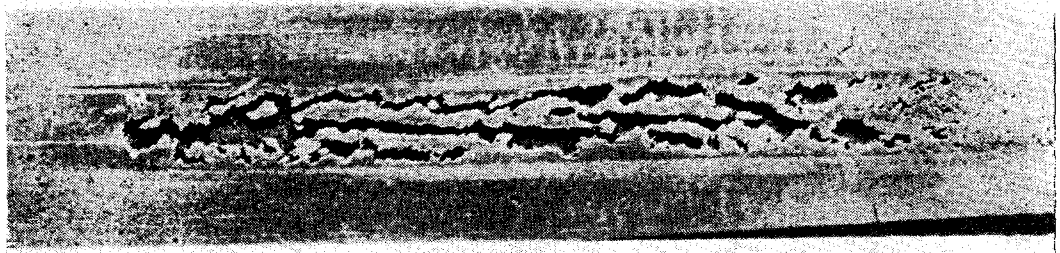

FIG. 17—FATIGUE BREAKOUT IN LOWER LOADED HALF OF A REPLACEMENT BEARING LIKE FIG. 16 CAUSED BY FAILURE TO REMOVE RAISED RIDGE WORN ON JOURNAL BY THE OIL GROOVE IN THE UPPER HALF

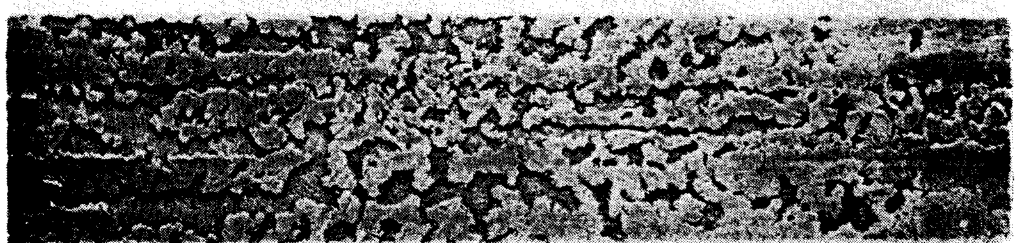

FIG. 18—IN CONTINUATION OF FIG. 17, THE REDUCTION IN AREA OF THE LOWER BEARING BY FATIGUE BREAKOUT RAISES UNIT LOADING ON THE REMAINING AREA AND ACCELERATES FATIGUE FAILURE OVER THE ENTIRE BEARING SURFACE

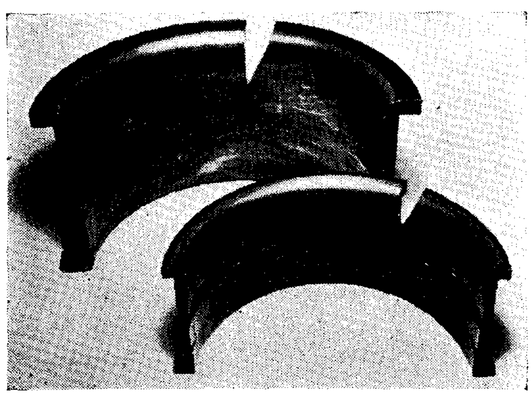

FIG. 19—CRESCENT-SHAPED WEAR SPOTS CAUSED BY MISALIGNMENT

groove along the centre and, although worn, can be quite serviceable.

However, if the worn bearing shells should now be replaced *without refinishing the journal*, a high stress area will be set up where the non-grooved bearing makes contact with the journal ridge, and rapid failure can be expected. FIG. 17 shows such a bearing shell where a band of fatigue breakouts defines the overload zone. In FIG. 18 this kind of fatigue breakout is even more pronounced.
A journal surface worn to any other non-cylindrical shape would also produce abnormal local stresses corresponding to the areas of highest load. In such instances it is essential to regrind the shaft before installing a new bearing set.

Misalignment

Misalignment between a journal and its bearing is readily apparent from a distorted wear pattern on the bearing surfaces. In sleeve bearing lubrication, misalignment generally can be regarded as any instance where the axes of the journal and bearing are not parallel. Normal wear produces a more-or-less rectangular visible band of contact across the bearing face; whereas misalignment forms a wear zone—depending on clearance ratio, degree of skew between the bearing and journal, etc.—which may be roughly trapezoidal, triangular or half-moon in shape as in FIGS. 19 and 20.

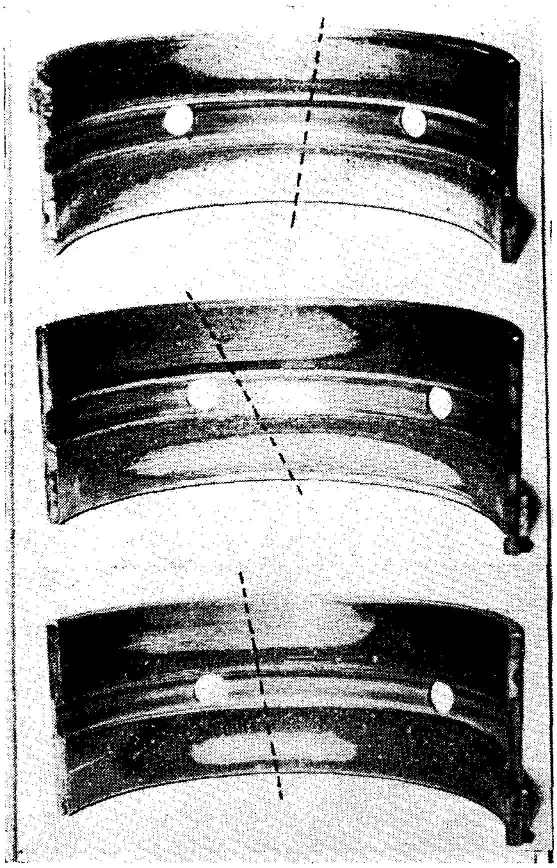

FIG. 20—DIAGONAL AXES OF WEAR PATTERNS INDICATE MISALIGNMENTS

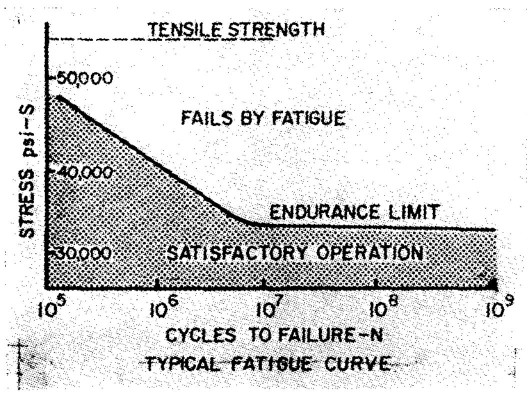

FIG. 21—A TYPICAL FATIGUE LIFE OR S/N CURVE. NOTE THAT THE FAILURES OCCUR WELL BELOW THE MATERIAL'S TENSILE STRENGTH AND ESPECIALLY SO AS THE NUMBER OF LOADING CYCLES IS INCREASED

In internal combustion engines, warped connecting rods and faulty bearing installation are common causes of misalignment. A bent rod often will create two wear spots at diagonally opposite regions on the bearing shell. In multi-bearing installations as, for example, in an automotive engine, warpage of the crankcase can cause severe wear on a centre main bearing, yet maintain an even wear pattern. Instead of the wear being centred in the lower half, however, crankcase warpage may cause maximum pressure zones (and, accordingly, the greatest rubbing) at one side or even on top. This clue to misalignment can then be followed by checking the wear zones of the end bearings; here wear probably will be found in different quadrants.

Fatigue

Except for abrasive wear generally attributable to solid contaminants in the lubricant, metal fatigue probably is the most dominant factor leading to premature bearing failures. In antifriction bearings, fatigue *is* the single greatest terminator of bearing life. The bearing design engineer gives metal fatigue the most attention because of the difficulty of preventing it or protecting against its effects.

Well-fitted journal bearings, even with clean, grit-free lubricants, can suffer fatigue. That kind of distress is most prevalent where loads are pulsating or cyclic, and perhaps aggravated by overloads or extreme temperatures, as in engines, punch presses, rock crushers, etc. In plain rotary motions, however, as in steam turbines, centrifugal compressors, fans, pumps, etc., fatigue is not so common, because pulsation or pounding on the bearing surface is normally of low intensity.

Forces which tend to compress, flex, pound or overheat a bearing are conducive to fatigue; however, to initiate damage the intensity of these forces must exceed a certain tolerance, called the endurance limit. The greater the stress, mechanical or calorific, the sooner damage occurs as in FIG. 21. Bearing fatigue is first visible as fine surface cracks like those in FIG. 22 which are hair-line cracks in the lead-alloy overlay on a bronze marine bearing. Repeated stressing deepens the cracks, usually more or less perpendicular to the surface, and sometimes almost to the backing of the bearing. Continued stress extends

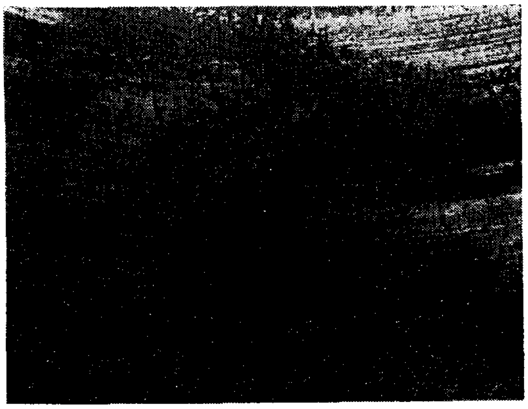

FIG. 22—THE FIRST INDICATION OF FATIGUE DAMAGE IS THE DEVELOPMENT OF FINE SURFACE CRACKS

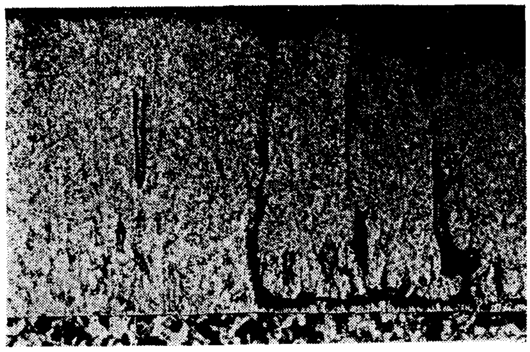

FIG. 23—PHOTOMICROGRAPH OF A CROSS-SECTION OF A FATIGUED COPPER-LEAD BEARING SHOWING HOW FATIGUE CRACKS FIRST PENETRATE VERTICALLY ALMOST TO THE BOND ON THE STEEL BACKING, THEN HORIZONTALLY TO SEPARATE FRAGMENTS OF COPPER-LEAD (x 80)

FIG. 24—HEAVILY FATIGUED CONNECTING ROD BEARING IN WHICH A RATHER THICK LAYER OF BABBIT HAS BEEN CAST ON TO THE STEEL BACKING

the cracks horizontally, undermining appreciable areas of bearing alloy until large segments are loosened, drop out, and radically reduce the area supporting the load. FIG. 23 shows a cross-section of a fatigue cracked copper-lead bearing. Note that the cracks do not penetrate all the way to the steel backing. The loss of metal by fatigue breakout disrupts the lubricating film, causes excessive lubricant loss from pressure-fed bearings, and frequently leads to bearing seizure and shaft damage.

Although fatigue failure is possible for any sleeve bearing material, susceptibility varies inversely with hardness, and directly with thickness. Soft bearing alloys such as lead-tin or babbitt can readily embed hard particles and therefore tolerate dirtier oils, but they also fatigue easily. FIG. 24 shows a babbitted connecting rod bearing which contains many deep fatigue cracks. Harder alloys such as bronze, copper-lead and aluminium withstand greater loads, but are more susceptible to abrasion and/or corrosion. 'Silver bushings', such as those of aircraft master rods and the piston pins of some heavy-duty Diesel engines can withstand very high impact punishment without showing surface damage. Very thin layers of silver alloy have a high order of fatigue resistance; thicknesses of 0·005 to 0·015 in. are generally adequate. Therefore, in bearing selection, compromises must be made, depending upon tolerances for load, cyclic stress alignment, contaminants, etc.

Bond Failure

Bond failure is a separation of the bearing alloy from the supporting shell at the interface between the two metals. It is characterized by a cracking or breakout resembling fatigue, and is caused by poor adhesion of bearing alloy to the backing metal. FIG. 25 shows the silver surface of an aircraft bearing which peeled from the steel base. A defective bond can occur during manufacture of the bearing and might be due to (1) oxide films (inadequate fluxing) on the base metals; (2) contamints such as dirt, soot or grease on the surface; (3) dross from the surface of molten alloy; (4) gas evolution from the metal; or (5) improper fabrication temperatures. A bond failure is visibly different

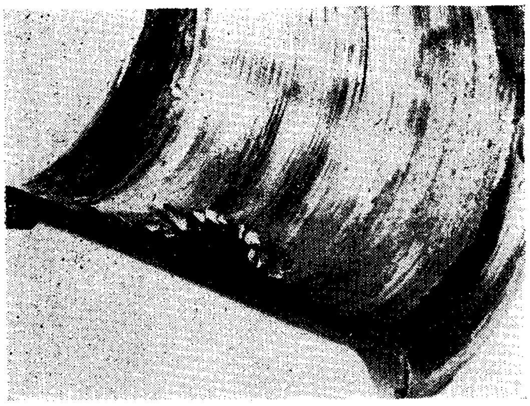

FIG. 25—POOR ADHERENCE AND PEELING OF SILVER FROM THE STEEL BACKING OF AN AIRCRAFT ENGINE BEARING

FIG. 26—POOR BONDING IS INDICATED BY CLEAN BREAKOUT OF BABBIT FROM THE 'PHONOGRAPH RECORD' MACHINING PATTERN (SEE ARROW) ON A STEEL BEARING BACKING (x 6)

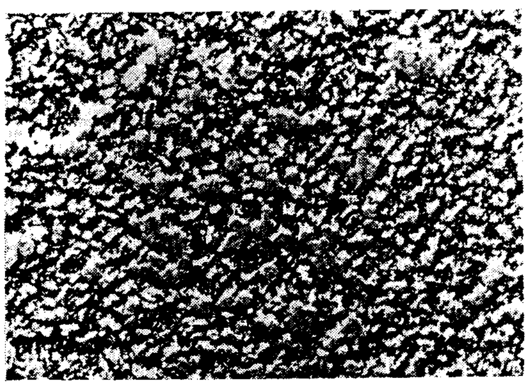

FIG. 27—ROUGH SURFACE OF A CORRODED HIGH-LEAD BEARING (x 8)

from ordinary fatigue breakout in that there is a clean separation of bearing metal from the backing. Fatigue cracking usually leaves some bearing metal adhering to the shell. On a backing that has been lathe-bored, breakout from a bond failure will usually expose a raw 'phonograph finish' of clean horizontal grooves devoid of bearing alloy like that in FIG. 26: loosened fragments of babbitt surround the breakout.

Corrosion

This discussion of bearing corrosion is concerned only with *chemical* mechanisms of attack, although it is realized that the term 'corrosion', as related to bearing damage sometimes embraces erosion and cavitation which are mechanical and hydrodynamic effects. The two common types of corrosive agents that attack most bearing alloys are *electrolytes* and *organic acids*.

Electrolytes

Water solutions of salts, acids or alkalis can corrode bearing alloys as well as steel journals. The corrosive effect might be pitting with removal of surface metal as shown in FIG. 27, or oxidation where the bearing surface converts to an oxide film. The latter condition is illustrated in the cross-sectional photomicrographs of FIGS. 28 and 29, where two different tin babbitt surfaces (top edges) have been oxidized to tin oxide (SnO_2). The large white cubes and needles are compounds of antimony-tin and copper-tin, respectively. The thickness of the oxide layer is 0·0025 in. in FIG. 28 and 0·003 in. in FIG. 29, although layers as thick as 0·007 in. have been observed. In the latter photomicrograph the specimen had not been metallographically etched, therefore the crystalline structure does not appear. The two elongated black diamonds are impressions made by a Tukon Hardness Tester at the same indenter load. The much smaller impression in the oxide layer (dark) shows it to be appreciably harder than the babbitt base (white). The oxide surface is also more brittle than the basic babbitt alloy and has poor frictional properties. Pieces of oxide can crack loose from the babbitt, become wedged in the bearing clearance and cause hot spots ultimately leading to complete failure.

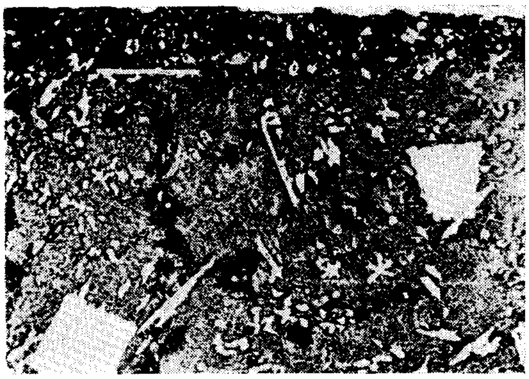

FIG. 28—PHOTOMICROGRAPH OF CROSS-SECTION OF A HIGH-TIN BABBIT BEARING SHOWING A DARK-COLOURED TIN OXIDE LAYER AT THE TOP WHICH FORMED THE BEARING RUBBING SURFACE. THE LARGE WHITE OBJECTS ARE CUBICAL CRYSTALS OF AN ANTIMONY COMPOUND IN THE BABBIT (x 120)

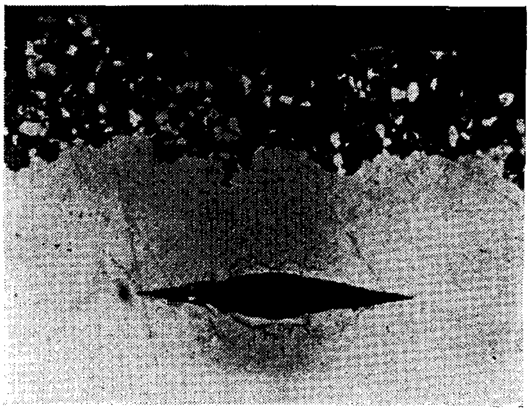

FIG. 29—PHOTOMICROGRAPH OF ANOTHER BABBIT BEARING WITH A TIN OXIDE SURFACE. A COMPARISON OF THE TWO DIAMOND-SHAPED INDENTATIONS (MADE WITH A TUKON HARDNESS TESTER) INDICATES THE MUCH GREATER HARDNESS OF THE UPPER OXIDE LAYER THAN THE BABBIT (x 200)

FIG. 30—CORROSION AND CONSEQUENT ROUGHENING OF THE SILVER SURFACE OF A DIESEL ENGINE WRIST PIN BUSHING NEAR ITS OIL GROOVE (LOWER RIGHT) (x 10)

Acid attack can occur in internal combustion engines under conditions generally arising from low crankcase temperatures and inadequate ventilation. Piston blow-by in a cold-running Diesel includes fuel sulphur oxides in combination with moisture and these add sulphuric and sulphurous acids to other crankcase contaminants.

Fuel sulphur can have other effects on Diesel bearings, especially those including silver. Incomplete combustion, or dilution with raw fuel can introduce reactive sulphur compounds directly into the crankcase lubricant. Of greater importance, perhaps, is a more direct influence of high-sulphur fuels on silver lubrication. Such fuels tend to dirty engines, stick rings, etc., but this problem and those with metals other than silver are overcome with highly fortified oils. Many additives, however, contain functional sulphur compounds which can be triggered to attack silver at higher engine temperatures. Indirectly, therefore, fuel sulphur narrows the choice of lubricants suitable for silver bearings. A corrosion-roughened surface of a silver bearing such as depicted in FIG. 30 frequently contains deposits of silver sulphide and lead sulphide in the oil grooves. Accumulations of these materials with fuel soot can clog the grooves, impair lubrication and ultimately cause seizure.

Stray electric currents passing through a moisture-laden bearing induce a corrosive effect which is almost impossible to prevent by lubricant selection. Stray currents must be eliminated. FIG. 31 shows the pock-marked and etched appearance of a cast copper-lead bearing which had been subjected to a stray current attack. Both the copper and the lead have been affected.

Organic Acids

These are derived from oxygenated or oxidized hydrocarbons. In internal combustion engines some of these acids are derived from partially burned fuel and are more serious under conditions of low temperature engine operation, excessive blow-by,

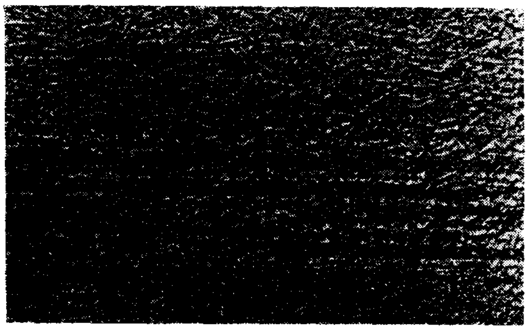

FIG. 31—CORROSION OF ELECTROLITIC ETCHING OF A COPPER-LEAD SURFACE BY STRAY ELECTRIC CURRENTS WHICH HAS REVEALED THE COPPER DENTRITES OF THE MATRIX (x 7)

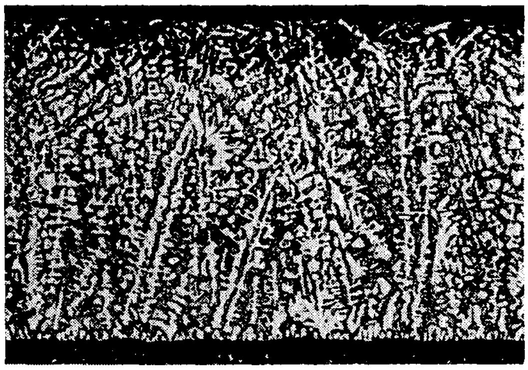

FIG. 32—PHOTOGRAPH OF CROSS-SECTION OF A CAST COPPER-LEAD BEARING SHOWING THE CORROSIVE REMOVAL OF GREY-COLOURED LEAD FROM THE BEARING SURFACE (AT TOP) TO FORM BLACK VOIDS IN THE WHITE COPPER MATRIX. SMALL PORTION OF STEEL BEARING BACKING SHOWS AT THE BOTTOM (x 80)

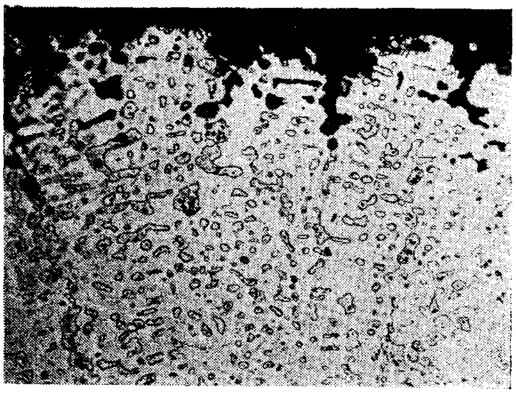

FIG. 33—ANOTHER EXAMPLE OF LEAD CORROSION IN ANOTHER CAST COPPER-LEAD STRUCTURE WHICH LEFT AN IRREGULAR BEARING SURFACE (AT TOP) (x 200)

fuel washing, etc. Acids produced from the oxidation of light fuel hydrocarbons are of relatively low molecular weight and are quite corrosive to some bearing metals, particularly lead. Pure lead is readily corroded, however the usual formulations of high-lead babbitts contain sufficient amounts of the hardening elements—antimony and tin—to provide good corrosion resistance. However, lead alloys in which the principal hardeners are calcium, aluminium or magnesium are sensitive to corrosion by organic acids; they usually contain more than 97 per cent of lead and generally are restricted to certain large Diesel engines. Tin-base babbitts are unaffected by most organic contaminants.

Lubricating oil also oxidizes under conditions of aeration, high temperatures, prolonged usage, and catalysis to form reaction products which have a solubilizing action, especially upon lead and cadmium. Heavy duty engine crankcase lubricants incorporate additives to retard oil oxidation and to protect bearing alloys against corrosive contaminants. When over-extended usage depletes the reserve protection afforded by such additives, the stage is set for bearing corrosion to begin.

Ethylene glycol (from leakage of permanent-type anti-freeze solutions) is another organic contaminant which can cause bearing corrosion. Glycol contamination in a crankcase often develops into a gummy deposit which, if thick enough, can seize pistons and bearings, but it also can convert to low-molecular-weight organic acids such as formic and oxalic which are strongly corrosive to lead. Unlike other crankcase deposits, those from glycol are readily distinguished by the fact that they are water soluble.

Although metallographic examination of a bearing cross-section readily reveals corrosive attack and can distinguish mechanical damage, such as scratching, abrasion, and overheating, it cannot determine whether the source of a corrodant was fuel combustion products or oxidized oil. FIGS. 32 to 35 show cross-sections of several automotive copper-lead bearings which had orroded in service. In such bearings, the copper and lead are *not* components

FIG. 34—PHOTOMICROGRAPH OF CROSS-SECTION OF A SINTERED (POWDER-METALLURGY) COPPER-LEAD STRUCTURE SHOWING CORROSIVE PITTING OF THE WHITE COPPER IN THE BEARING SURFACE (AT TOP). NOTE THAT GREY-COLOURED LEAD ON THE BEARING SURFACE HAS ALSO BEEN EXPOSED TO CORROSION, BUT IS STILL INTACT (x 120)

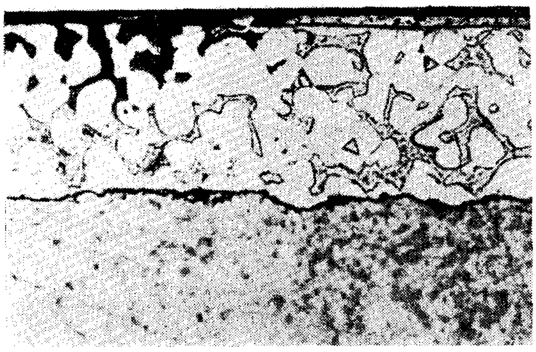

FIG. 35—PHOTOMICROGRAPH OF CROSS-SECTION HAVING A GREY-COLOURED LEAD ALLOY OVERLAY ON THE BEARING SURFACE (AT TOP). NOTE THAT CORROSIVE REMOVAL OF GREY-COLOURED LEAD IN THE BEARING STRUCTURE AND CONSEQUENT BLACK VOIDS HAVE OCCURRED ONLY WHERE THE OVERLAY WAS ABSENT (x 200)

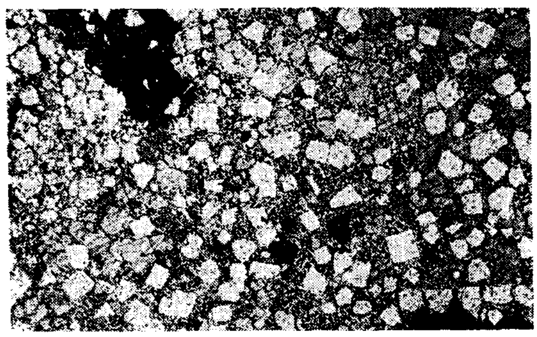

FIG. 36—PHOTOMICROGRAPH OF A CAST BABBIT ALLOY SHOWING INCLUSIONS OF A BLACK-COLOURED CONTAMINANT (x 40)

of a true alloy, but rather of a mechanical mixture in which the proportions and distribution of the copper and lead components can vary considerably with corresponding effects on bearing properties. Though a poor bearing material in itself, the copper structure or matrix lends mechanical strength to the weak lead which could not be used alone. FIG. 32 (in which copper is white and lead is grey) shows a corroded medium cast structure of copper-lead in which the irregular dark speckled band along the top edge consists only of copper, while the black areas are voids formerly occupied by lead. Though such a copper matrix is easily crushed under load, in this instance the original level of the bearing surface was not disturbed.

FIG. 33 shows another copper-lead structure in which globules of lead have been removed from the upper portion, leaving an irregular surface which to the naked eye had a 'peppered' appearance. FIG. 34 shows a very coarse, sintered structure which experienced corrosion of copper (white), allowing the weaker lead (grey) to break away. The original surface is estimated to have been at the top edge of the photo. FIG. 35 illustrates a copper-lead bearing protected by a non-corrodible lead-tin overlay with only partial coverage. Corrosion of the underlying lead occurred only at the left side where the protective overlay had been worn or abraded away.

Porosity

There have been a few instances where bearings made by nominally reputable manufacturers were found to contain defects which showed up as blisters or cavities within the matrix. More frequently encountered are defective babbitt shells which have been recast in the user's own shop; here the problem arises from too little know-how or from limitations in local facilities. Porosity defects fall into several distinctive categories.

Foreign Inclusions

Cavities occur from inclusions such as slag or dross from the melting pot

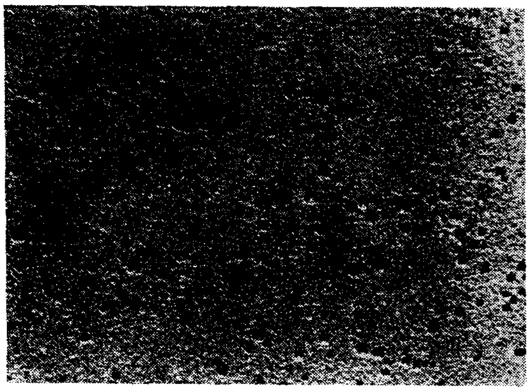

FIG. 37—PINHOLE POROSITY OF A CAST BABBIT BEARING SURFACE ON A CAST IRON SHELL (x 12)

FIG. 38—PHOTOMICROGRAPH OF A CROSS-SECTION OF A PINHOLE FROM FIG. 37 SHOWING THAT THE PINHOLE EXTENDS INWARDS TO THE GRAPHITIC IRON BACKING (x 200)

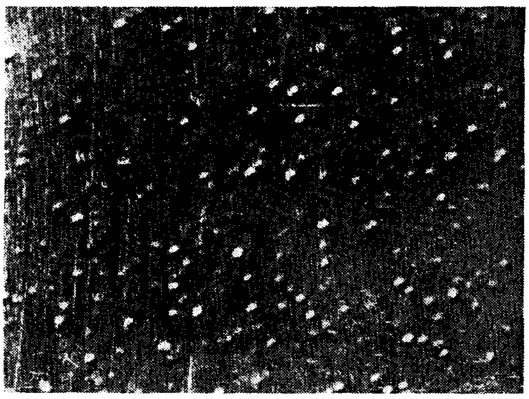

FIG. 39—WHEN HEATED, GAS TRAPPED IN AN ALUMINIUM BEARING SHELL CAN RAISE BLISTERS IN ITS LEAD-TIN OVERLAY SURFACE (x 8)

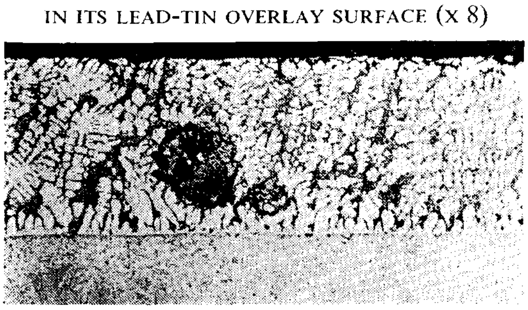

FIG. 40—BLACK AND GREY-COLOURED CONTAMINANTS OR TRASH TRAPPED IN A COPPER-LEAD BEARING STRUCTURE DURING MANUFACTURE (x 60)

being trapped within the structure; this is the most common defect. FIG. 36 shows a babbitt with an appreciable amount of carbonaceous matter and dross resulting from poor casting practice. Such inclusions create a weak structure, sensitive to fatigue cracking.

Absorbed Gas

Cavities or blisters can also be caused by evolution of gases during the solidification of cast metal. FIG. 37 illustrates the surface of a high-lead babbitt which had developed many small cavities on being cast on to a cast iron backing. The photomicrograph, FIG. 38, reveals that pinholes were caused by absorbed gas escaping from graphite flakes close to the babbitt-iron interface. Apparently the cast iron surface had not been degraphitized prior to casting the babbitt, thus, gases produced at graphitic foci during pouring were trapped within the babbitt microstructure.

Dissolved Gas

Some gases are soluble in molten metal and are rejected upon freezing causing blisters. Molten aluminium alloys have a marked tendency to absorb hydrogen from anything near the molten surface that can liberate hydrogen. This would include atmospheric water vapour or organic materials such as oil hydrocarbons, etc. When the melt freezes, most of the dissolved hydrogen is rejected, but some becomes trapped in pores throughout the microstructure. As this trapped hydrogen can be expelled upon heating, engine operating temperatures are sometimes sufficient to raise bubbles or blisters in an overlay structure. FIG. 39 shows blistering of a lead-tin overplate on an aluminium alloy bearing. A temperature of less than 300 degrees F was sufficient to raise new blisters on this bearing.

Powder Impurities

Porosity can arise from impurities in the metallic powders which are

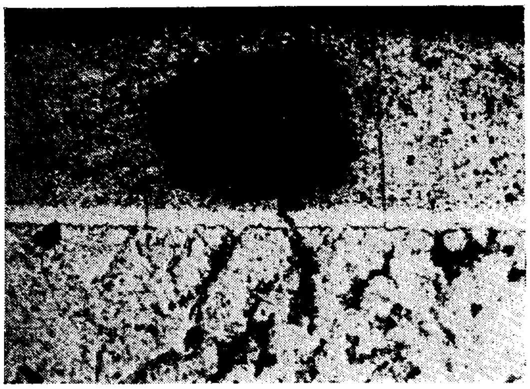

FIG. 41—PHOTOMICROGRAPH OF A CROSS-SECTION OF AN ALUMINIUM BEARING SHOWING A GAS POCKET IN ITS LEAD OVERLAY. NOTE CHANNEL THROUGH WHITE-COLOURED SILVER DAM CONNECTING GAS POCKET WITH A BLACK INTRUSION IN THE ALUMINIUM (x 160)

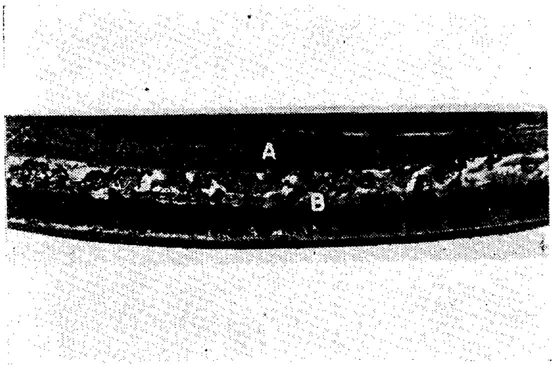

FIG. 42—EDGE OF A COPPER-LEAD BEARING SHELL (A) SHOWING GLOBULES OF METALLIC LEAD; METALLIC LEAD (B) SWEATING OR EXTRUDING FROM IT (x 8)

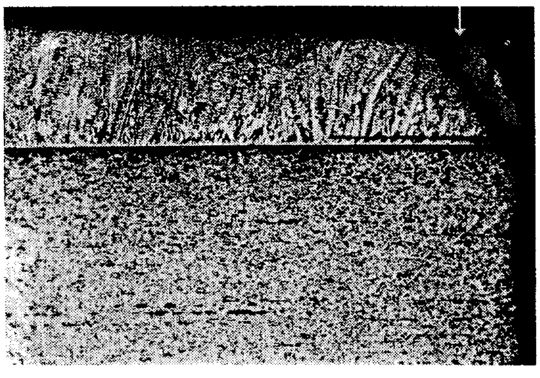

FIG. 43—PHOTOMICROGRAPH OF SAME BEARING SHOWN IN FIG. 42. ARROW POINTS TO BUILD-UP OF LEAD ON THE LEADING EDGE (x 40)

compacted to produce sintered-structure bearings. Each particle of organic matter—lint, paper, wood splinters, etc.—produces gases and carbonized residues at sintering temperatures, thereby creating a small void. FIG. 40 shows the result of a bit of trash trapped within the microstructure of a sintered copper lead bearing.

Hydrogen Electroplating

Gases, usually hydrogen, may accumulate under an electro-deposit, especially when the base support is steel. When certain metals—chromium, copper, silver, cadmium——are electroplated on to steel, the potentials are such that hydrogen has a tendency to 'plate out' concurrently with the primary metal. Some of this hydrogen gathers into bubble in the plating solution; some diffuses into the steel base which, when unalloyed, is quite 'transparent' to atomic hydrogen. When electroplating is completed, subsequent heating must frequently be employed to expel the hydrogen which otherwise can lead to embrittlement of the steel. If the metal plated on the steel is not sufficiently porous, atomic hydrogen beneath the plating collects in molecular form with sufficient pressure to push up the plating, thereby forming blisters. If the plating is soft and thin (such as a lead overlay) the blisters often break, creating a pitted surface.

Subsurface gas entrapment is illustrated in FIG. 41, which shows a spherical bubble in the lead-tin overlay on an aluminium alloy shell. The thin white band visible between the overlay and the aluminium base is an electro-deposit of silver; the intermediate silver plating was probably the source of absorbed hydrogen.

Lead Sweating

Misalignment or overload, often in combination with high operating temperatures, sometimes results in plastic deformation of the bearing structure with no visible cracking. When this occurs in copper-lead bearings, the lead phase, being relatively soft, can be squeezed from or 'sweated' out of the structure. FIG. 42 shows the edge of an overloaded bearing; 'A' is the bearing surface and 'B', the droplets of lead squeezed from the matrix. FIG. 43 is a cross-section through the same bearing; the arrow points to 'lead sweating' at the edge.

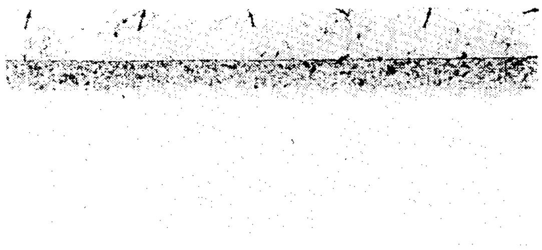

FIG. 44—PHOTOMICROGRAPH OF CROSS-SECTION OF A COPPER-LEAD FORMATION IN WHICH THE STRUCTURE HAS BEEN DEFORMED IN THE DIRECTION OF SHAFT MOTION BY HEAT AND MOTION BY HEAT AND OVERLOADING. ARROWS POINT OUT RESULTING SLANTING 'STRINGERS' OF LEAD (x 140)

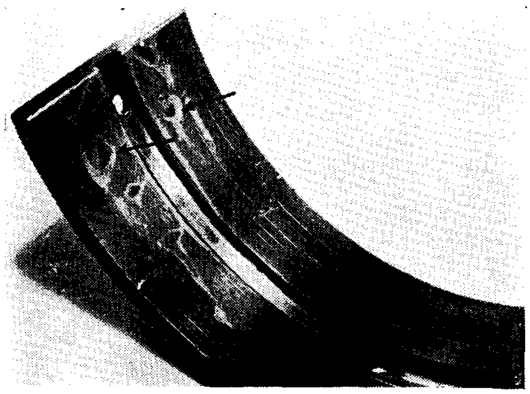

FIG. 45—SPOTTY REMOVAL OF OVERLAY BY CAVITATION

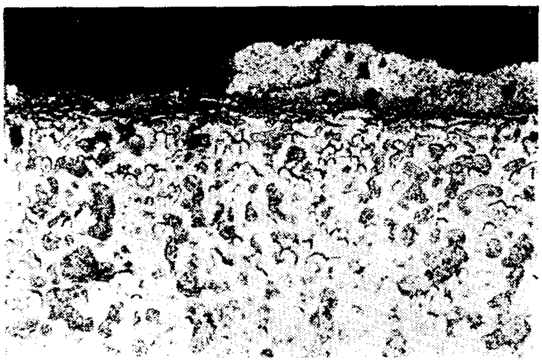

FIG. 46—PHOTOMICROGRAPH OF CROSS-SECTION OF A BEARING IN WHICH THE OVERLAY HAS BEEN REMOVED BY CAVITATION AT UPPER LEFT AND THE REMAINING OVERLAY AT UPPER RIGHT IS DEVELOPING A FATIGUE CRACK BENEATH IT (x 200)

FIG. 44 shows in cross-section a copper-lead Diesel connecting rod bearing which had been operated in fast express service in an overloaded, hot-running engine. The entire matrix shows deformation slanting upward to the right, the direction of shaft motion. Most of the lead has been squeezed from the structure. Arrows designate the few remaining 'stringers' of lead. The resultant bearing has an abnormally high copper content and contains many fine cracks which are collapsed voids originally occupied by lead. These cracks so weaken the structure that ultimate failure by fatigue breakout can be anticipated.

Cavitation

Cavitation (sometimes called 'cavitation erosion' or 'cavitation corrosion') can occur in bearings subjected to heavy duty or high speed service, as in railway Diesel engines. This results in a spotty removal of surface metals as indicated by arrows in FIG. 45 with no evidence of abrasion or corrosion. First inspection of the damaged overplate might suggest abrasive wear; however, cavitation is characterized by repetition of similar damage, not randomly distributed but usually in the same area. A new replacement shell often will show surface removal in the same location, frequently adjacent to oil holes or grooves, or where the journal-to-bearing clearance is increasing. Microscopic examination also reveals fatigue cracks in the damaged area, a condition not found with abrasive erosion. The cross-sectional photomicrograph, FIG. 46, through a cavitation zone shows the overlay missing at the left while to the right it is undermined by a crack (black). FIG. 47, at a higher magnification, shows another fatigue crack running from the surface to the bond line where it changes direction and parallels the bond. Continued operation would result in breaking out the cracked region.

Cavitation damage is attributed to high energy hydraulic impulses within the oil film. This condition is brought about by intense fluctuations in the oil-film pressure which causes high vacuum cavities to open and collapse at great frequency. These tiny but numerous shocks are of sufficient intensity to fatigue the surface and literally nibble away the metal, bit by bit.

FIG. 47—PHOTOMICROGRAPH AT A HIGHER MAGNIFICATION (x 410) OF A CAVITATION FATIGUE CRACK IN A BEARING OVERLAY WHICH EXTENDS DOWNWARDS AT THE RIGHT ALMOST TO THE OVERLAY BOND, THEN CHANGES DIRECTION TO THE LEFT

Cavitation can be induced by a pulsating bearing load as in an internal combustion engine or by shafts driven by gear trains with teeth of improper profile. A more viscous lubricant sometimes will relieve the effect by its increased damping action; however, the best remedy is to eliminate the high-frequency fluctuating load.

SUMMARY

Plain bearings, by far the most widely used type, can fail from a number of causes, most of which are unrelated to lubrication. To facilitate identification and correction, this article describes and illustrates sixteen types of plain bearing failures caused in general by incorrect installation, poor adjustment or inadequate maintenance.