INTERSTATE-McBEE

FAILURE ANALYSIS GUIDE

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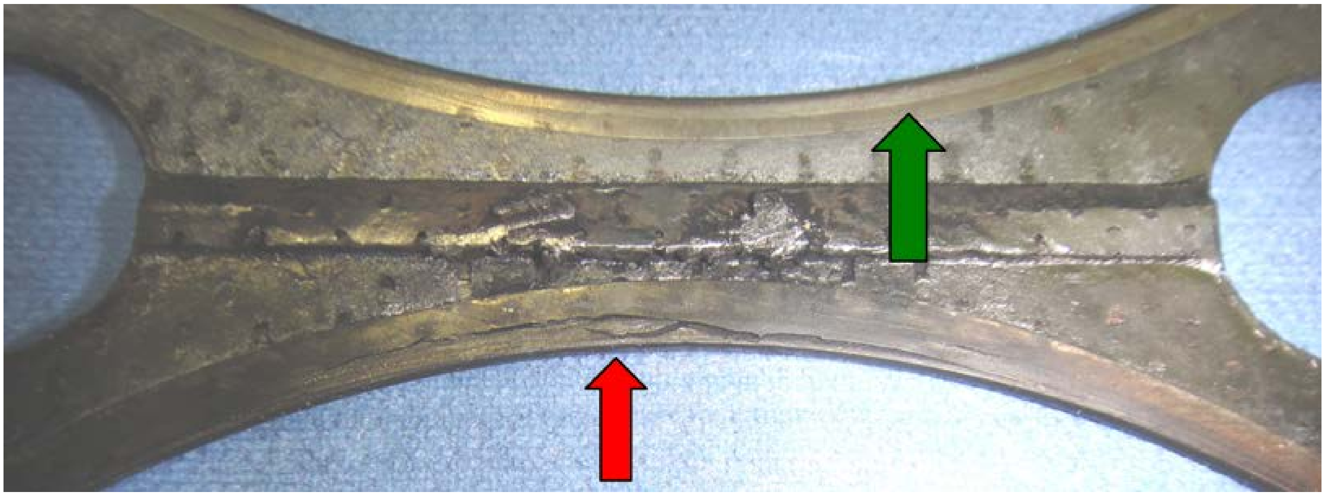
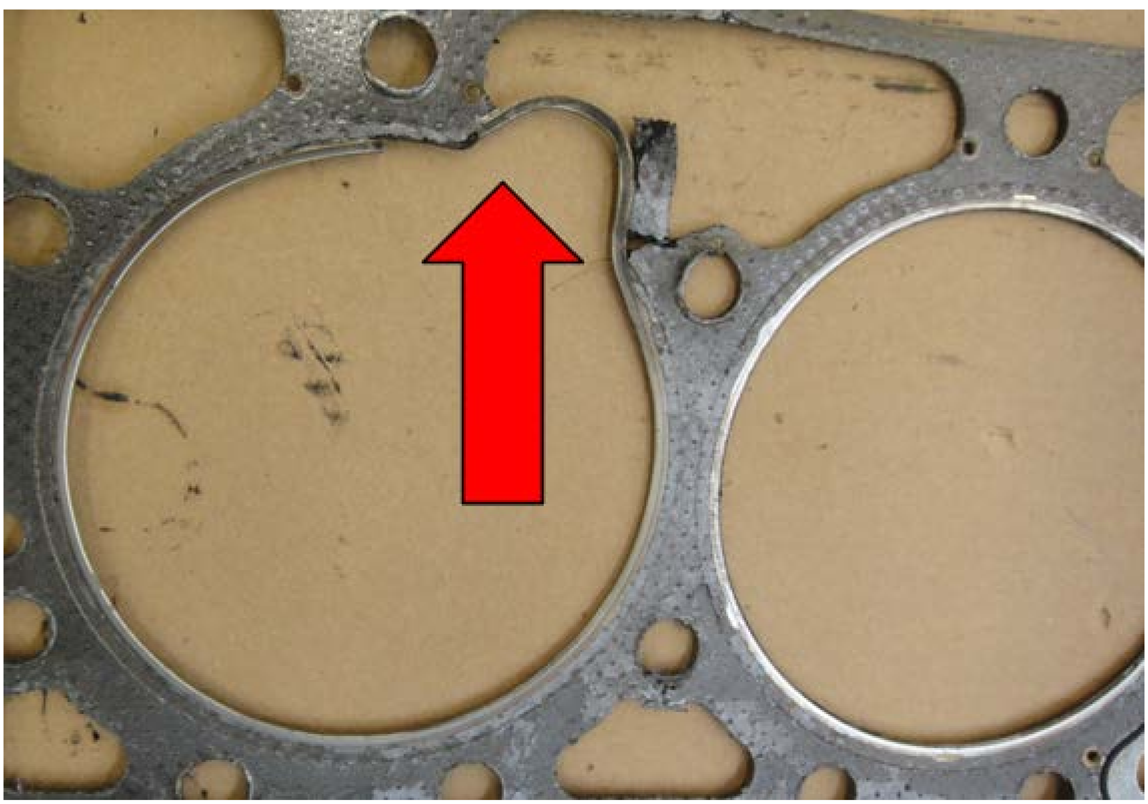
1.1 HEAD GASKETS

A. <u>Gasket failure caused by detonation</u>

The first picture shows the damage to the fire ring on #4 cylinder of the returned head gasket. Note: the condition of the fire ring in the adjoining cylinder which did not fail. The head gasket failed from detonation causing thermo push fracturing the fire ring.



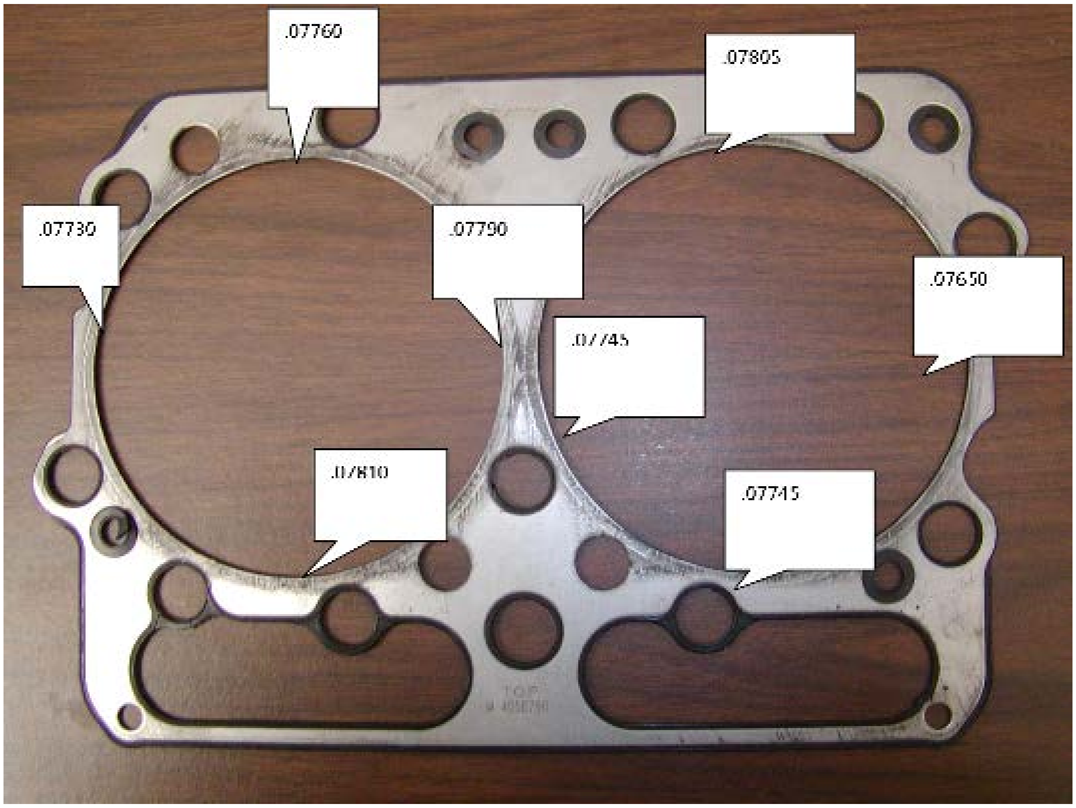
The following picture shows the result of thermo push caused by detonation.



Conclusion: Inspection revealed the head gasket failed due to detonation resulting in thermal push. Detonation is uncontrollable combustion creating combustion temperatures and pressures exceeding cylinder components design capabilities.

B. **<u>Head gasket failure caused by poor surface conditions</u>**

The first picture shows top view and measurements of head thickness variations. Note lines on gasket indicate head surface may be too rough.



This picture shows bottom side of head gasket; note no coarse resurface lines showing.

Conclusion: Minor variations in the gasket thickness indicate surface flatness, liner perpendicularity and even head bolt clamping force. Failure of seals was caused by too rough a surface on the cylinder head. This allowed multiple combustion leak paths resulting in damage to the head seals.

C. <u>Water leaking from head gasket due to use of sealant</u>

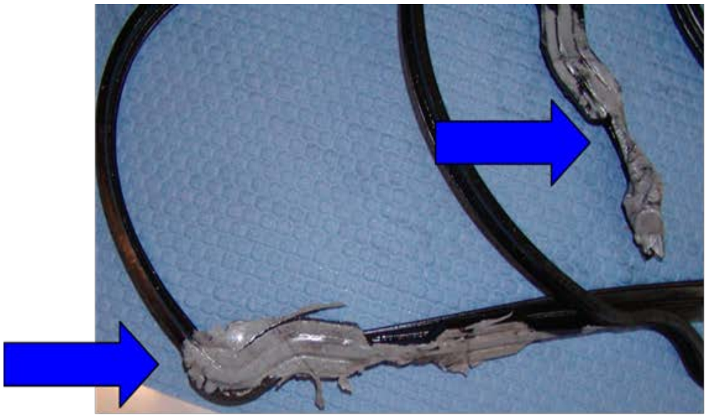
Claim: Water leakage from o-rings during engine run in and the seal rings “contracted”.

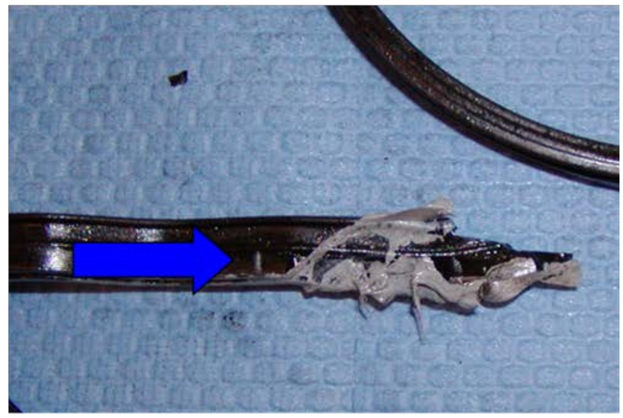
Observations: Gasket was examined for possible leak cause. Red Silicone sealant was found around the water and oil sealing areas. Gasket was assembled using a liquid gasket compound. This is never advised and prevents proper seating of the gasket, as well as uneven loading and increases stress on assembled joint and gasket. Liquids are not compressible and therefore can cause many problems on assembled joints. The liquid also creates a low coefficient of friction and will actually lessen proper torque value. Gasket sealer has extruded into the seal area, potentially the reason of the complaint of seals “contracted” when in actuality, liquid rubber has cured inside of the seal area.

1.2 BLOCK GASKETS

A. <u>Gasket failure caused by assembly errors – use of sealant/glue</u>

Complaint: Oil pan gasket leaks and comes apart. The following pictures show the oil pan gaskets were installed using a glue/sealer.





Conclusion: Use of any type of glue or sealer on this type of pan gasket will cause oil leaks and gasket failure. Gasket should be installed on a clean dry surface.

B. <u>Gasket failure caused by using adhesive</u>

Claim: Gasket split.

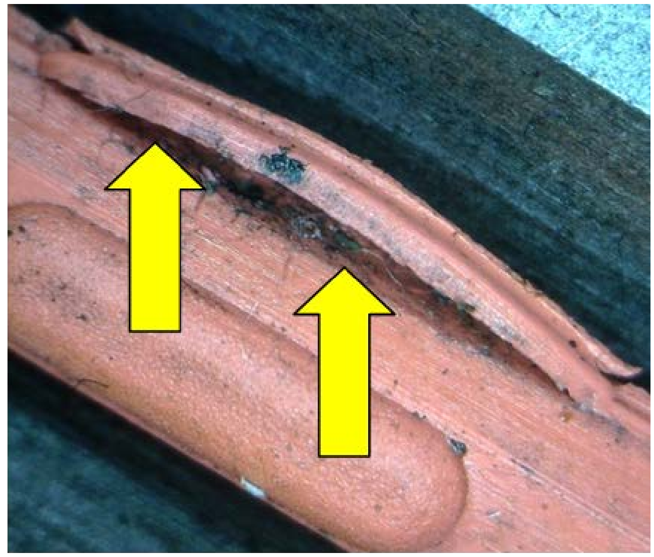
Observations: Inspection revealed there has been gasket sealer applied to the gasket. Both sides of the gasket are “sticky” to the touch. Application of gasket adhesives is not recommended as it can cause the gasket to be over loaded particularly around the bolts where the flange pressures are at the highest. The adhesive will not allow the gasket to conform properly to the flange surfaces and will cause the gasket to tear or split as observed in the gasket sent for evaluation.

Gaskets must be installed completely dry. If adhesives are needed to temporarily hold the gasket in place during assembly, it is recommended the adhesive be used sparingly and placed away from bolt holes.

1.3 SEALS

A. <u>Seal failure caused by installation error</u>

The following two pictures show two locations on the seal that are damaged and provide a leak path for oil. The cause of failure, oil leak, is the result of the damage to the seal during assembly.



2.1 VALVES

A. <u>Natural gas engine valve failure</u>

The first picture shows two valves with extreme recession.

The following is by Lloyd Leugner of Maintenance Technology International, Inc. It deals with the main cause of valve recession.

Natural Gas Engine Lubrication and Oil Analysis - A Primer in Predictive Maintenance and Condition Monitoring
Lloyd Leugner, Maintenance Technology International, Inc.

Sulfated Ash

Any discussion of the elemental analysis of natural gas engine oils is not complete without a comment concerning the issue of sulfated ash content. Natural gas engine operation tends to form various deposits such as varnish, sludge and an ash residue which remains after the oil is burned during operation.

The varnish and sludge are controlled by the detergent/dispersant additives, however these detergent/dispersant additives tend to leave a grey, fluffy ash residue after the oil has been burned. This ash residue is made up of metal sulfates from such additives as barium, calcium, phosphorus, zinc, magnesium and boron.

Therefore, lubricant formulators must ensure that these additive concentrations are high enough to help prevent valve recession, but not so high as to cause unwanted and harmful deposits, or cause catalysts to become ineffective.

Valve recession is the premature wearing of the valve seat into the cylinder head. The sulfated ash residue helps to prevent premature valve recession by “cushioning” the valve seat area.

Figure 1. Typical Valve Recession in a Natural Gas Engine

Excessively high concentrations of certain additives, such as zinc or phosphorus, can also be harmful to catalyst equipped natural gas engines, because these additives may deactivate the exhaust catalyst by forming glassy-amorphous deposits, which prevent the exhaust gas from reaching the active surfaces of the catalyst, which in turn makes control of harmful emissions impossible.

In addition, natural gas engine manufacturers also list the levels of sulfated ash and the additive concentrations that are acceptable for use in their particular engines. For specific recommendations concerning ash content and additive levels, the engine operator should contact both the engine manufacturer and the lubricant supplier.

Conclusion: The most likely cause of the premature valve wear is improper maintenance procedures for the engine conditions.

B. <u>Premature valve component wear caused by various external conditions</u>

The first picture shows abrasive wear on valve stems. Wear of this type is due to improper adjustment and is not a defect in material.

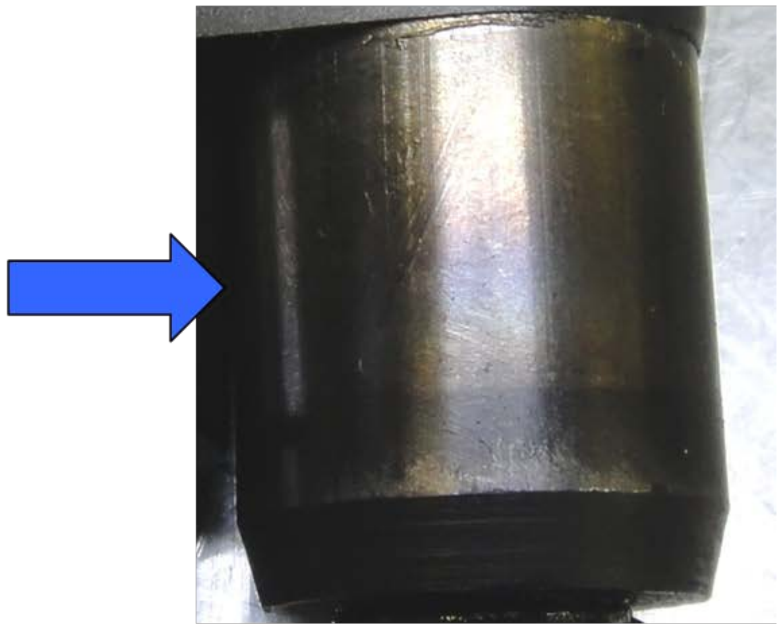
Failures due to carbon build-up and/or corrosives

The next several pictures will show the heavy abrasive carbon build up on the valve, valve spring and rotator and the valve guide. Note the heat discoloration of the guide (blue arrow). These parts failed due to carbon build up due to external conditions and not defects in the product.

The next picture shows the stem of the broken valve. Note the break (green arrow) is just above the valve face (strongest part of a valve). Also note the erosion of the valve stem from carbon cutting (red arrow).

C. <u>Valve and valve guide wear caused by poor maintenance</u>

The first two pictures show the wear in the lower part of the valve guide closest to the valve head. The second picture shows the heat discoloration on the lower part of the guide was caused from excessive heat. Excessive guide wear most likely occurred from improperly set valve bridges and maintenance issues.



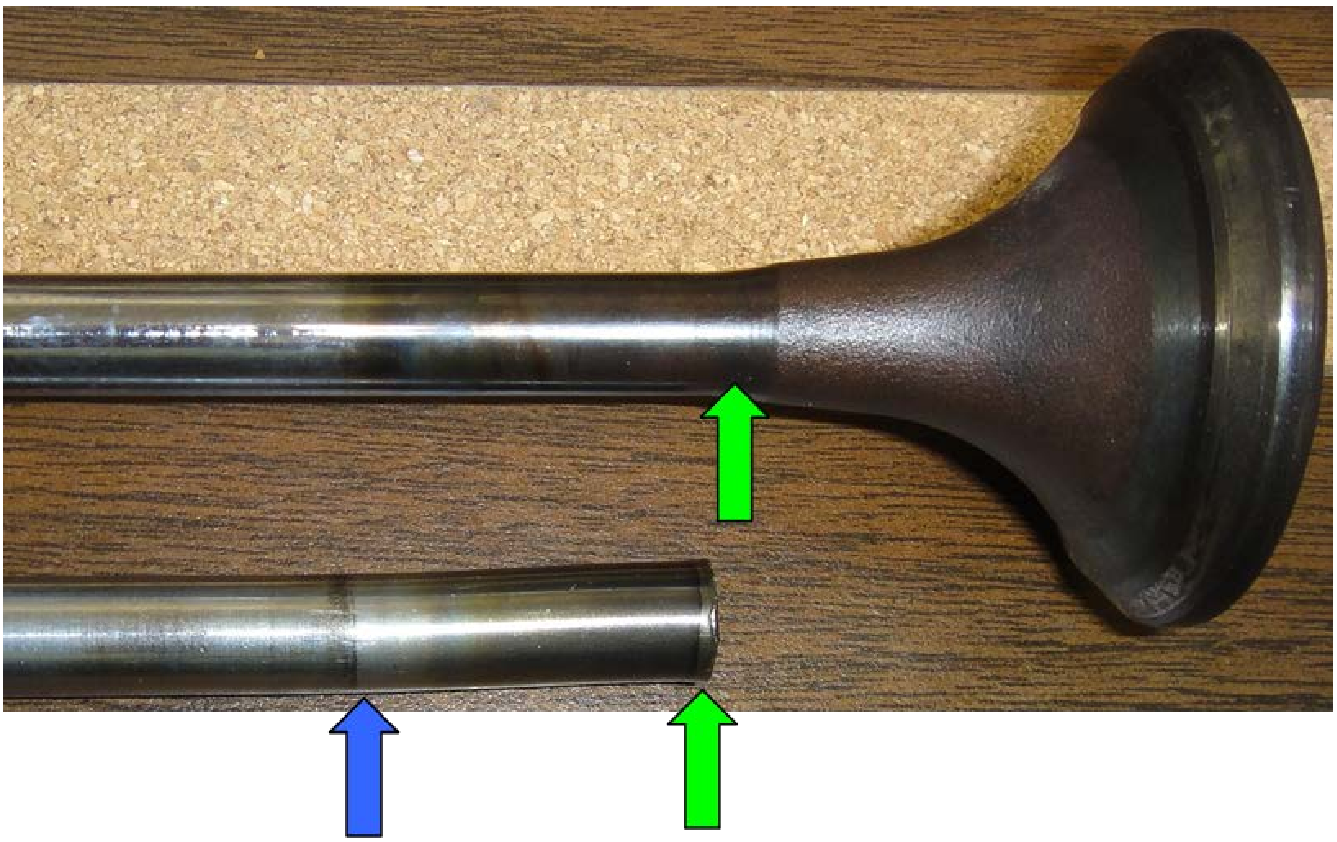
Valve wear caused by misadjusted

This picture shows the seat wear on one of the valves. Most of the valves had similar wear and a few had severe wear.

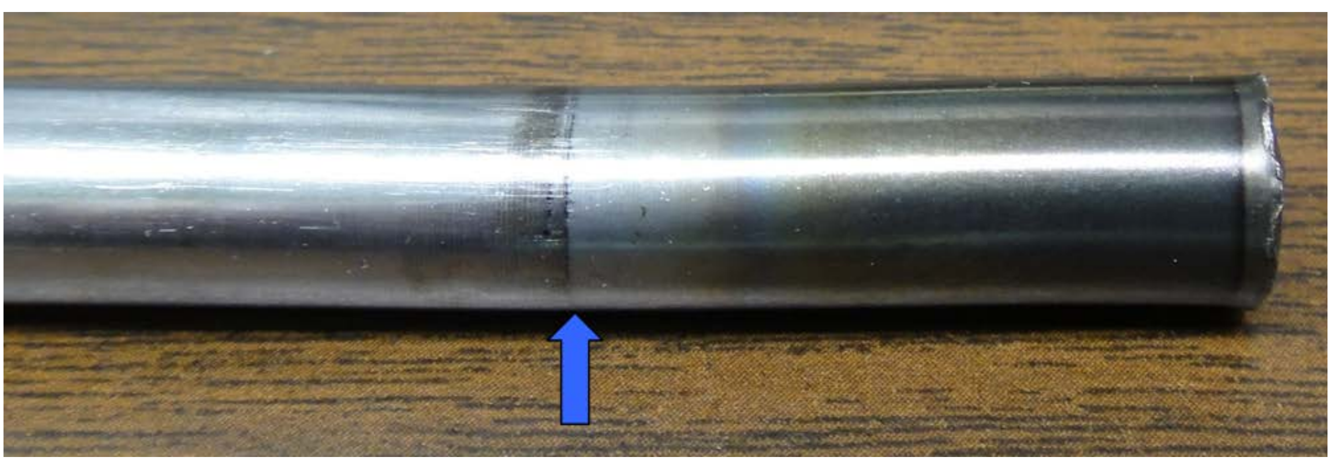
Valve seat wear will reduce valve lash and effect when a valve opens and closes which changes timing. It also effects scavenging, valve overlap and both valve and valve seat cooling. Lack of proper scavenging can also cause excessive heat build up in the exhaust ports and damage the valve guides. If there is a variation in wear of the two valves that share a common crosshead it can create side loading of the valves and wear in the valve stems. Crossheads must also be inspected prior to installation for both wear and orientation.

D. <u>Valve failure caused by bending fatigue</u>

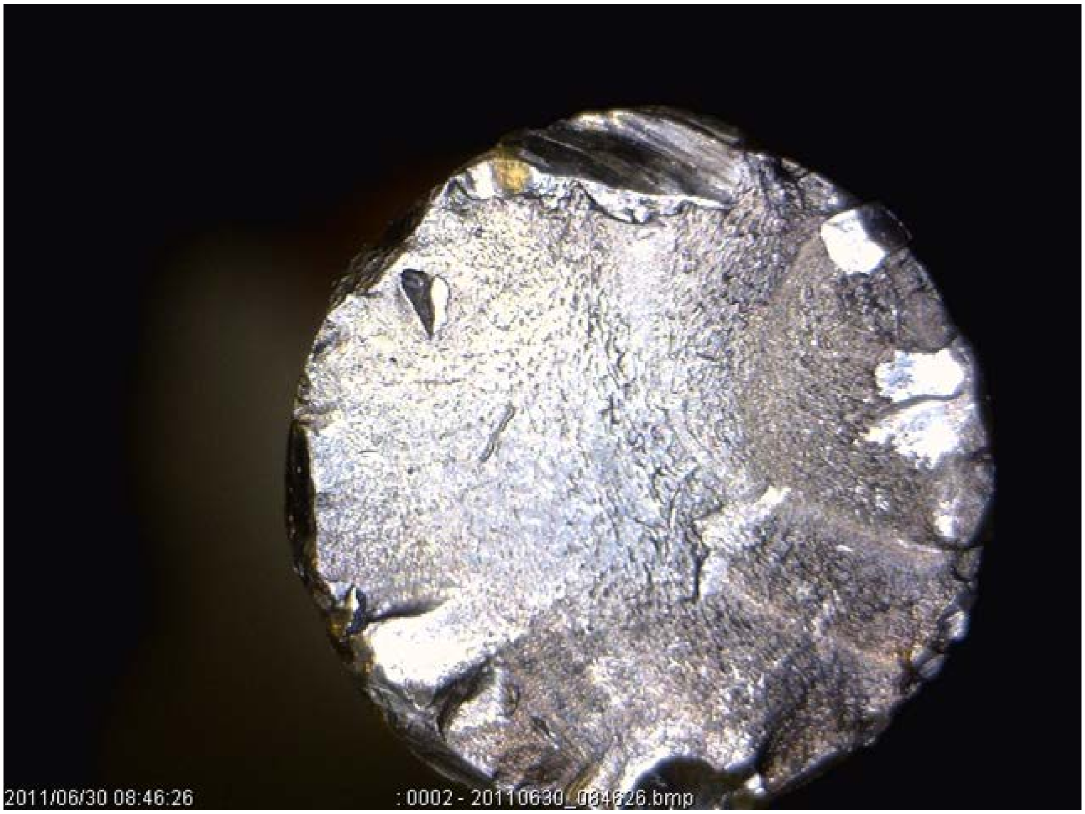
The following picture shows a complete valve and the stem of the failed valve. The green arrows will point out where the failed valve broke in relationship to the complete valve. The blue arrow will point out where the valve head is welded to the valve stem.



The next picture of the stem of the failed valve shows the welded area of the stem a little clearer.



The next picture is a view of the valve stem break that is a bending fatigue failure.



Final picture of damage to cylinder head at failed cylinder. Note valve missing head at bottom shows remains of stem, this occurred as a secondary failure.

The failed valve had no inclusions or flaws in the break area. The valve did not break at the weld attaching the valve head to the shaft as claimed. The most likely cause for the failure is bending fatigue caused by misalignment.

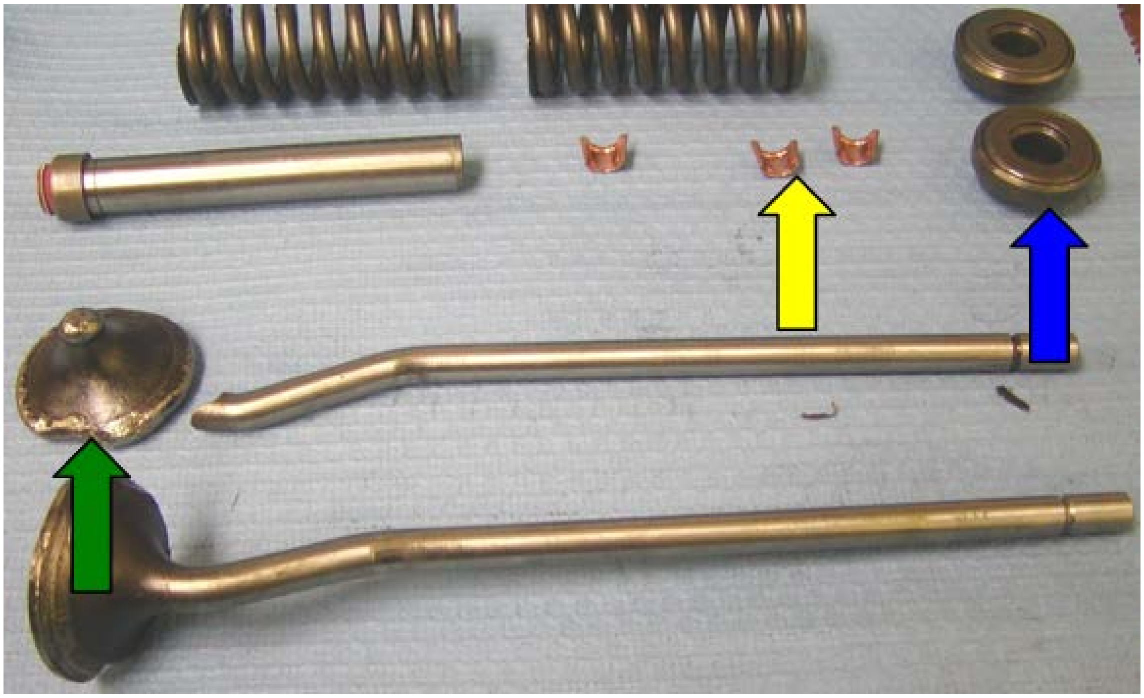
E. Valve failure caused by impact loading

• The yellow arrow pointing at the valve retainers show they are undamaged.

• The rotators indicated by the blue arrow were inspected and function properly showing no damage.

• The two valves in the foreground show no galling in the stem indicating they did not seize in the valve guide.

• The Green arrow points to the broken valve, note location of break.

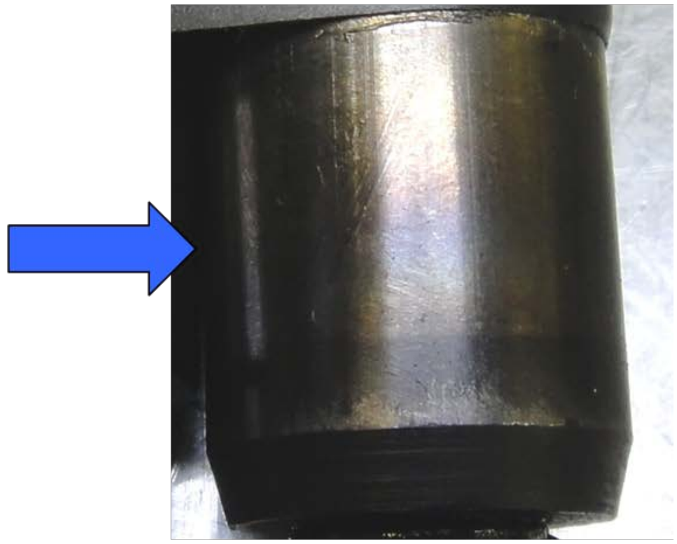


In the above picture the green arrow points to the valve head and the area the valve broke. This is in the weld area of the valve, the strongest part of a valve. This type of failure only occurs from impact. The second valve is bent in the same location but did not break. All the possible causes such as valve sticking in guide, broken valve retainers show no signs of failure as seen in the first picture.

2.2 VALVE GUIDES

A. <u>Valve and valve guide wear caused by poor maintenance</u>

The first two pictures show the wear in the lower part of the valve guide closest to the valve head. The second picture shows the heat discoloration on the lower part of the guide was caused from excessive heat. Excessive guide wear most likely occurred from improperly set valve bridges and maintenance issues.



Valve wear caused by misadjusted

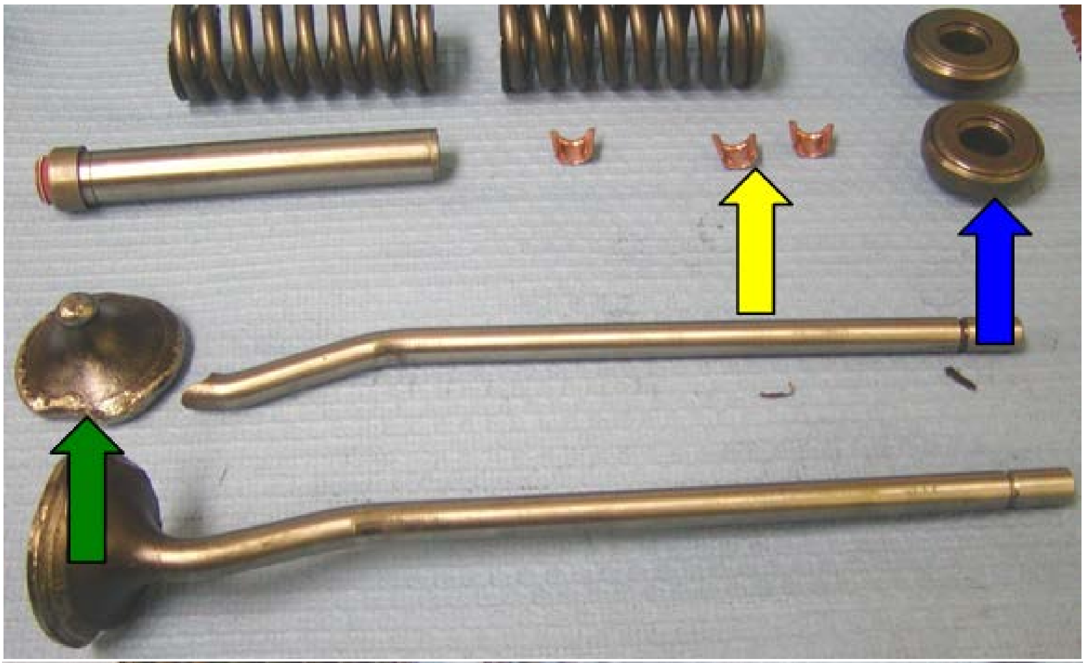
This picture shows the seat wear on one of the valves. Most of the valves had similar wear and a few had severe wear.

Valve seat wear will reduce valve lash and effect when a valve opens and closes which changes timing. It also effects scavenging, valve overlap and both valve and valve seat cooling. Lack of proper scavenging can also cause excessive heat buildup in the exhaust ports and damage the valve guides. If there is a variation in wear of the two valves that share a common crosshead it can create side loading of the valves and wear in the valve stems. Crossheads must also be inspected prior to installation for both wear and orientation.

2.3 VALVE KEEPERS/RETAINERS

A. <u>Valve failure caused by impact loading</u>

The following pictures shows material returned. The yellow arrow pointing at the valve retainers show they are undamaged. The rotators indicated by the blue arrow were inspected and function properly showing no damage. The two valves in the foreground show no galling in the stem indicating they did not seize in the valve guide. The Green arrow points to the broken valve, note location of break.



In the above picture the green arrow points to the valve head and the area the valve broke. This is the strongest part of a valve. This type of failure only occurs from impact. The second valve is bent in the same location but did not break. All the possible causes such as valve sticking in guide, broken valve retainers show no signs of failure as seen in the first picture.

Conclusion: Since both valves are bent in a similar manner, the piston hit the valves and not some random piece of foreign material. The root cause of failure is impact loading.

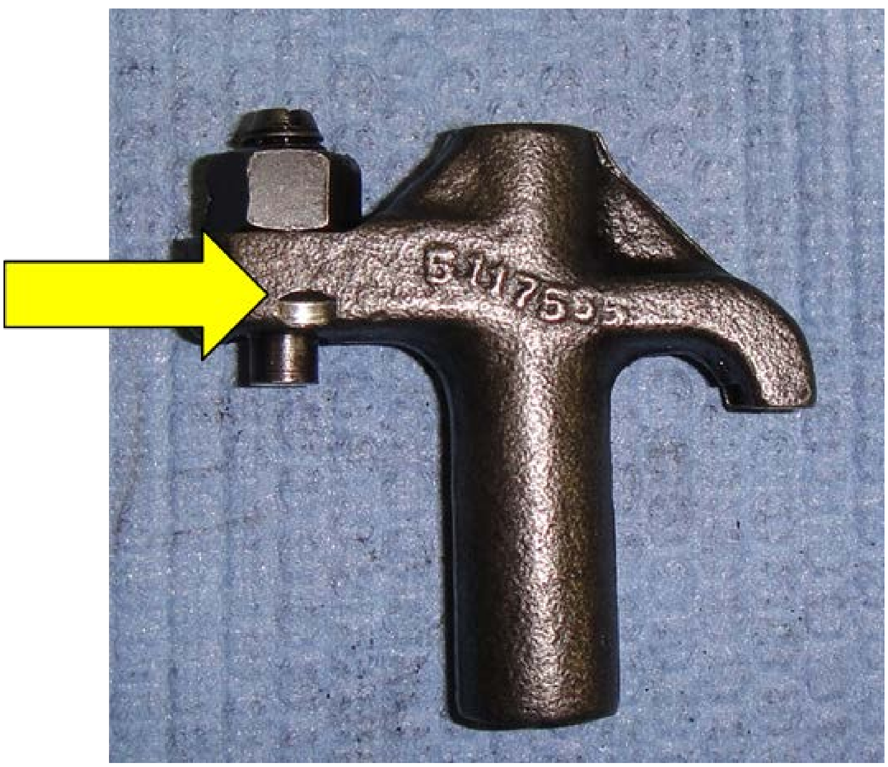
2.4 VALVE BRIDGES

B. <u>Valve failure caused by turned valve bridge</u>

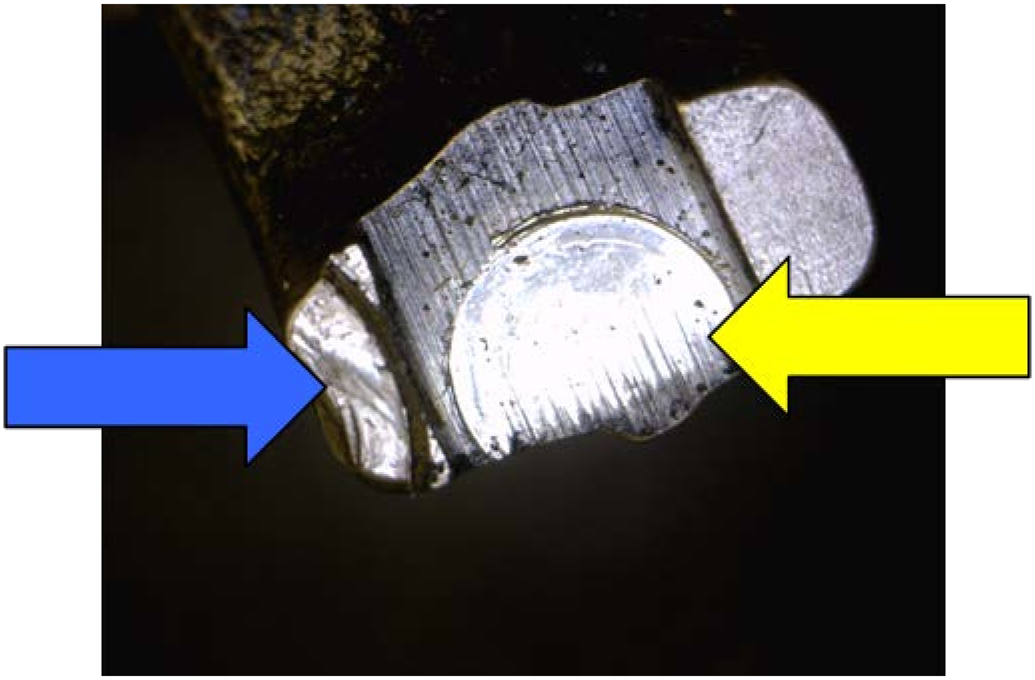
Complaint: Valve head came off damaging cylinder kit and head.

The first picture shows the valve head. The valve broke in the strongest part of the valve and not at the parting line between the valve head and stem. Breaks in this part of the valve occur when the valve is hit and the failure is caused by impact loading.

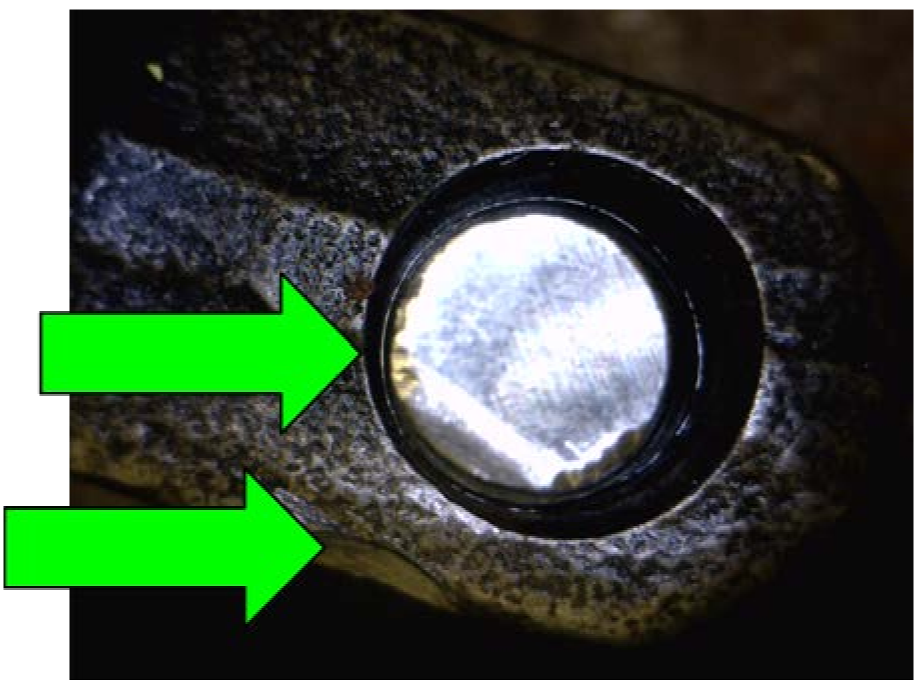
The next few pictures show a damaged valve bridge.



On inboard side of valve bridge note limited contact area, yellow arrow and edge damage blue arrow. The edge damage was caused when the bridge turned and the valve was in running contact with the outside of the bridge.



The next picture shows the out board side of the bridge, note witness marks, green arrows, showing running contact wear on edge of normal contact area and on outside edge of bridge.

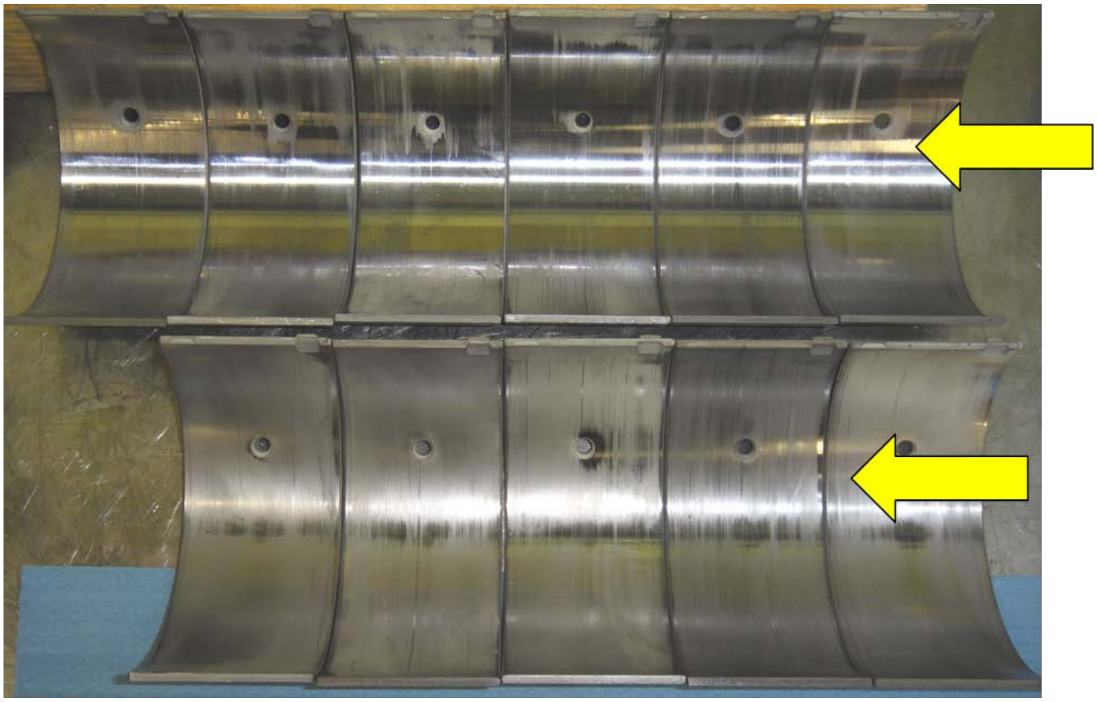


Conclusion: The most likely cause for the valve failure was found to be impact loading caused when the valve was momentarily locked in the open position by the turned valve bridge allowing the piston to strike the valve breaking it off from the stem.

3.1 MAIN BEARINGS

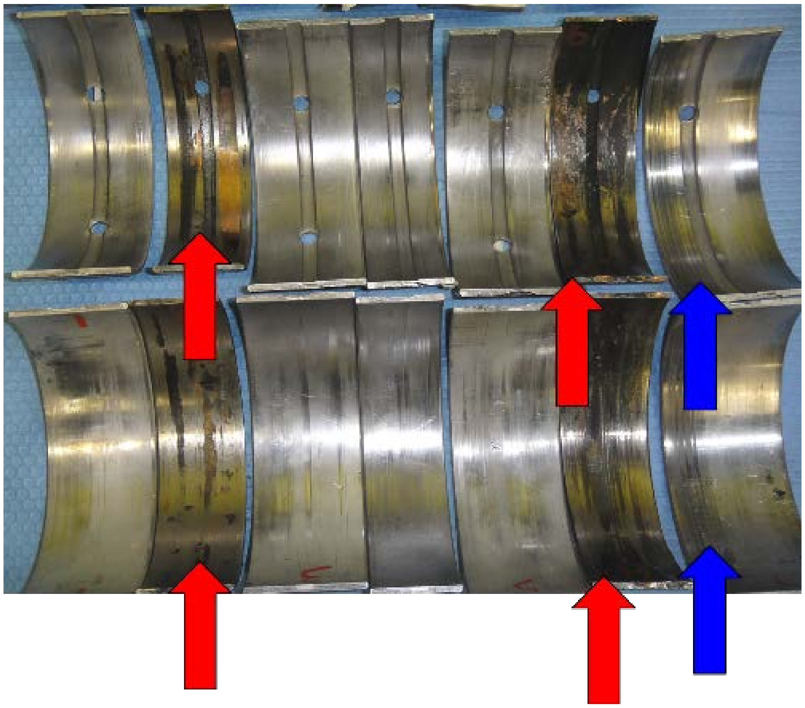
A. <u>Bearing failures caused by lack of proper lubrication</u>

Notice the extremely polished condition of the bearings with the worst streaking toward the center of the bearing. This is an indicator of oil starvation, possibly from a dry start up or low oil.



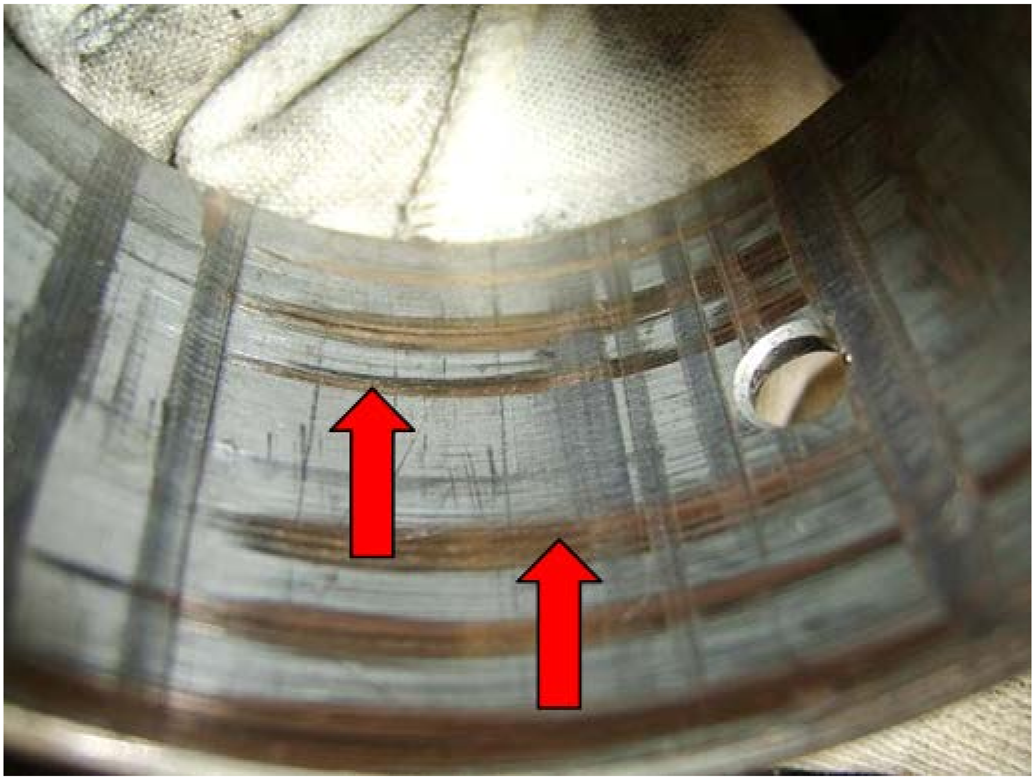
B. <u>Bearing failures caused by lack of proper lubrication</u>

The following picture shows all of the main bearings laid out in the order they were removed. Red arrows point to bearings experiencing catastrophic failure. The blue arrow shows number seven bearing set starting to failure. Note all the bearing show shiny rub spots that are a further indication of lack of lubrication.



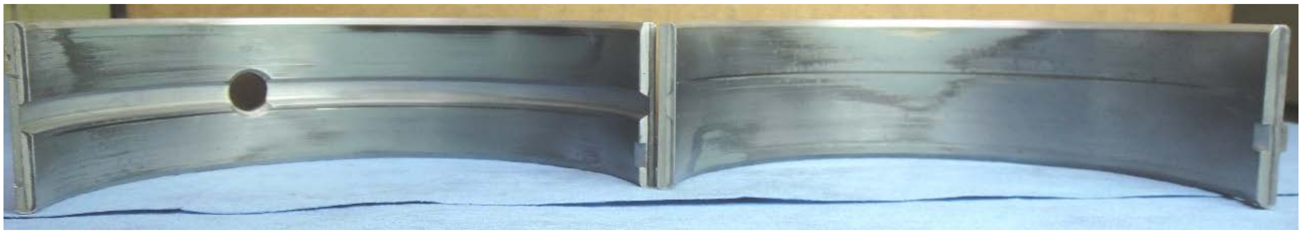
C. Examples of bearing failures

The picture shows a wear pattern caused by an uneven and rough cam bearing bore in block.



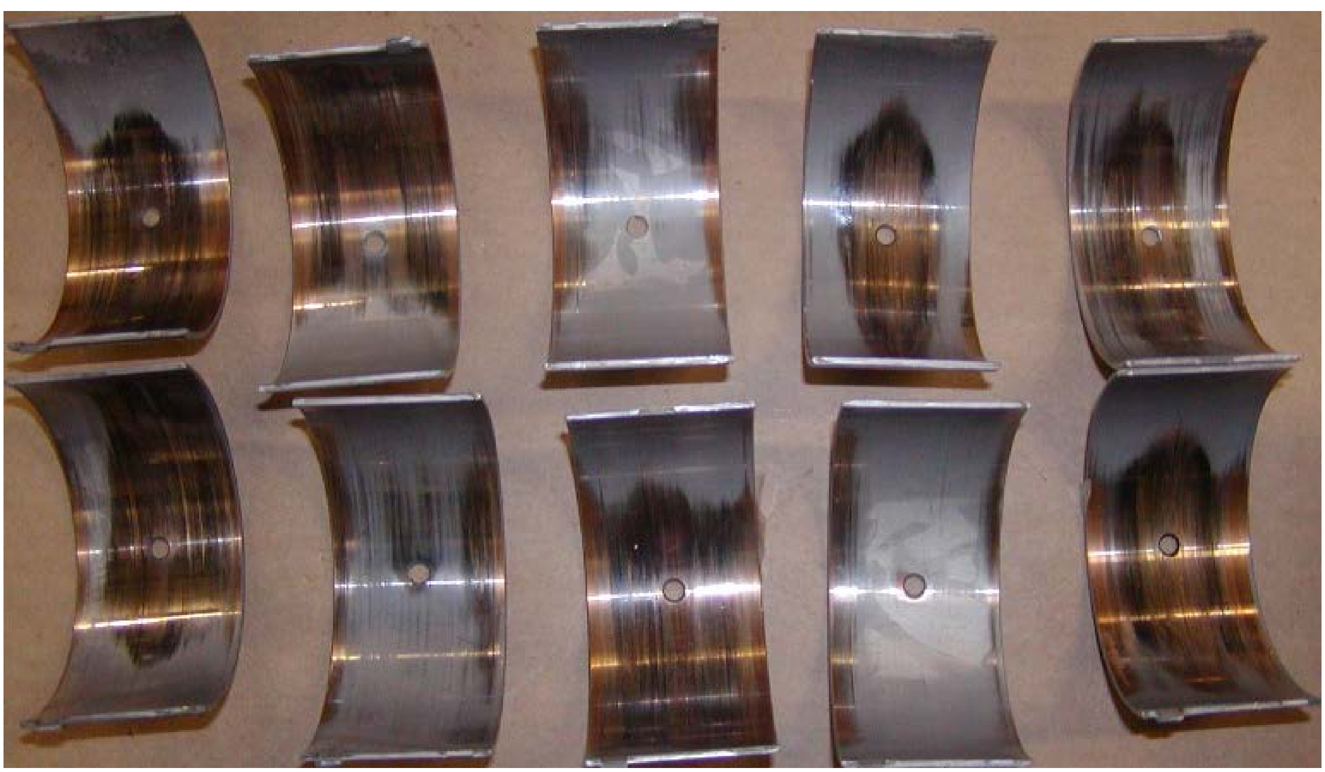
Foreign material trapped between main bearing and block.

Example of uneven wear caused by bore distortion



Example of uneven wear caused by a bent connecting rod

Example of uneven wear caused by severely worn crankshaft rod journals

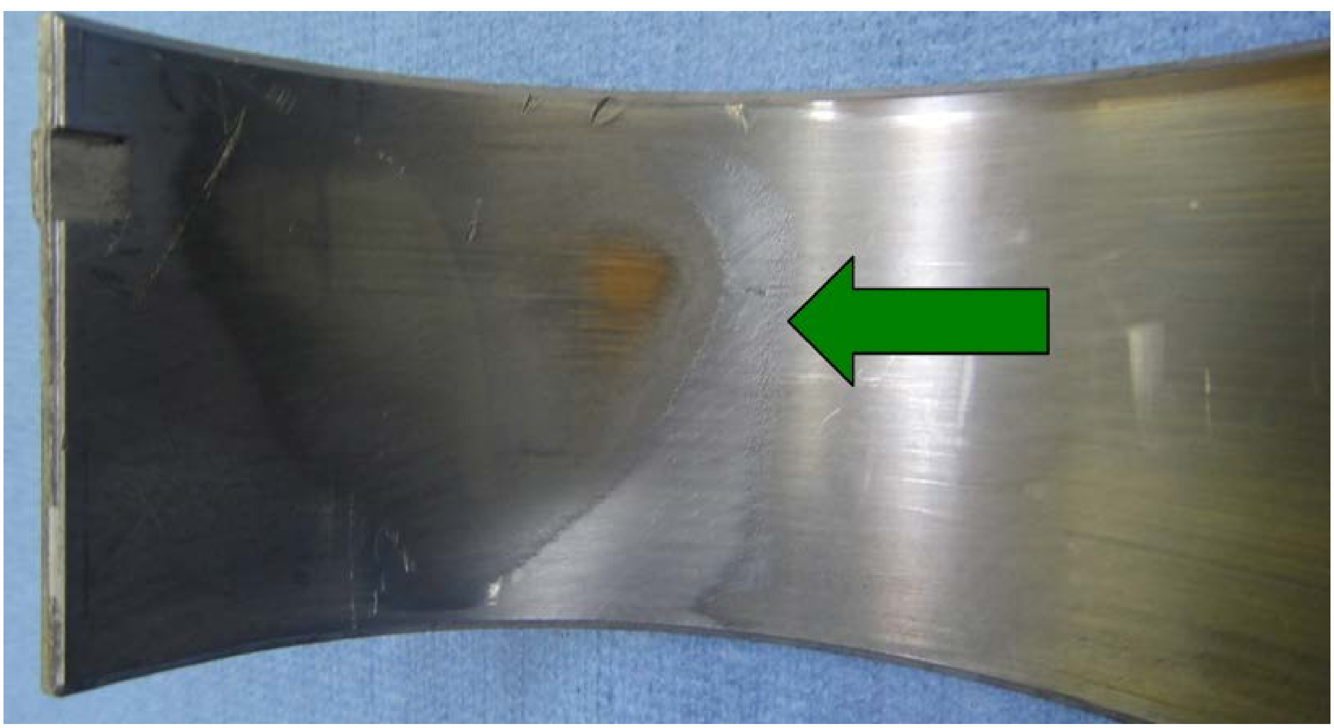


Example of a bearing failure caused by assembly error; the oil feed hole in the connecting rod was not lined up with the bear lubrication hole.

3.2 ROD BEARINGS

A. <u>Bearing failure caused by foreign material on the back of the bearing</u>

The next two pictures show a rod bearing with a piece of tape or paper on the back of the bearing where it seats in the connecting rod (blue arrow); the pattern of the tape is clearly visible on the front side of the bearing where it came in contact with the crankshaft connecting rod journal (green arrow).

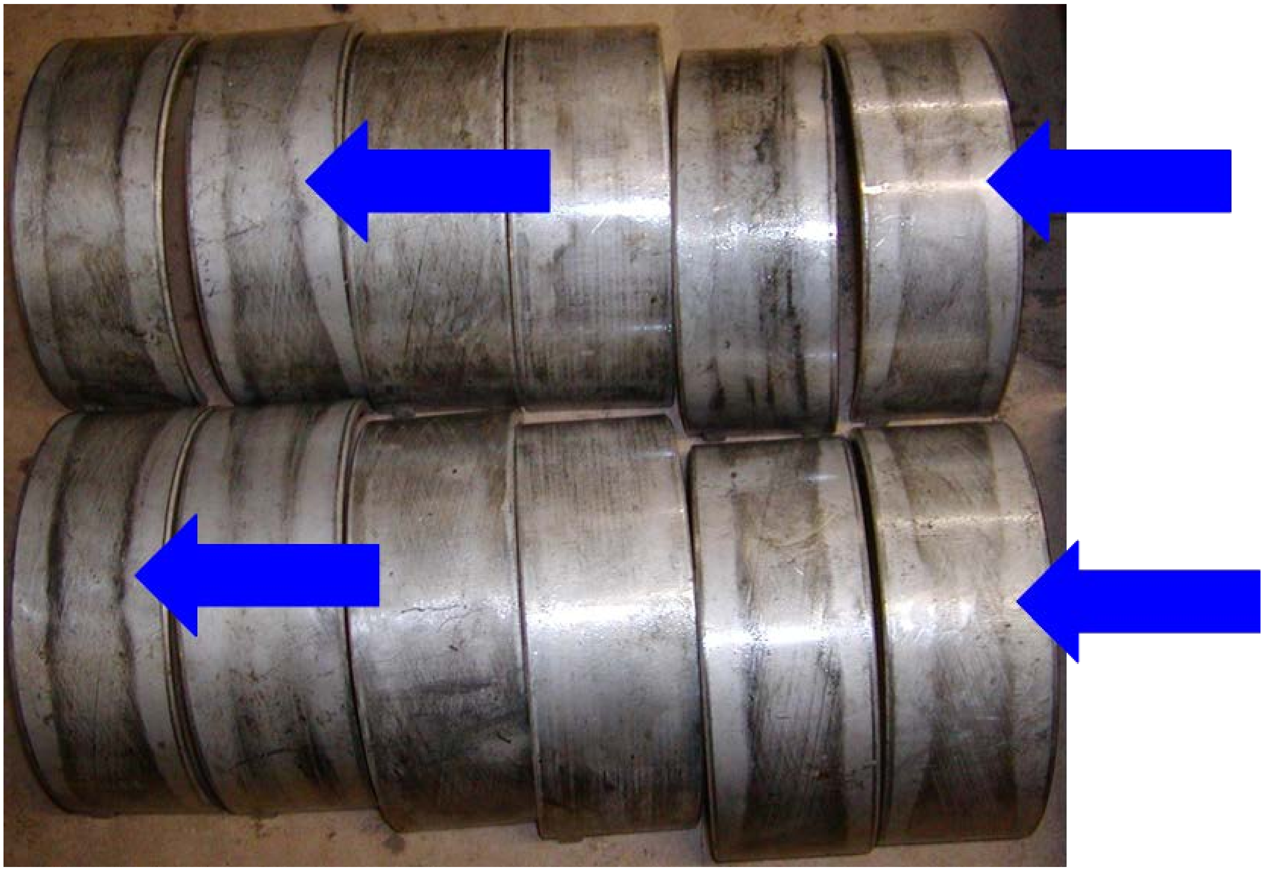


The final picture shows the uneven wear patterns on the rod bearings. Gouges in the bearings are caused from abrasive contamination not properly removed from the engine during overhaul.

Conclusion: The bearings have uneven wear spots most likely caused by either a worn crankshaft or out of round connecting rod bearing bores. One bearing had a piece of tape on it that was between the bearing and the rod bearing surface. The pattern of the tape was clearly visible on the reverse side of the bearing.

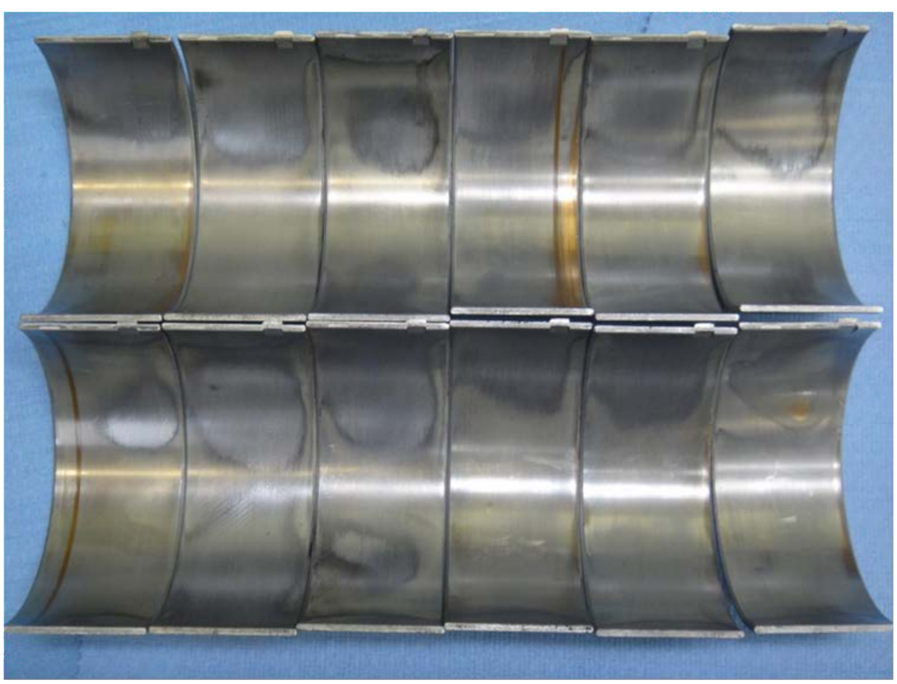
B. Bearing failure caused by excessive wear in support components

The pattern on the rod bearings indicate either a barrel shaped crankshaft or distorted and worn connecting rod bores.



C. Bearing failure due to worn crankshaft or out of round connecting rods

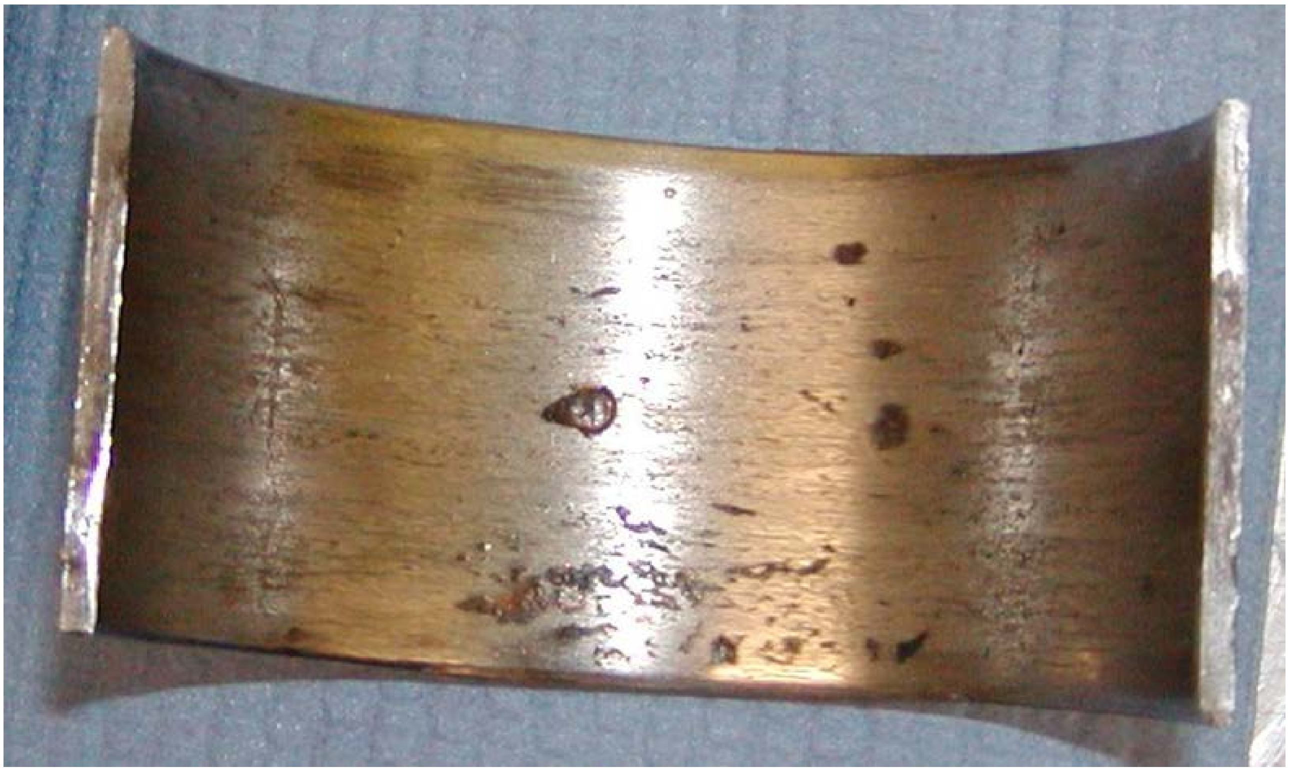
The final picture shows the uneven wear patterns on the rod bearings. Gouges in the bearings are caused from abrasive contamination not properly removed from the engine during overhaul.



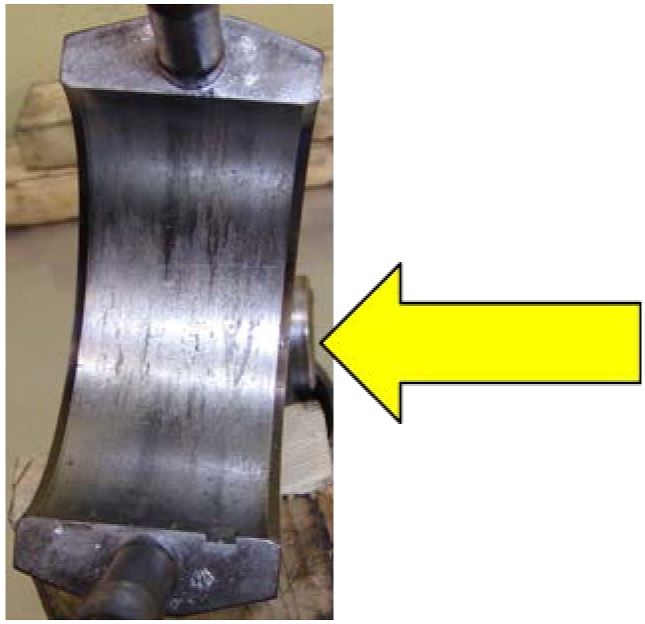
Conclusion: The bearings have uneven wear spots most likely caused by either a worn crankshaft or out of round connecting rod bearing bores. One bearing had a piece of tape on it that was between the bearing and the rod bearing surface. The pattern of the tape was clearly visible on the reverse side of the bearing.

D. <u>Cylinder kit failure from lack of proper lubrication</u>

The first two pictures show the spun connecting rod bearings.



The next picture shows the lower part of the connecting rod that holds the rod bearing. Note; the rod is not drilled for an oil feed hole to the piston pin.



The next picture shows the failed piston and connecting rod. The piston skirt and liner were reduced to pieces.

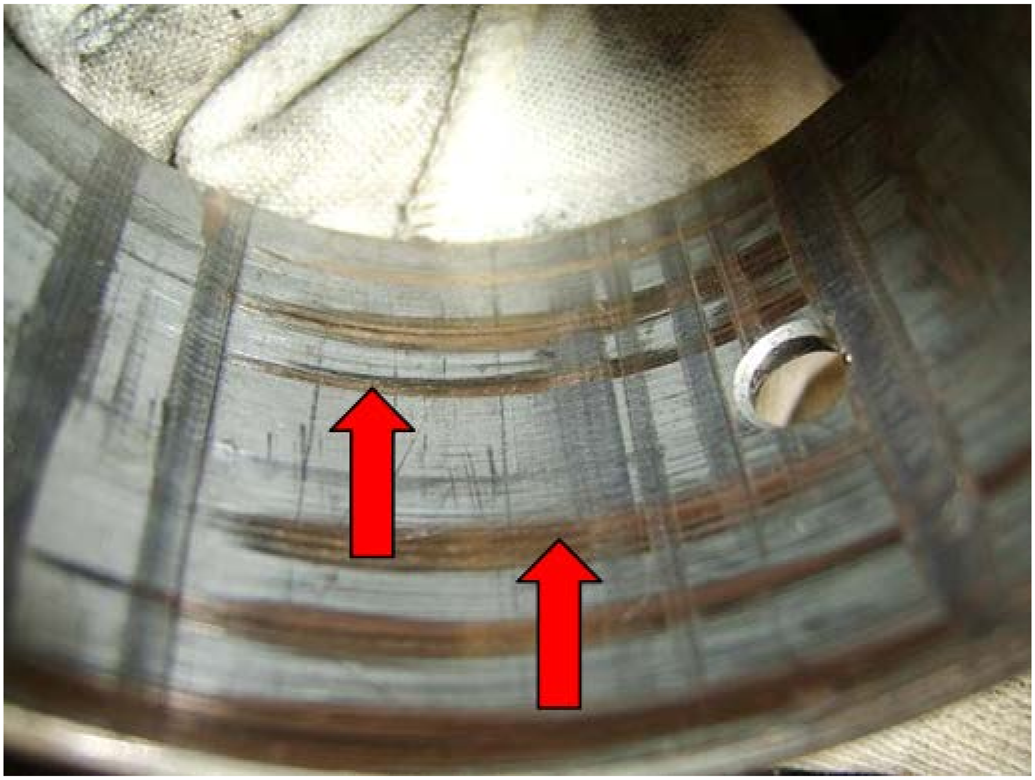
The final picture shows the remains of the piston cooler.

Conclusion: The above pictures show two areas of failure, the connecting rod bearing and the cylinder kit. Also shown is a damaged piston cooler. The piston cooler if bent can cause a piston to seize and cause the piston pin bearing to fail. The connecting rod was not up dated at time of overhaul to the recommended drilled rod. The rod bearing failure caused by lack of proper lubrication.

3.3 VARIOUS EXAMPLE OF BEARING FAILURES

A. Examples of bearing failures

The picture shows a wear pattern caused by and uneven and rough cam bearing bore in block.
Cause of failure uneven support.

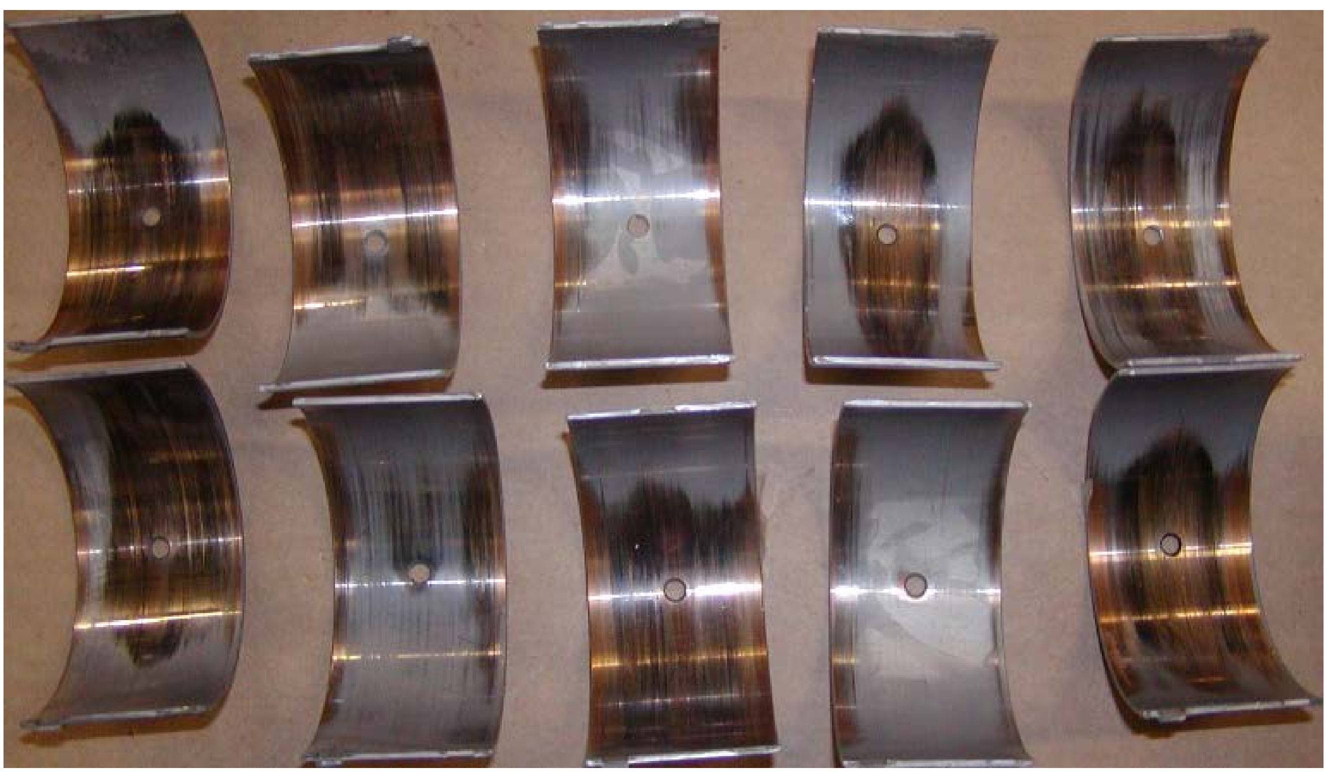


Foreign material trapped between main bearing and block

Example of uneven wear caused by bore distortion

Example of uneven wear caused by a bent connecting rod

Example of uneven wear caused by severely worn crankshaft rod journals



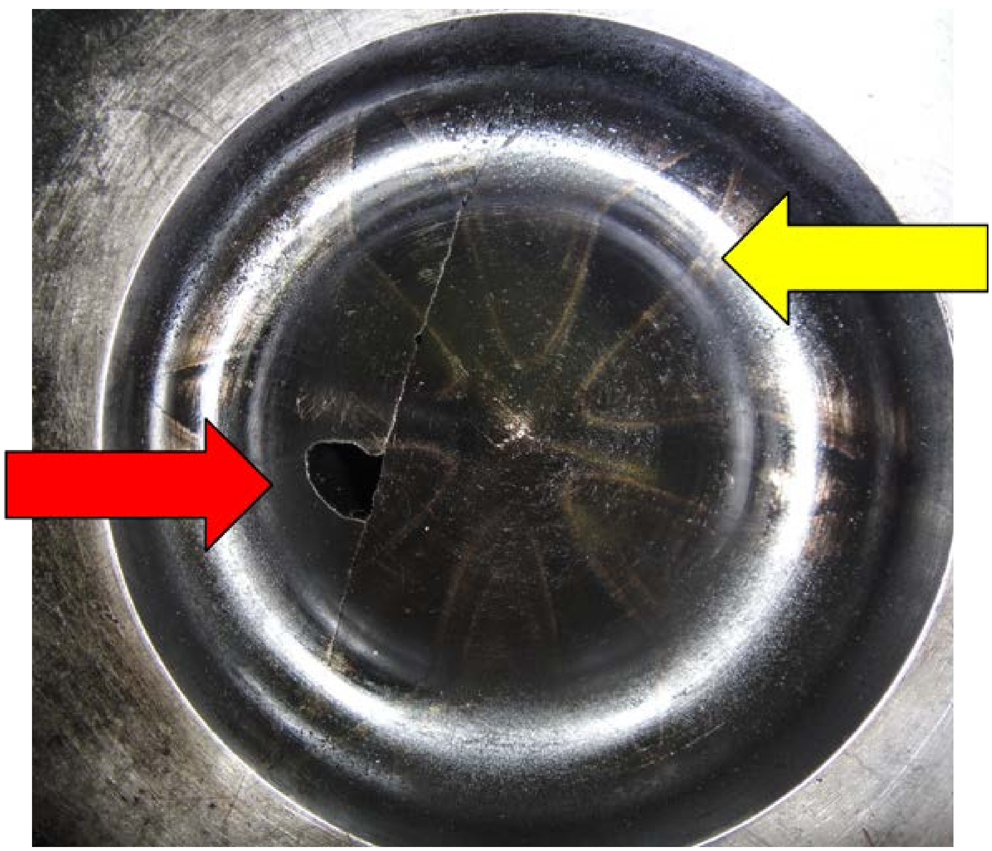
4.1 PISTON CROWNS

A. <u>Piston damaged by adding cold coolant to a hot engine</u>

B. <u>Piston failure caused by overheat and detonation</u>

Cylinder kit failure caused by overheat and detonation. The first picture shows the scored piston and the second picture shows scoring on the inside of the liner.

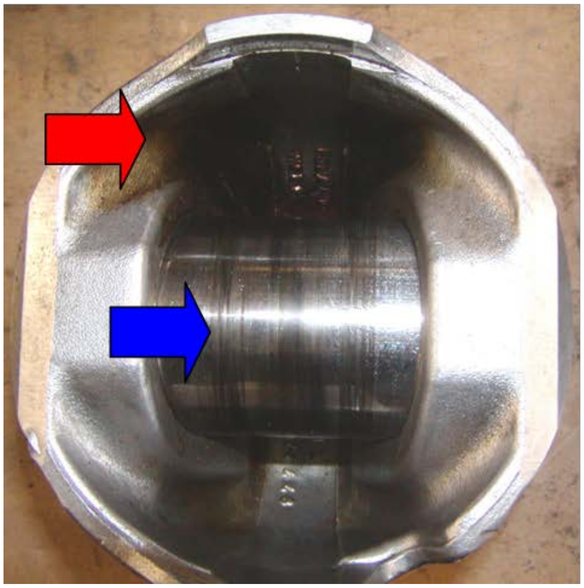
The final picture shows the piston crown. The red arrow points out the crack and hole in the crown and the yellow arrow points out the fuel pattern.



The piston and liner are severely scored from overheat. Top of piston is cracked and has a hole in it caused by detonation. The fuel spray pattern on the piston crown is too close to the center of the bowl indicating a timing issue or a damaged fuel injector. The most likely cause of failure would be incorrect timing.

C. **Piston failure caused by overheat**

The following pictures show the bottom of the piston with the piston pin in place, note the black streaks on the pin "blue arrow" and the burnt area of the under crown "red arrow".



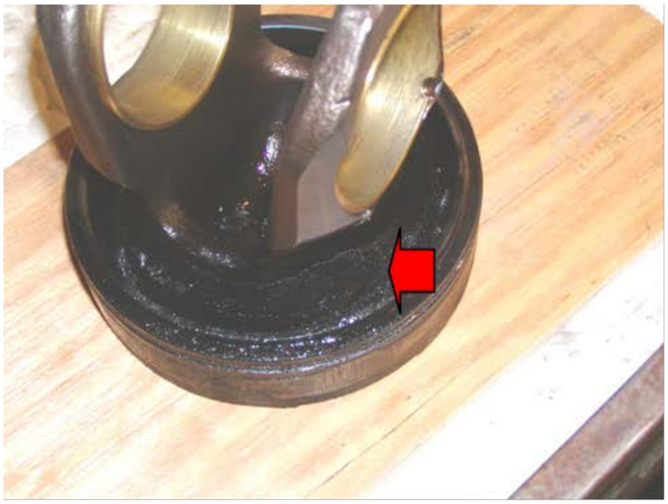
The next picture of the top of the piston shows no unusual injector pattern, indicating it did not overheat from a defective injector.

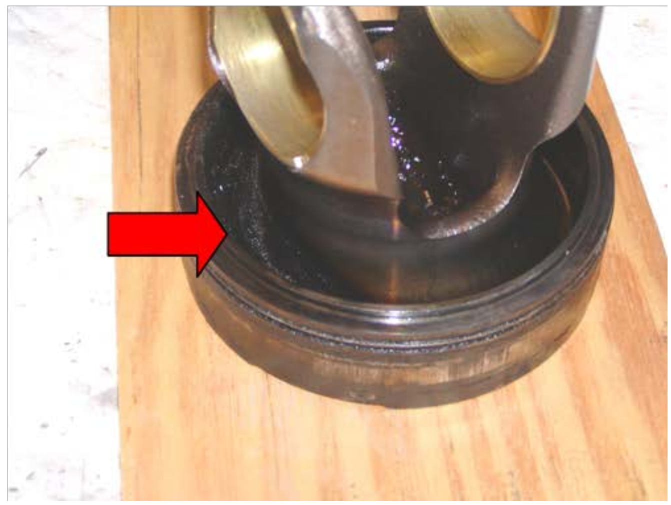
Conclusion: The connecting rod bearings for this failed cylinder kit were returned with the failed parts were in pristine condition showing normal wear. The top of the piston showed no sign of an injector problem. The piston pin showed signs of lack of proper lubrication, blue arrow. The underside of the crown was burnt, red arrows. The piston is cooled on the underside by oil from the piston cooler.

The root cause of failure was severe overheat from lack of proper lubrication. The piston cooler should be checked for damage. The engine should also be checked that it contains the correct type of oil, correct amount of oil and that the oil pressure is per manufacture's specification.

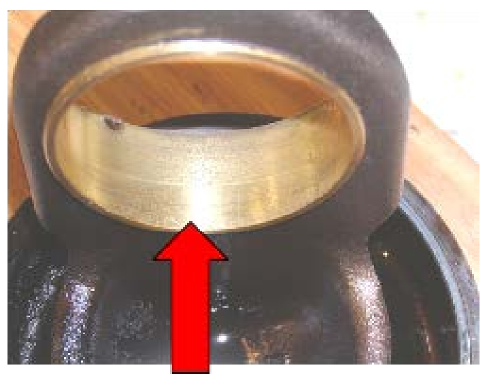
D. <u>Piston failure caused damaged piston cooler</u>

Pictures of underside of piston crown show heavy deposits of burnt oil.

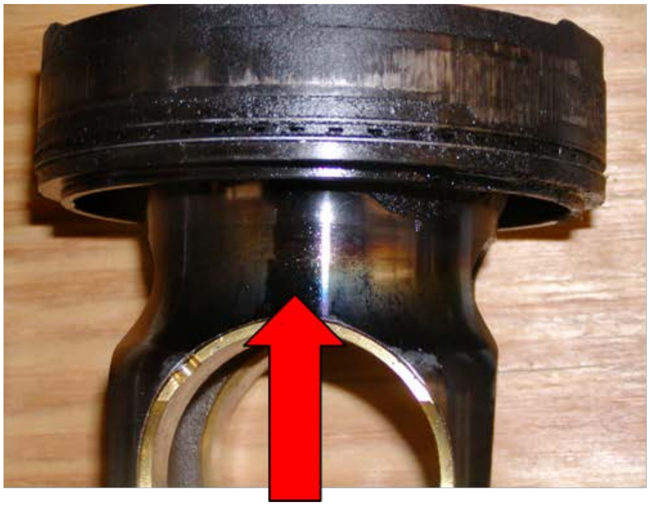




The following pictures show the start of discoloration of piston pin and fretting in piston pin bearings from lack of sufficient lubrication.



Following pictures show discoloration of piston crowns caused by extreme overheat.



The above pictures indicate the root cause of failure to be extreme overheat of the piston crown. This caused the over expansion of the crown and skirt and heavy scoring of the cylinder kit. This type of single cylinder failure is usually caused by a damaged or plugged piston cooler.

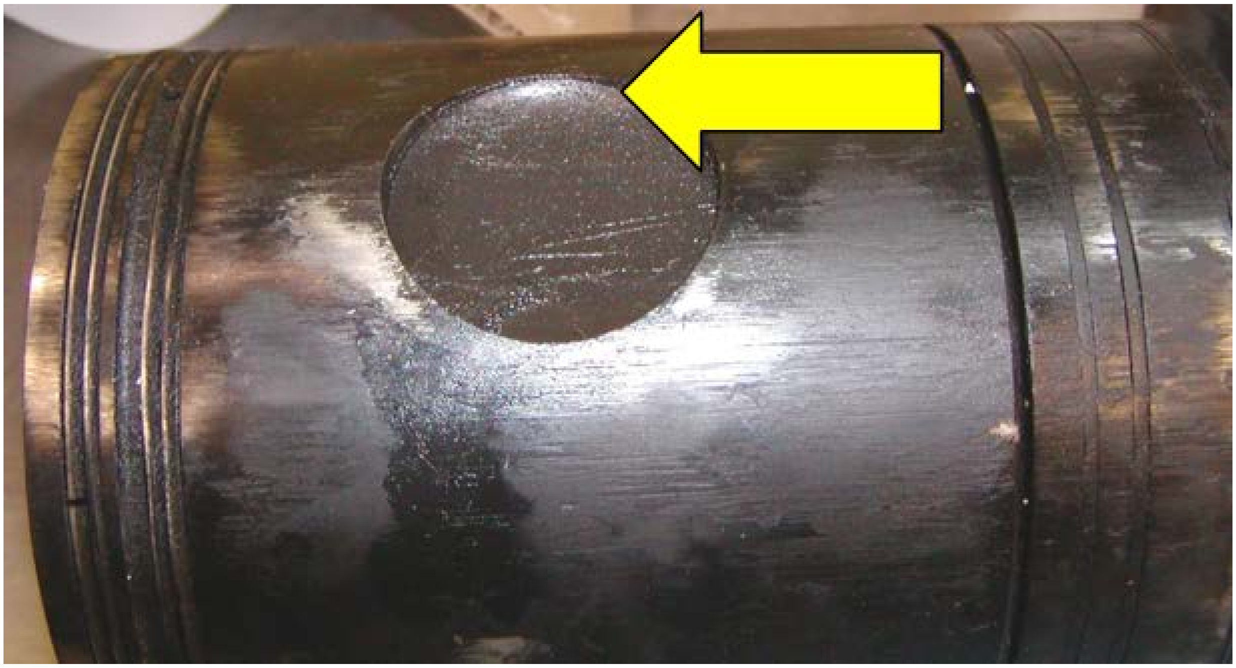
E. <u>Piston failures Due to Carbon Build Up</u>

The first two pictures show two piston crowns that have heavy deposits of carbon; with impressions of the valves are in the carbon buildup.

The next two pictures show the effects of carbon cutting and blow by on the compression rings.

F. <u>Piston failure due to improper assembly procedures</u>

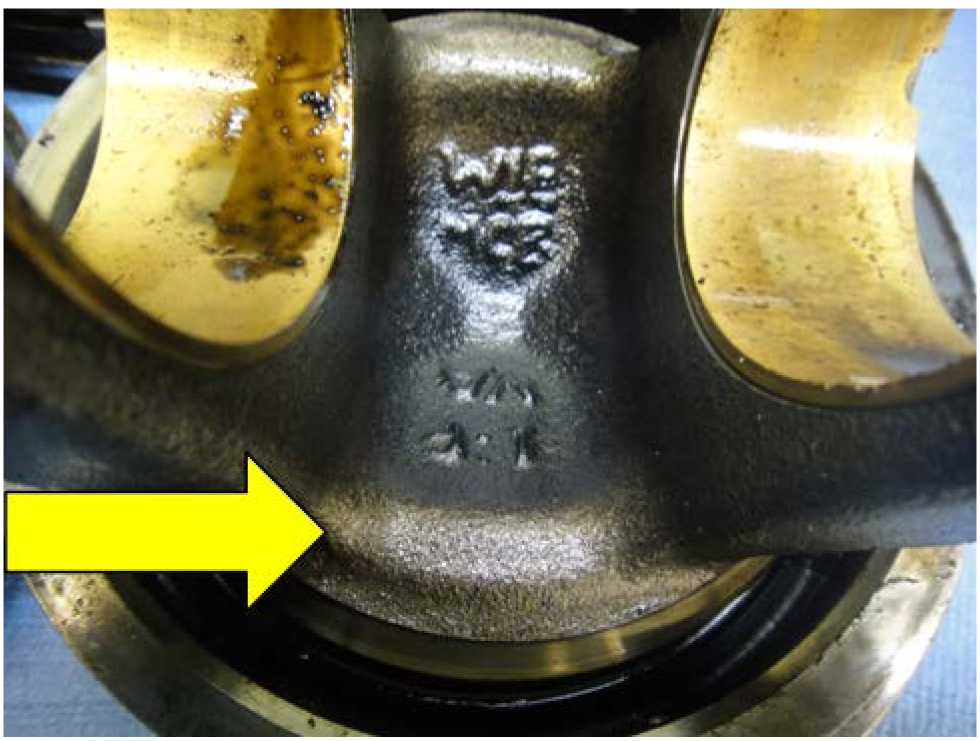
The pictures show the piston pin retainer bent on the edge and not fully seated in the recess. Cause of failure, leaking wrist pin retainers. Oil leaking from retainers overcame the piston rings and became an external fuel source. At the same time the oil loss reduced the flow of lubrication used in cooling the underside of the piston. The combination of both these conditions caused the extreme overheat and excessive thermal expansion of the piston, causing the piston and liner to make contact and seize.



G. <u>Piston failure caused from a severe over-heat</u>

The first picture shows the top of the piston crowns discolored from excessive heat.

The next picture shows the underside of one of the piston crowns burnt from over heat.



The tops of the piston crowns are discolored (blue) and the underside of the crowns are burnt. This is caused from severe overheat and lack of proper lubrication. The most likely cause of the failure is operating the engine with low oil pressure.

H. Piston failures caused by fuel injector problems

The following is an example of an uneven fuel injector spray pattern.

This picture shows crown edge breakdown caused by fuel injector spray outside of bowl. This is caused by a bad spray pattern or a timing error.

This piston failed due to a bad injector tip spraying fuel out of the combustion bowl and between crown and liner creating a hot spot that burned through the piston.

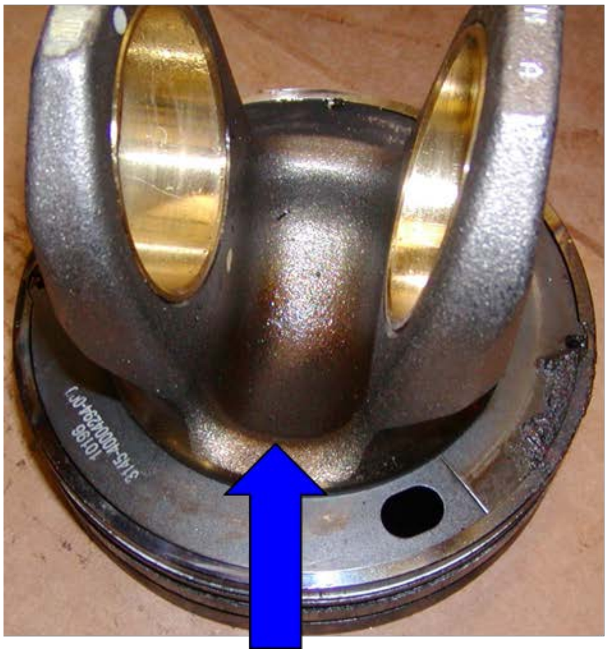
Piston below shows edge nibbling from a faulty injector spray pattern.

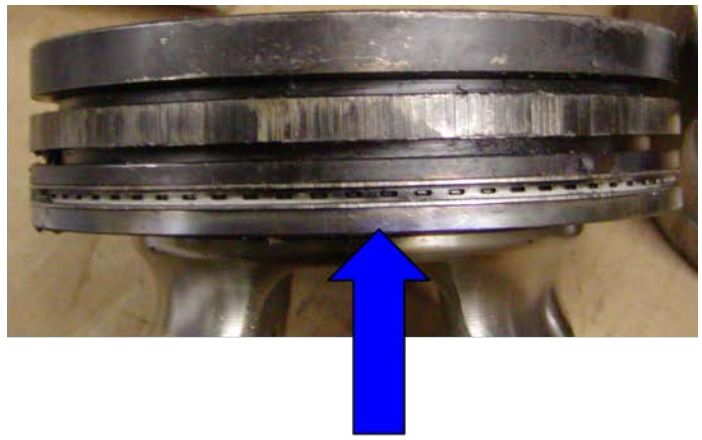
More extreme damage due to fuel injector failure

Final example of fuel caused failure.

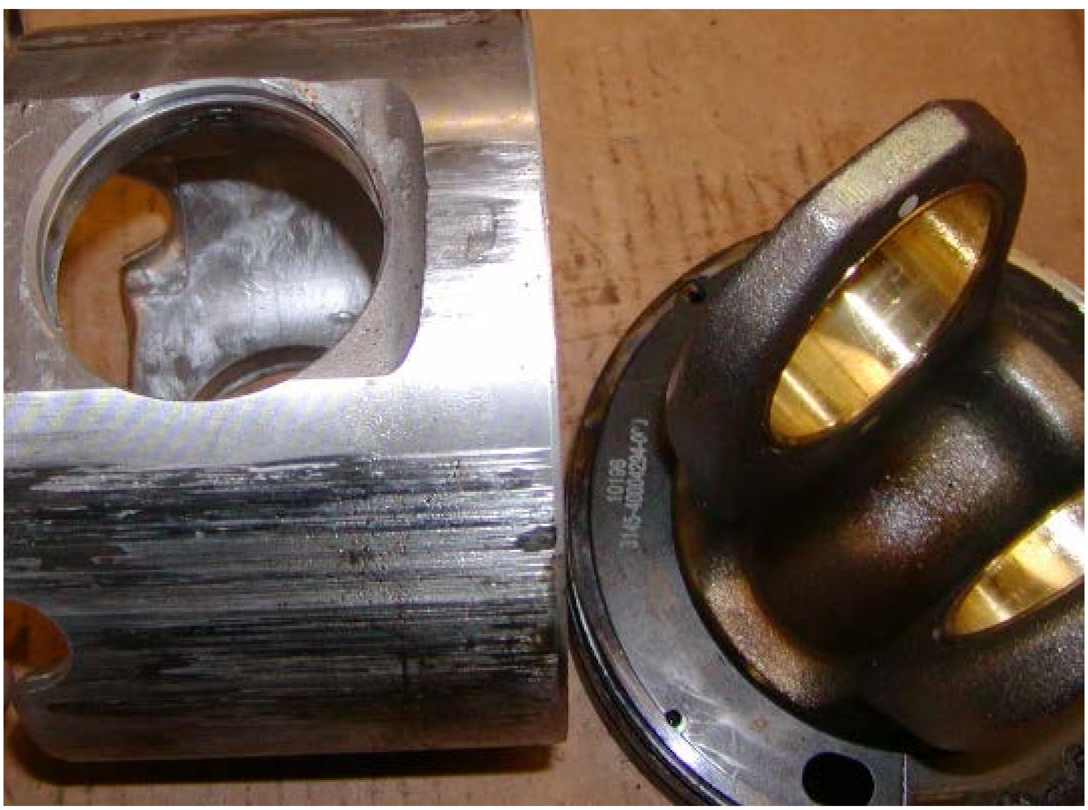
I. <u>Piston failures caused by incorrect timing</u>

The following pictures show the piston crown burnt on underside and blue in color from severe overheat. The cylinder kit failed due to overheat. A spray pattern could not be detected on the crown. The piston pin and bearing appear to have normal wear however the underside of the crown is burnt and the piston began to turn blue. This by itself would indicate low oil pressure. Another area that could cause overheat would be a timing issue. Valve marks on the crown of the piston indicate the root cause of this failure, incorrect timing.

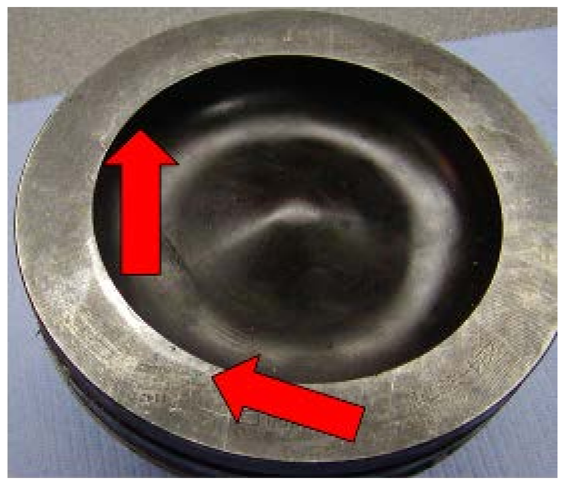




The next pictures show the piston skirt and liner scored from abnormal expansion.

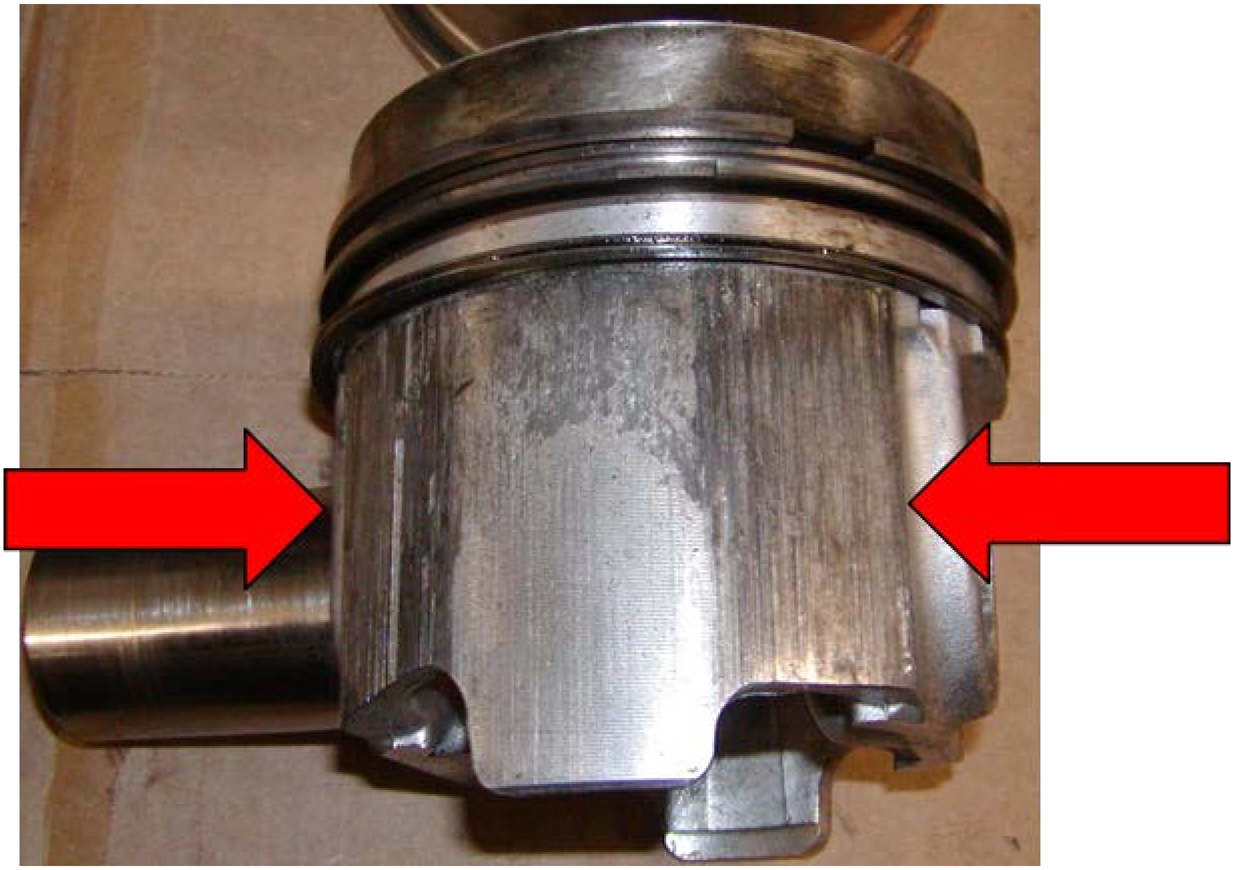


The final pictures will show valve contact marks on the crown of the piston.

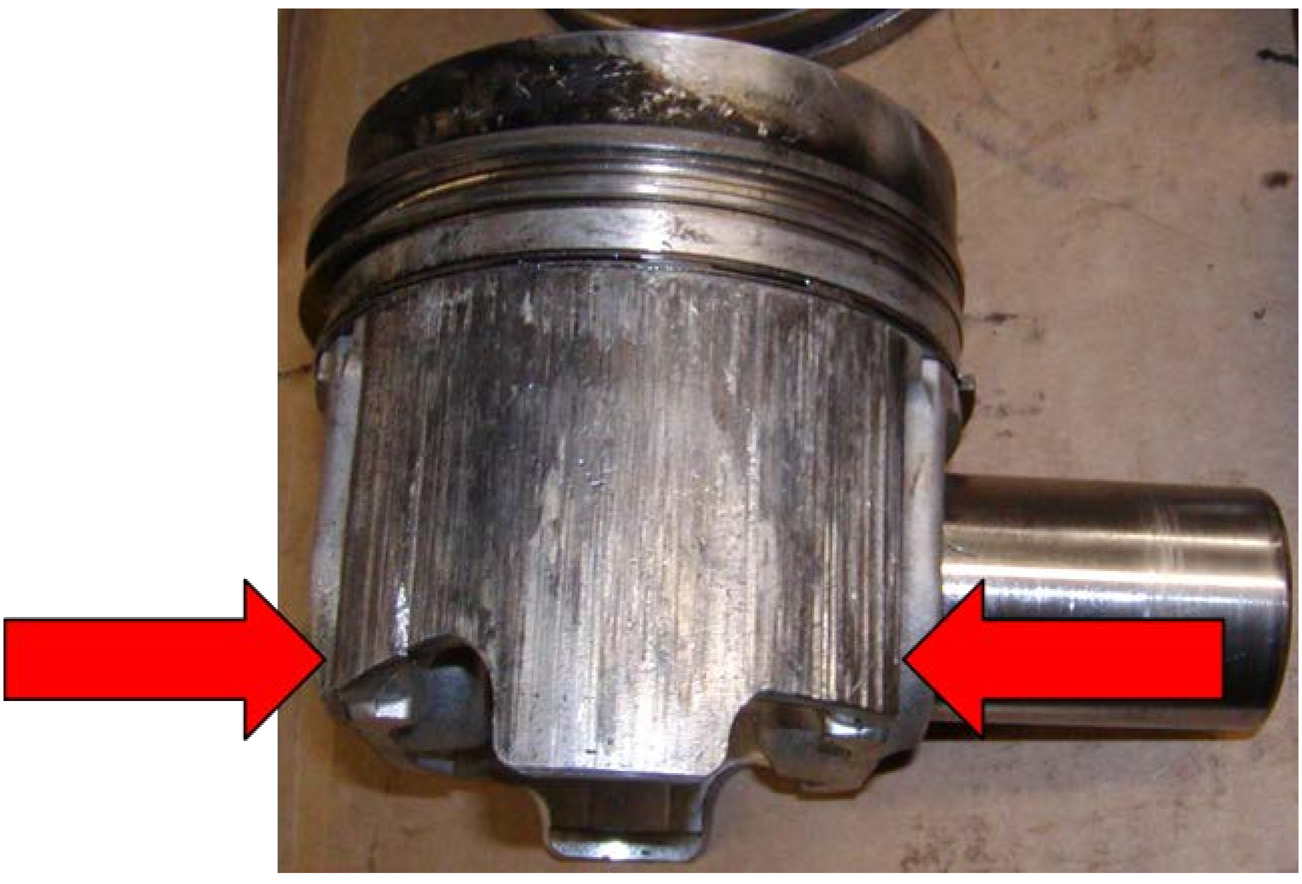


J. <u>Piston overheat quarter point scuffing</u>

The following pictures show quarter point scuffing. Pattern of fuel injector on top of piston appeared normal. The underside of the piston was clean with no burnt oil indicating that lack of lubrication was not the root cause. The most likely cause of failure points to the cooling system and the possibility of air entrainment.

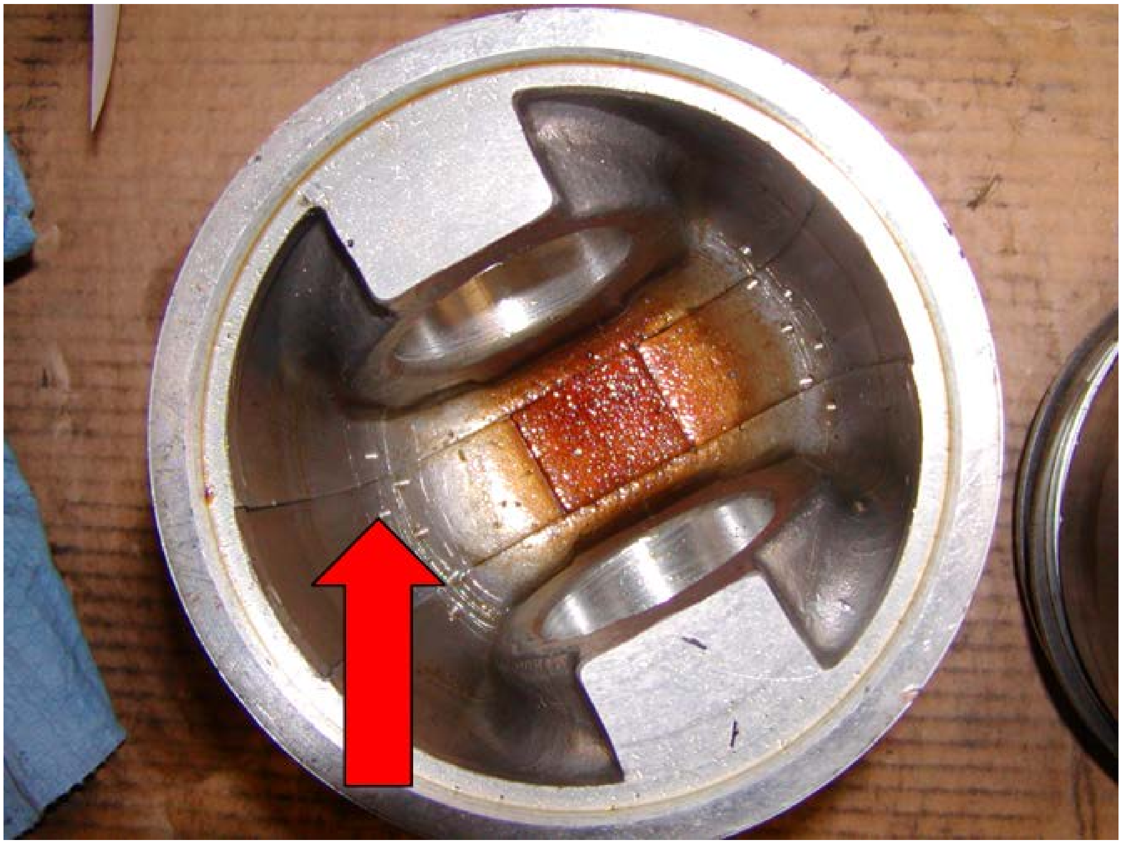


Thrust side of piston.

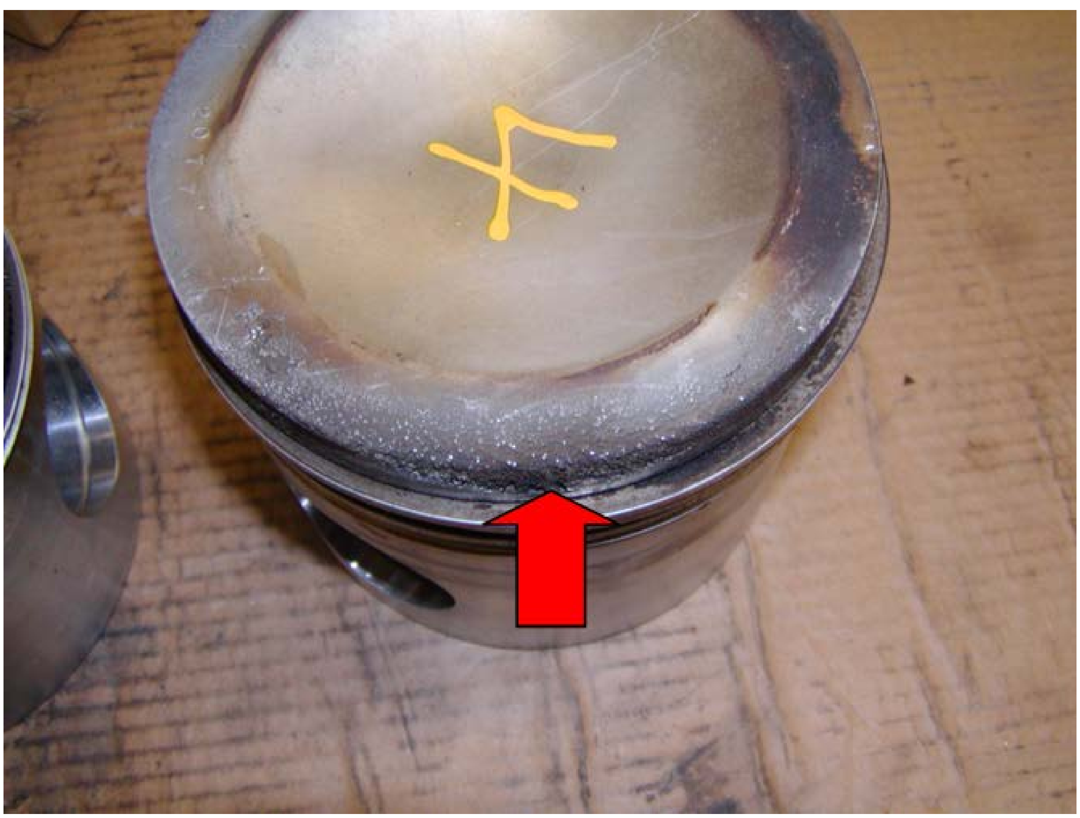


K. **Underside of piston crown burnt from high combustion temperatures**

Natural gas application - The picture shows discoloration of piston crown caused by excessive combustion chamber temperatures. In a natural gas application, this type of failure is normally the result of improper engine timing or incorrect fuel mixture.



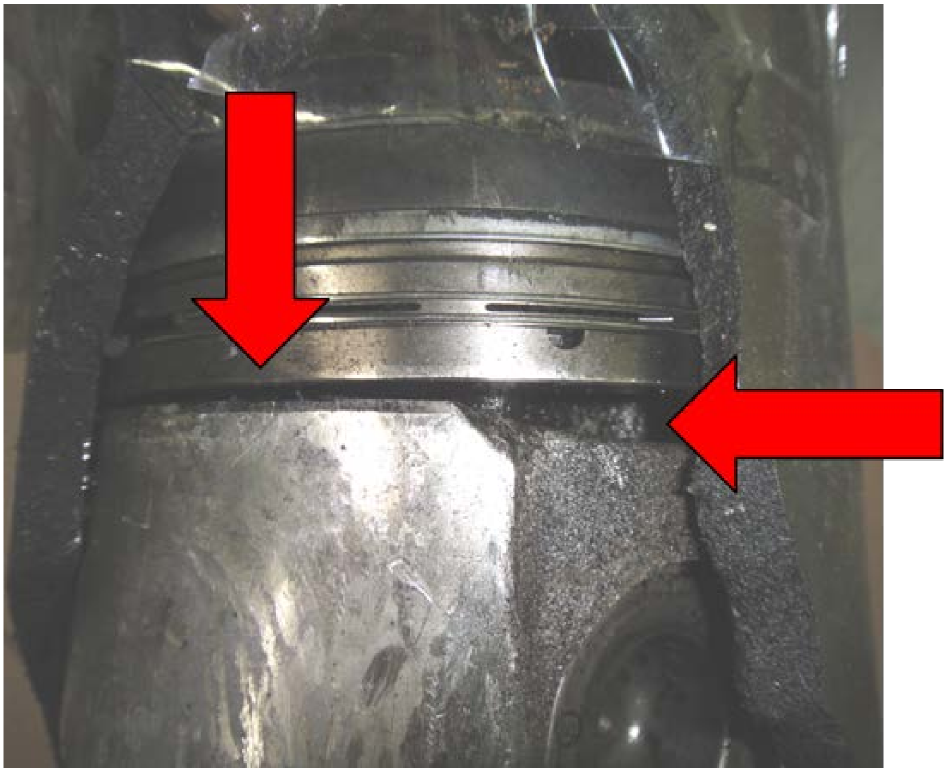
The picture below shows the piston crowns starting to melt from overheat.



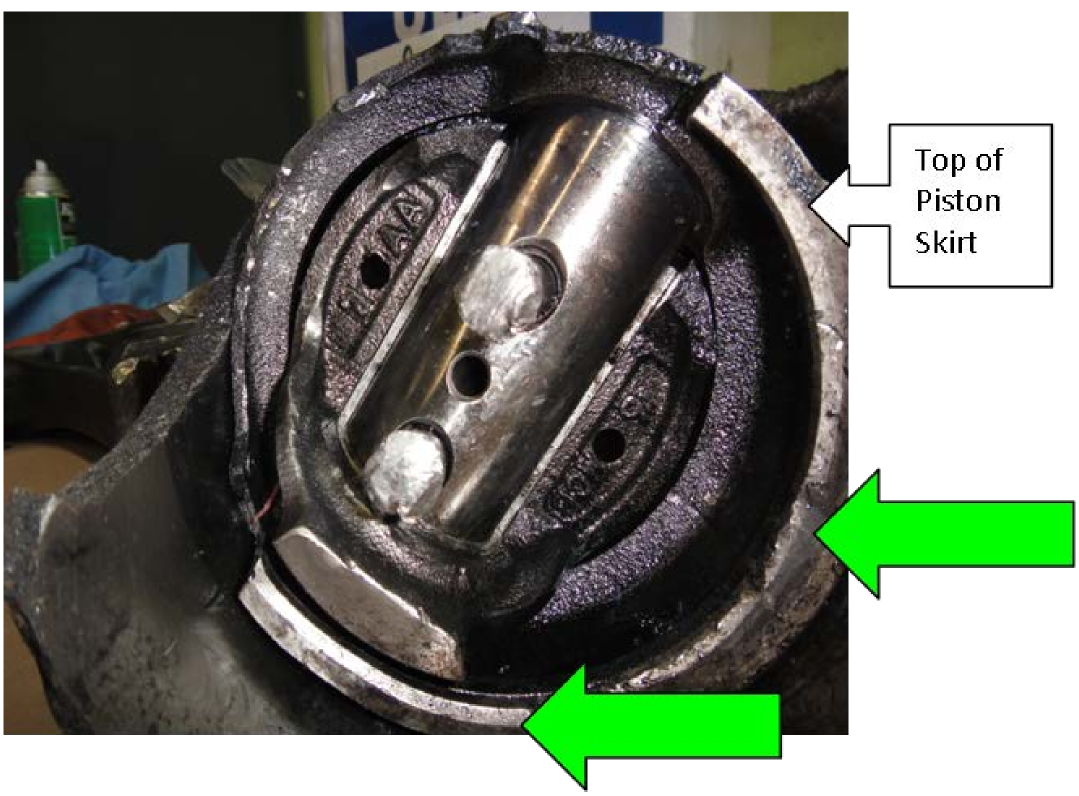
4.2 PISTON SKIRTS

A. <u>Piston skirt on upside down</u>

The following picture shows the piston skirt in the liner with the skirt on upside down. Red arrows point to bottom of skirt.



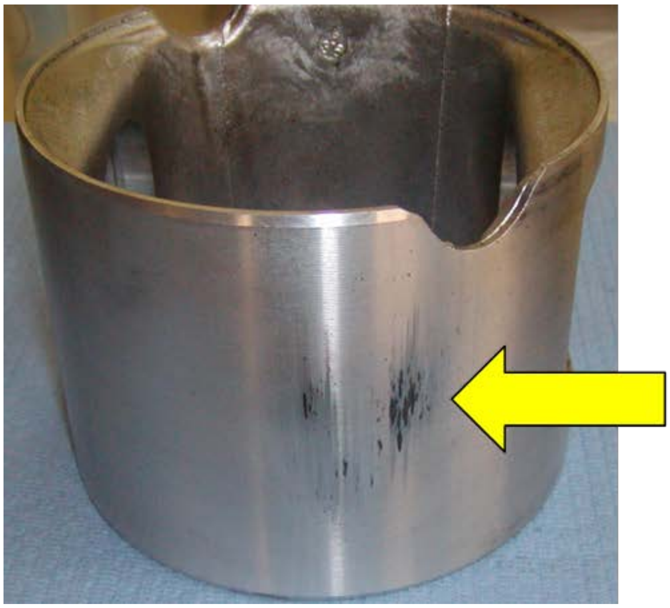
The next picture shows the bolts broken in the piston pin and the top of the piston skirt pointing down.



Conclusion: The cause of failure is assembly error. Piston skirts were installed upside down on the pistons. When installed in this manner the skirt can make contact with the crankshaft throws. This will place excessive loads on the connecting rod retaining bolts causing them to fracture.

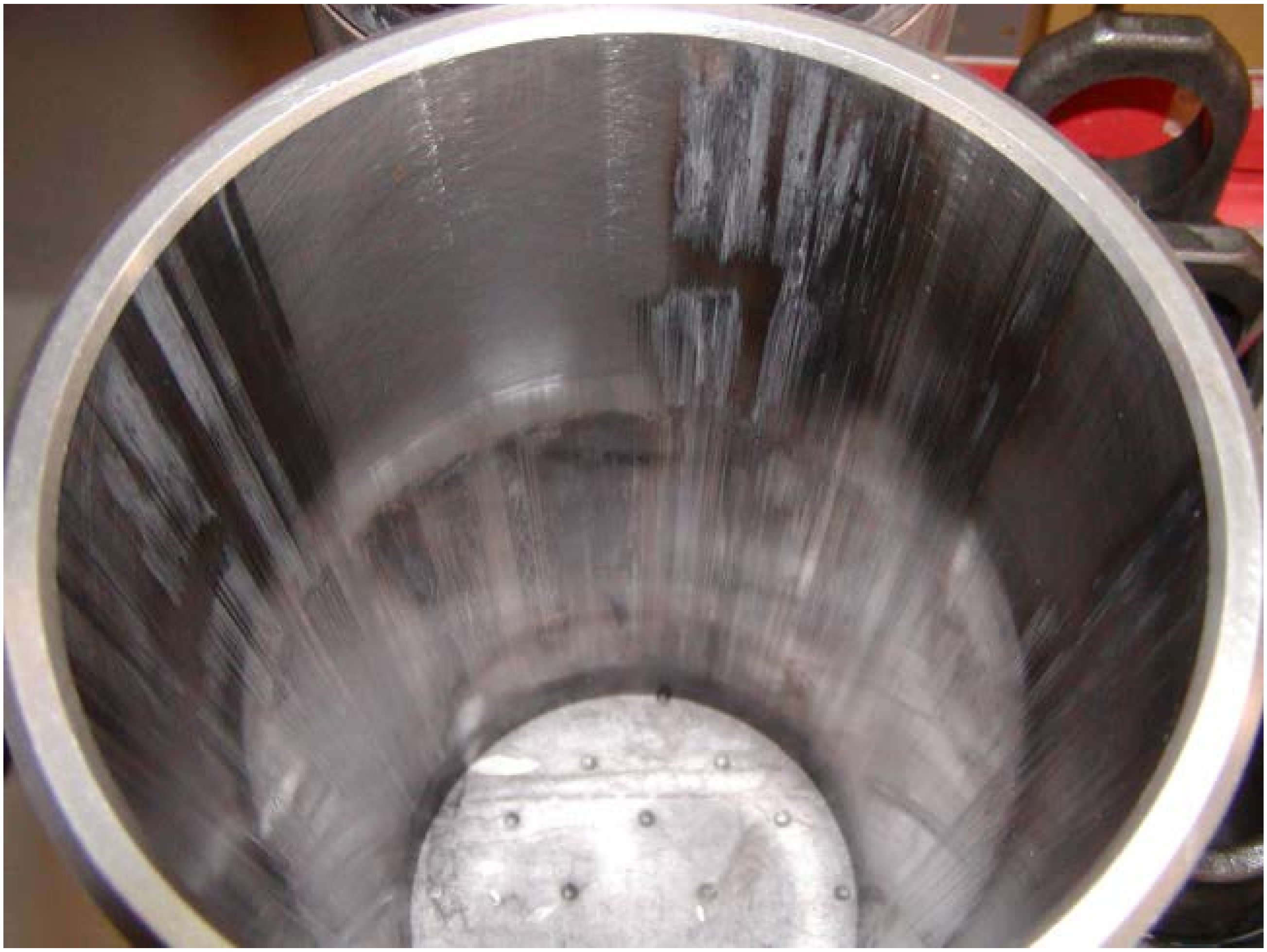
B. <u>Piston skirt scuffing caused by low coolant level</u>

The following pictures show scuffing on piston skirts. The first two pictures show light scuffing on the major thrust side of the skirt and only a few scratches on the minor side.




The next picture shows both sides of the piston showing heavy scuffing.


The final picture is the inside of the liner showing 360 degree scuffing on the upper half of the liner and the quarter point on the lower half. Liner is upside down in this picture.

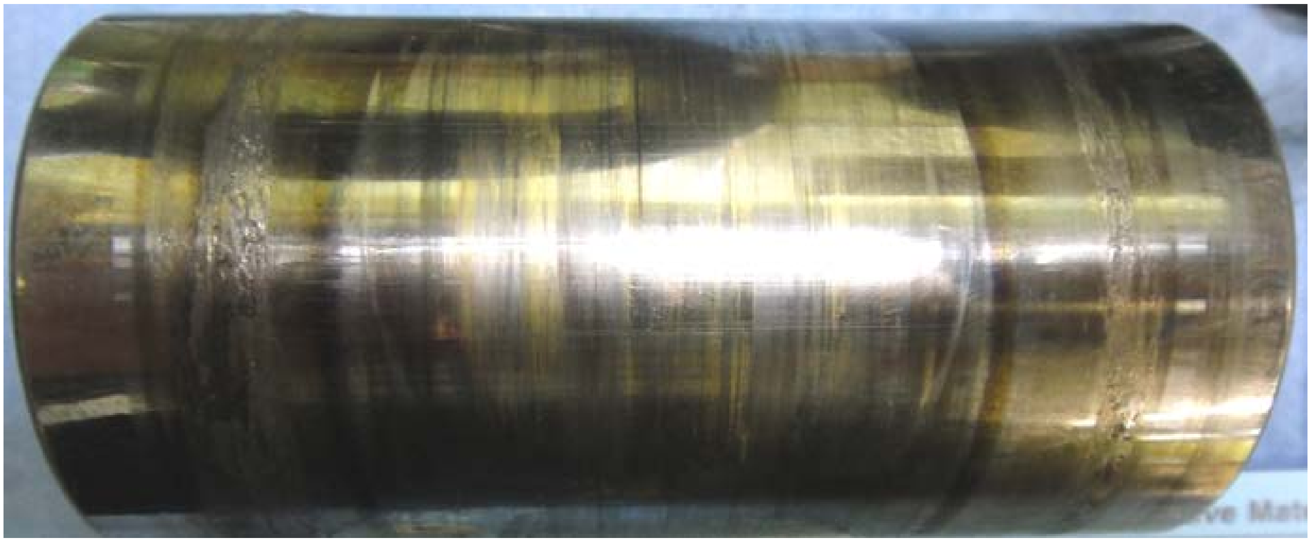


Conclusion: Both failures are caused by overheat. The most likely cause of the scuffing is low coolant.

4.3 PISTON PINS

A. <u>Piston pin failure caused by lack of lubrication</u>

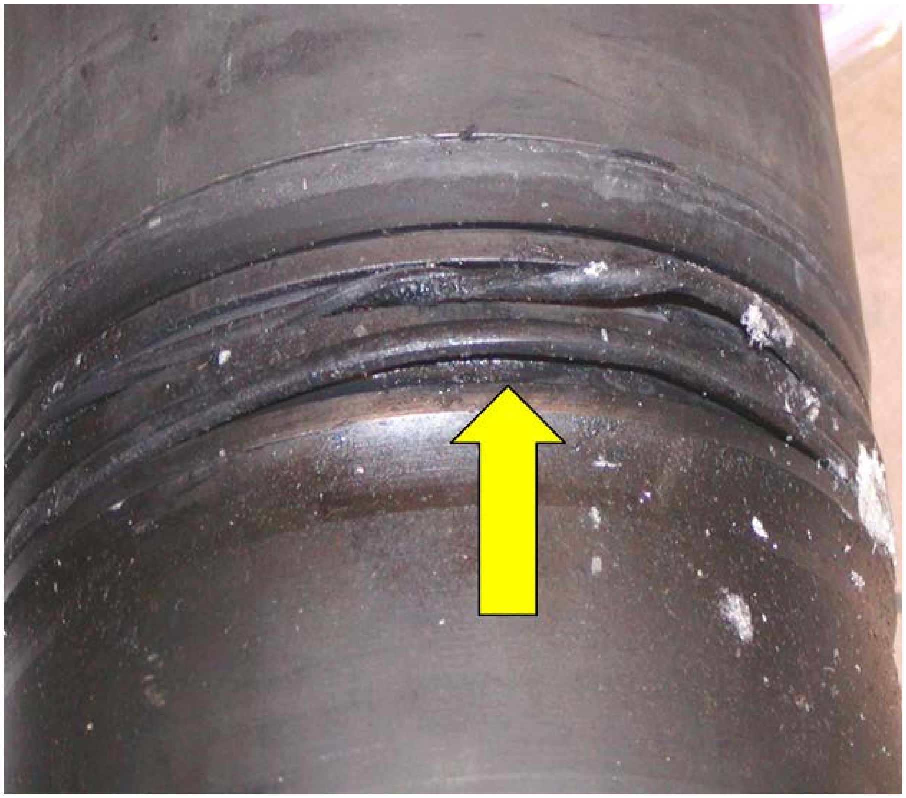
Lack of proper lubrication is cause of the galled and worn piston pin.



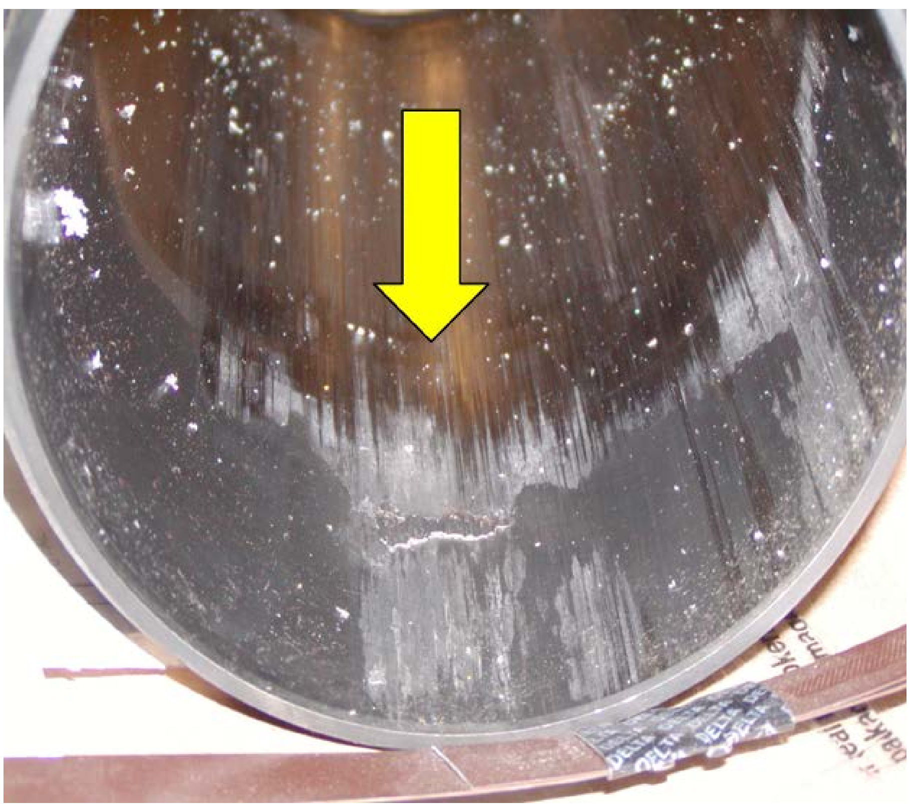
4.4 LINERS

A. <u>Cylinder kit failure caused by twisted liner o-ring</u>

The picture shows one of the liner o-rings that twisted during assembly in engine.



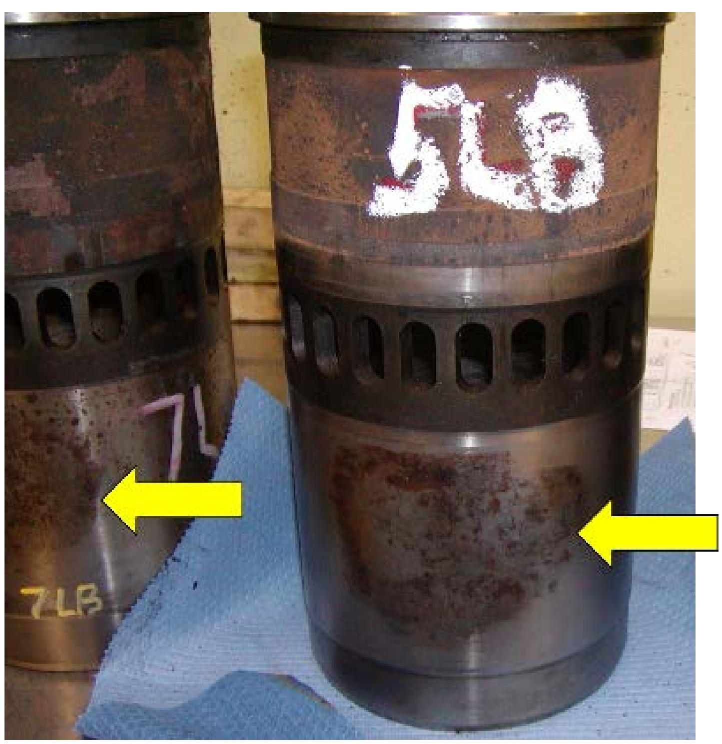
View of inside of above liner shows a buildup of transferred skirt material at bottom of liner caused by the o-ring forcing the liner inward.



The final result of the twisted o-ring

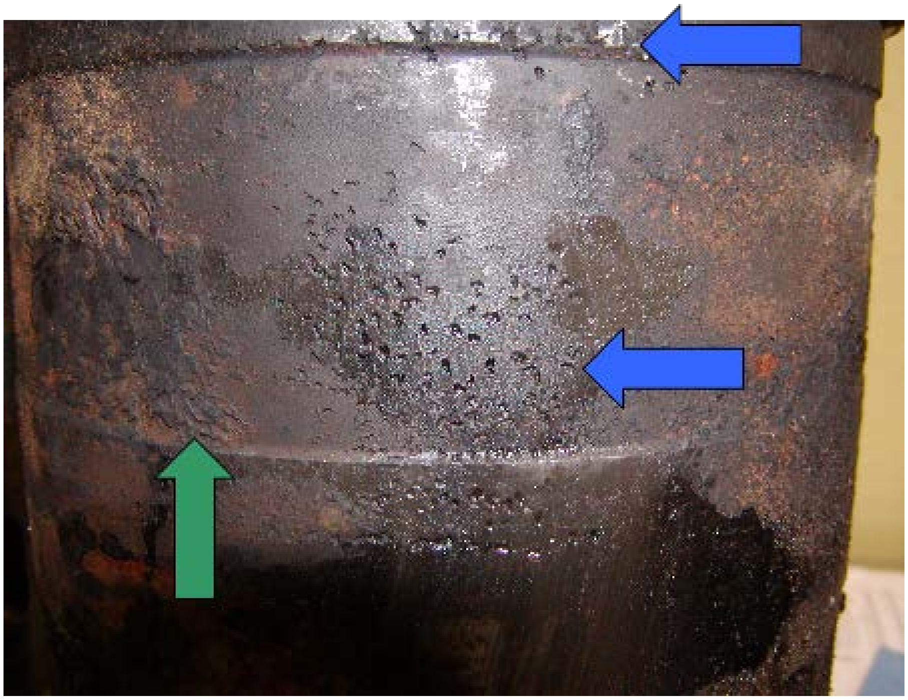
B. <u>Cylinder kit failure due to maintenance and assembly errors</u>

The first picture is of two liners from a 16V149 Detroit Diesel marine engine. Note the presence of heat spots on the lower area of the liners as pointed out with the yellow arrows.



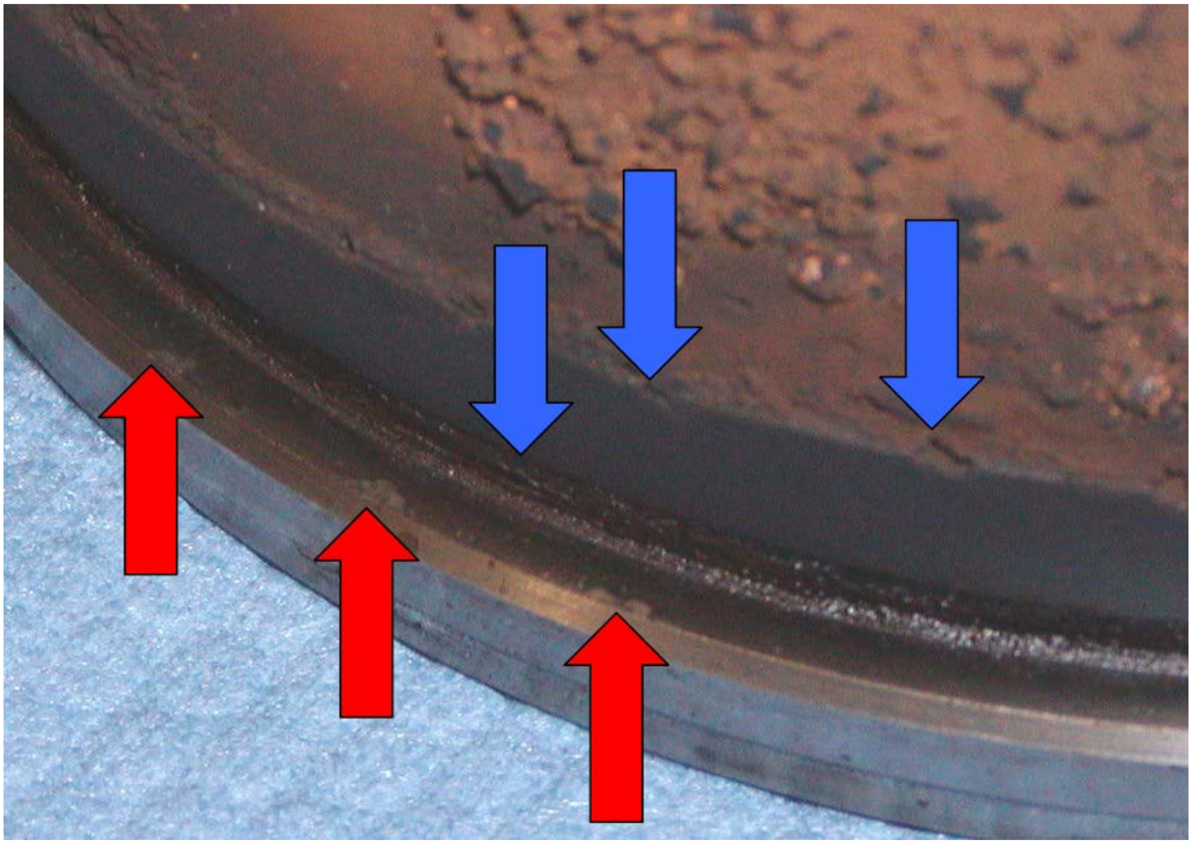
Heat spots occur when there is excessive clearance between the liner and the block. This area will have very poor heat transfer and will allow for liner movement and distortion. This can cause the liner to crack in the port area or other locations on the liner where stress loads exceed design strength.

The next picture shows the pitting (blue arrow) and scale build up (green arrow) on one of the liners.

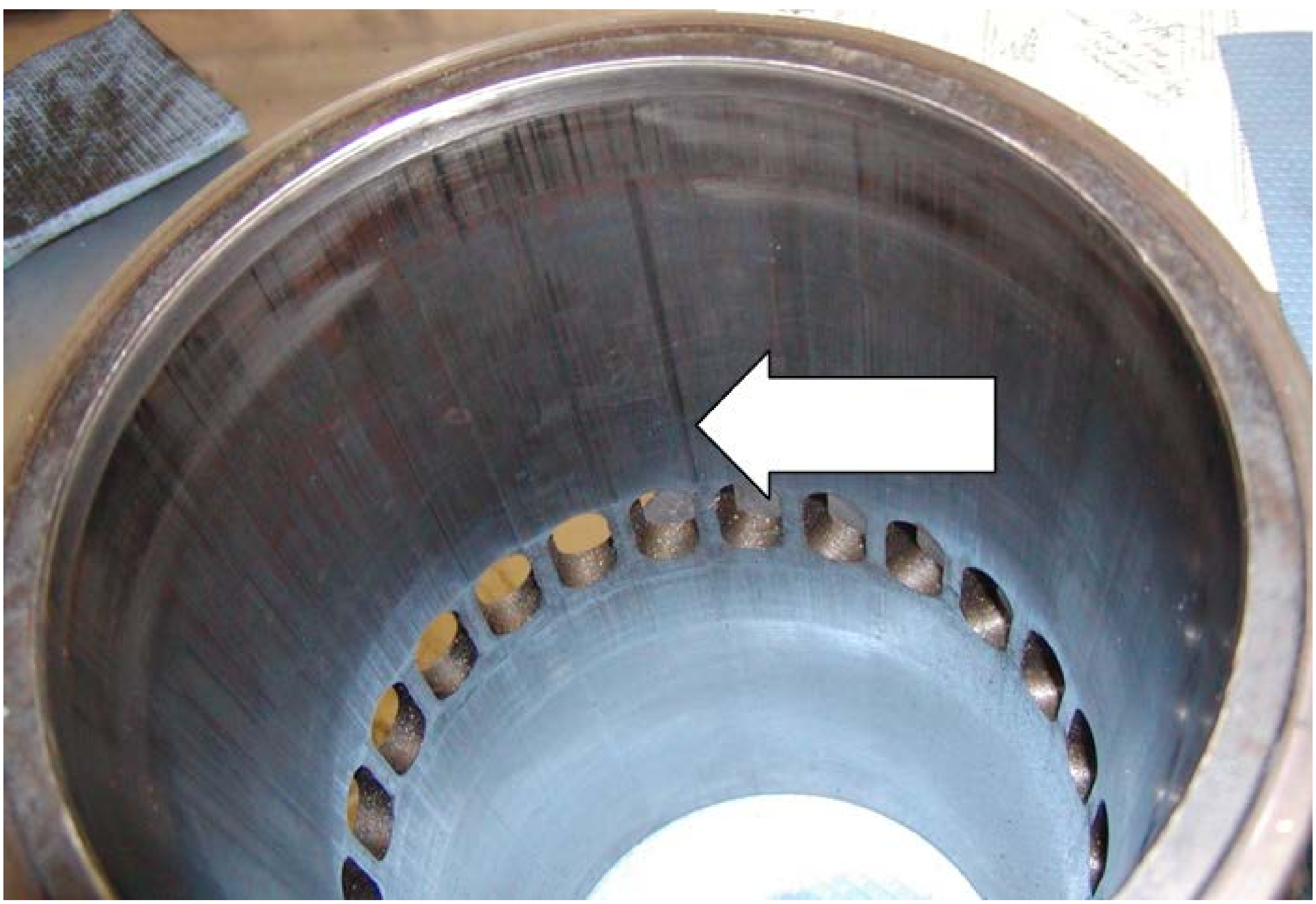


Pitting and scale build up is a clear indication the cooling system has not been maintained and no additives or corrosion inhibitors were used. Scale build up will affect heat transfer and cause higher than normal cylinder temperatures potentially leading to scoring and premature failure of cylinder components. The pitting can and will cause stress risers to develop in the liner potentially leading to cracks and premature liner failure.

The next picture shows the underside of the liner flange in front of the fractured area of #5 left bank liner. Note the pits (blue arrow) and the four clean marks indicating foreign material was trapped between the flange and the block (red arrows).



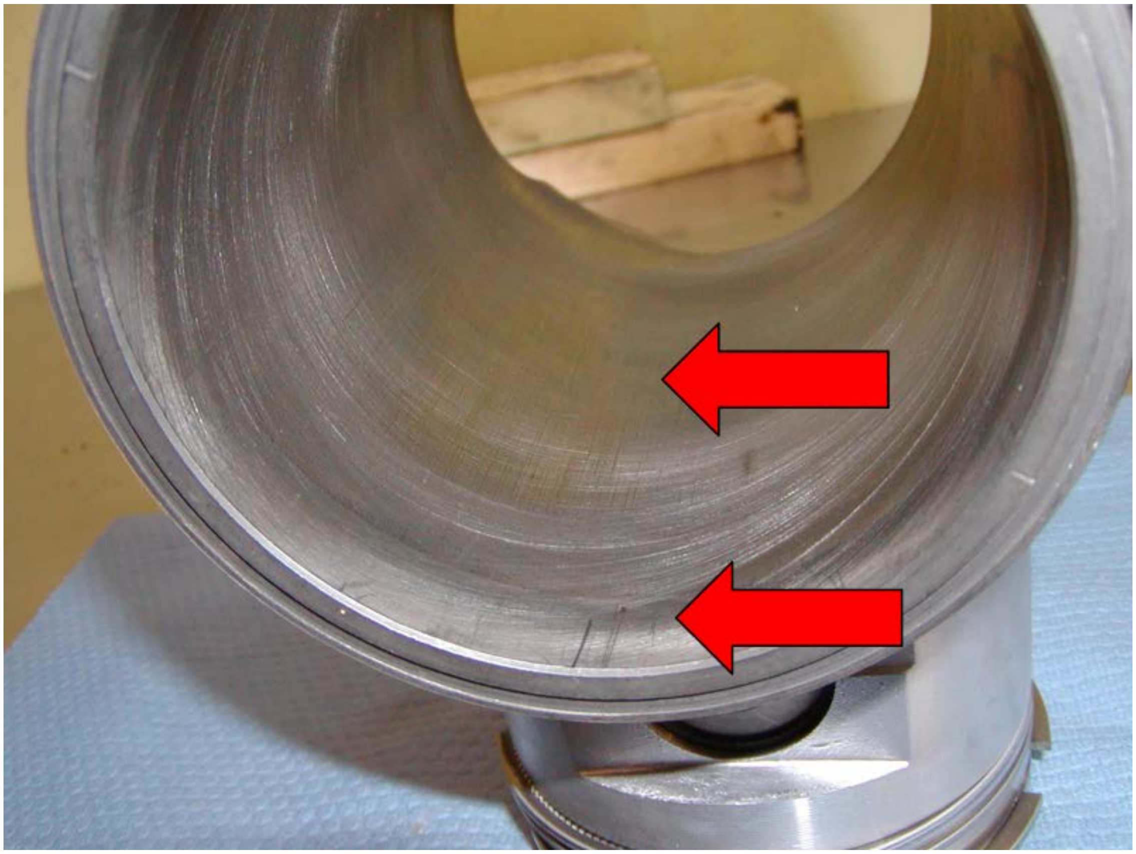
The next picture shows the score marks inside one of the liners (white arrow). Scratches and some scoring is present in most of the liners.



The final picture shows the crown and rings on one of the pistons; all the pistons are similar in appearance. The white deposits are caused by additives in the oil. A perfect seal between the piston rings can never be achieved, thus a certain amount of engine oil will enter the combustion burn. As the engine oil enters the combustion chamber and burns, residue forms an ash-like material. This ash-like material contributes to deposits in the crown land above the piston ring as well as to deposits in the ring grooves. These deposits can lead to rubbing wear on the cylinder liner causing the piston rings to cease operate freely. Ultimately, the cylinder liner-to-ring interface is compromised and high oil consumption can occur.

C. <u>Excessive blow-by caused by abrasive contamination during assembly</u>

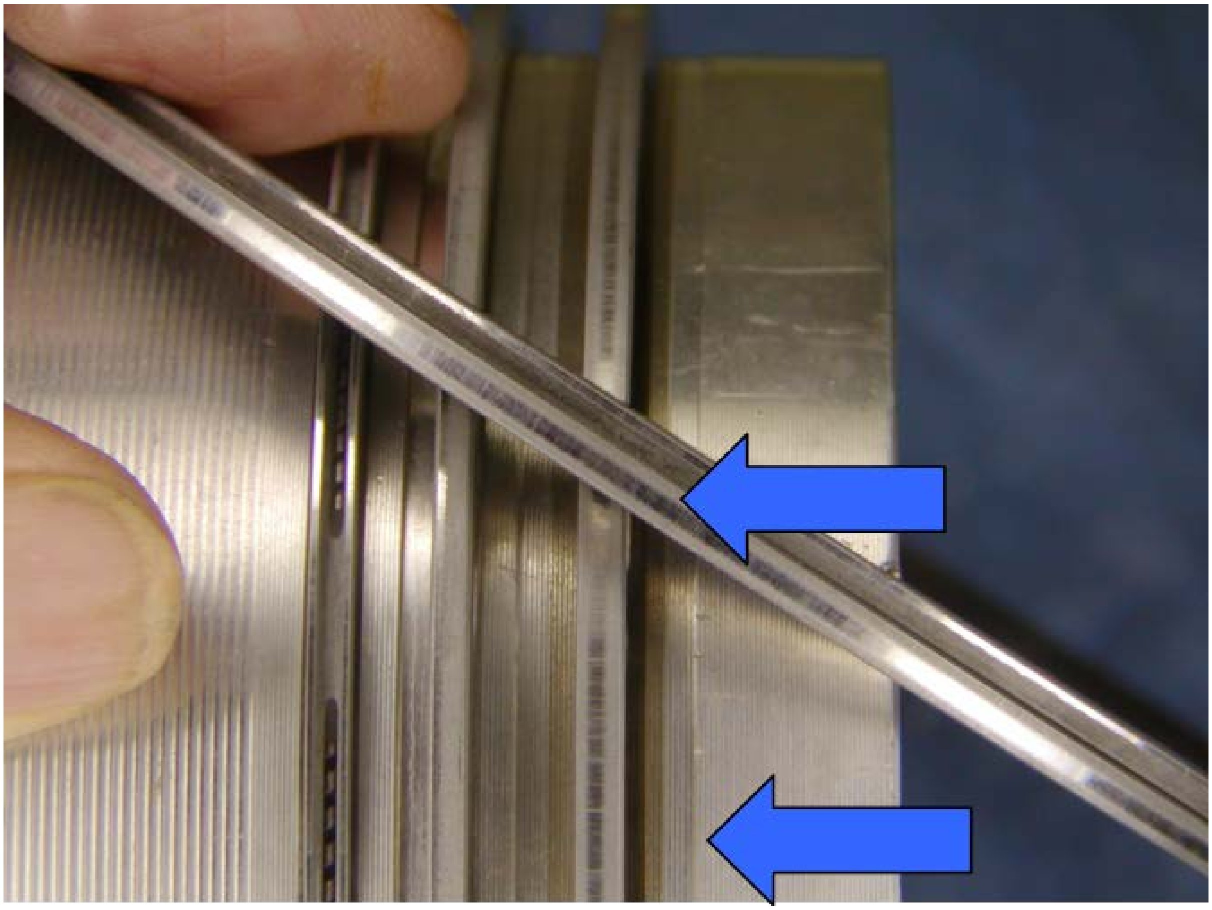
The following pictures show the liner, piston with rings attached, and a set of piston rings that were marked: “original ring set”. After the original rebuild the customer complained of excessive blow-by. He disassembled the engine, honed the liners and installed new rings. Upon start up the engine was found to have excessive blow-by.

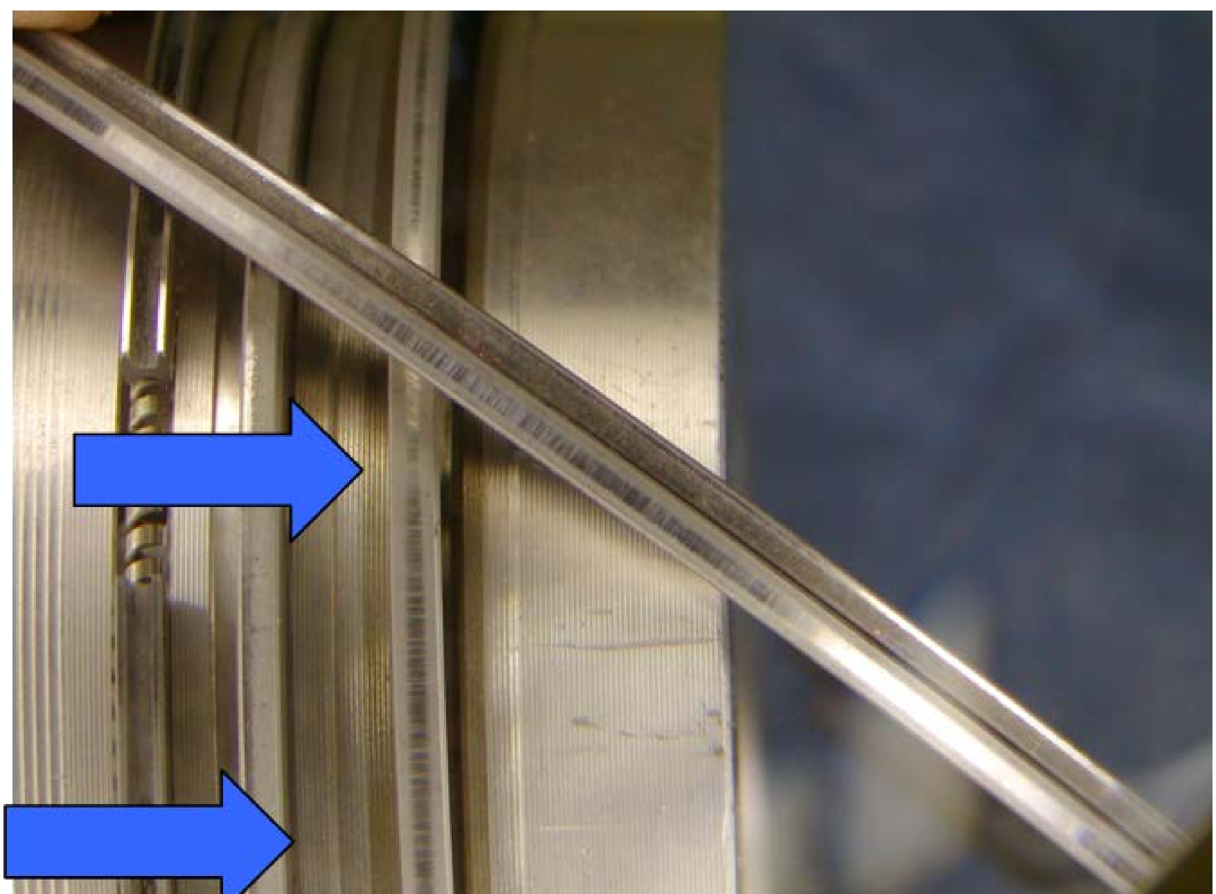


The above picture of the liner shows deep scratches from abrasive foreign material causing a path for blow-by. This is caused by lack of cleanliness during assembly of the engine. The liner also shows where it was honed. The honing angle or cross hatch is not uniform. This will cause uneven wear.

More pictures of foreign material scoring.

The next group of pictures will show the rings marked "original ring set" set on top of the piston that has the rings installed. Please note the heavy scratch marks on both sets of rings.

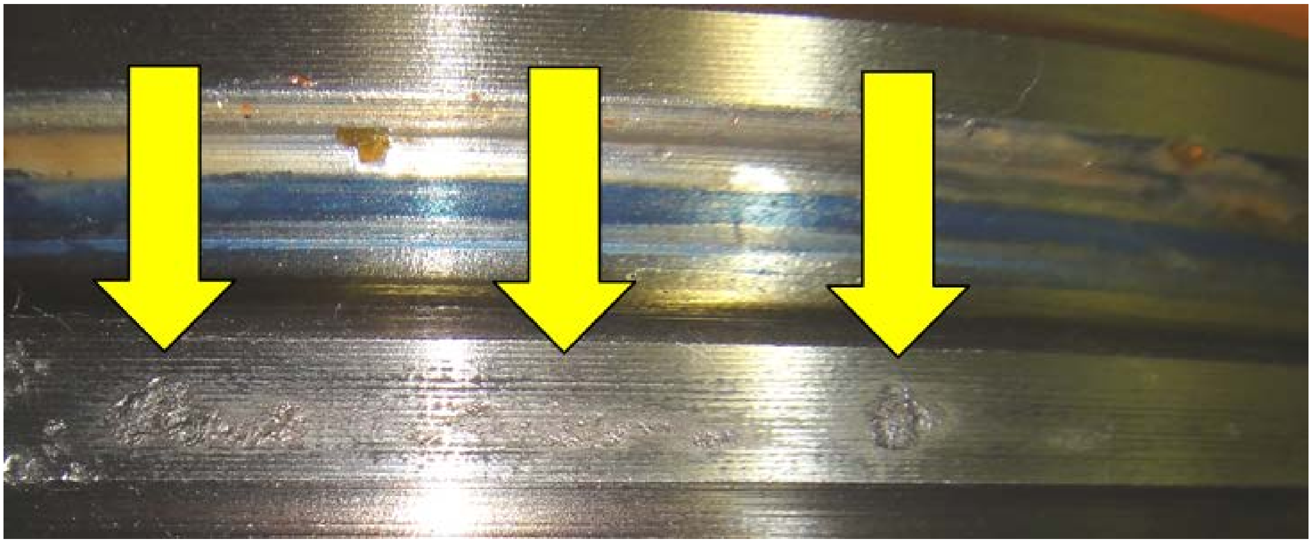




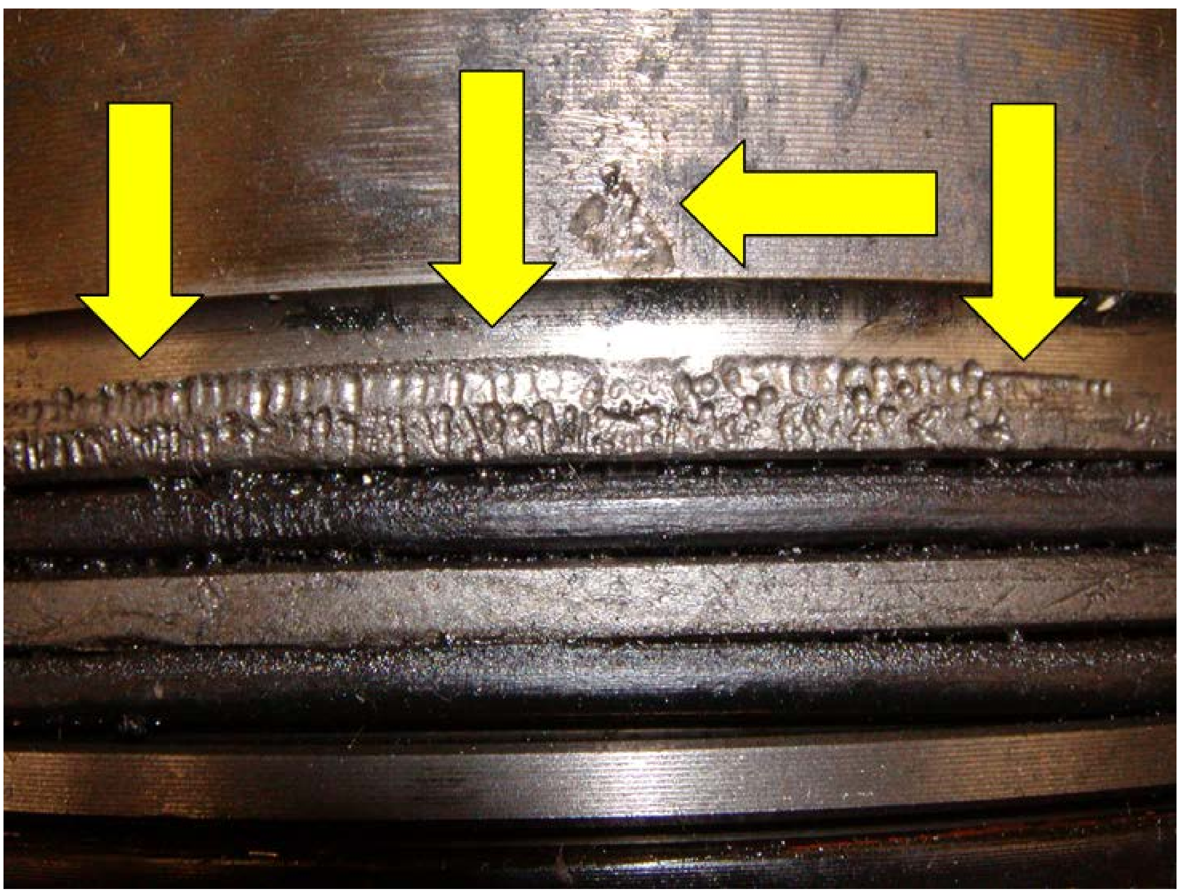
The root cause of failure was caused by foreign material contamination due to poor assembly practices and procedures. The contamination caused blow-by in the first set of rings was not corrected and caused the same failure condition in the second set of rings.

D. Flange failure causes

The lower part of the liner has fretting where it interfaces with the lower receiver bore in the block. Lack of support allowed the liner to move, eventually causing the liner flange to fracture.



An example of severe fretting on the lower part of the liner



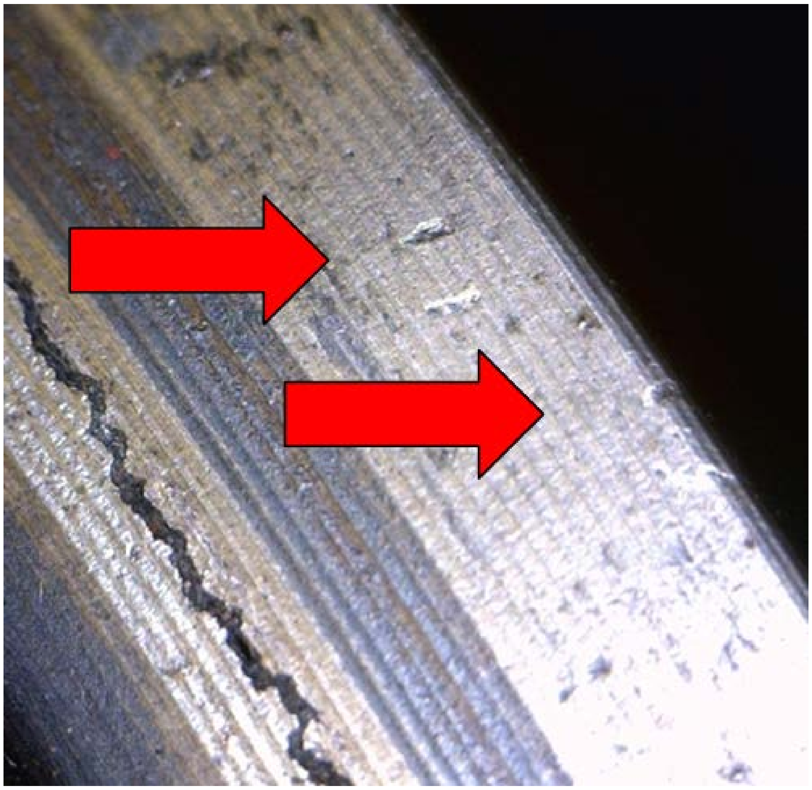
Liner flange failure caused by uneven mounting surface.
The flange is intact and has broken free of the liner. The under side of flange displays an uneven contact pattern. The un-even wear pattern on the under side of the flange indicates mating block surface is worn and caused the failure.

E. Improper cooling system maintenance

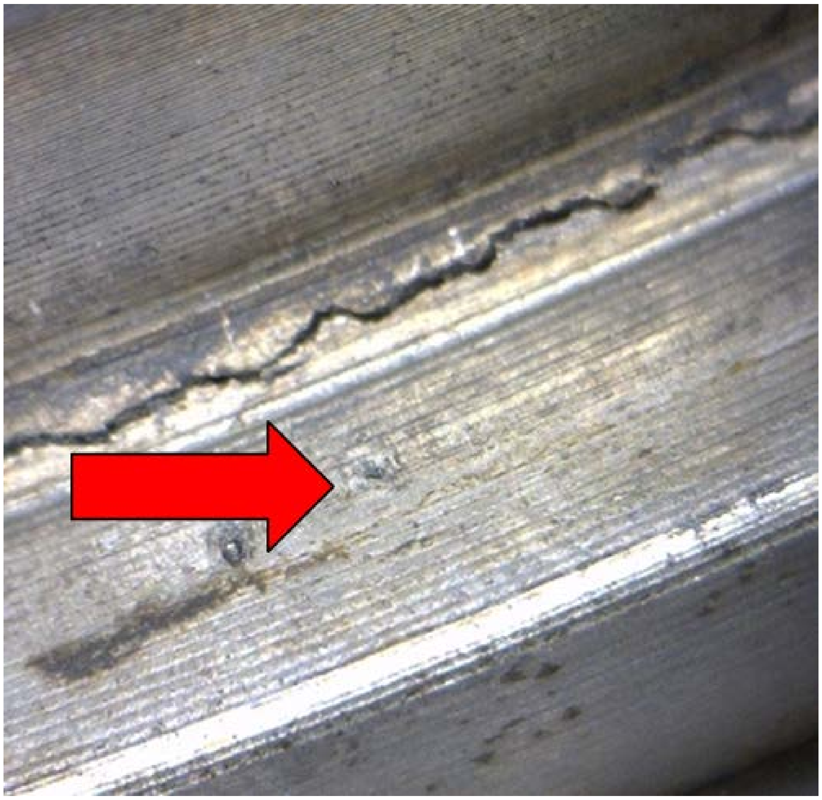
The liners in this engine failed within 800 miles. Improper cooling system maintenance is the root cause of failure. Cooling system corrosion inhibitors are needed in all situations even if antifreeze is installed. This liner was subjected to plain water with an extremely high mineral content.

F. <u>Liner flange breakage caused by foreign material trapped under or on top of flange</u>

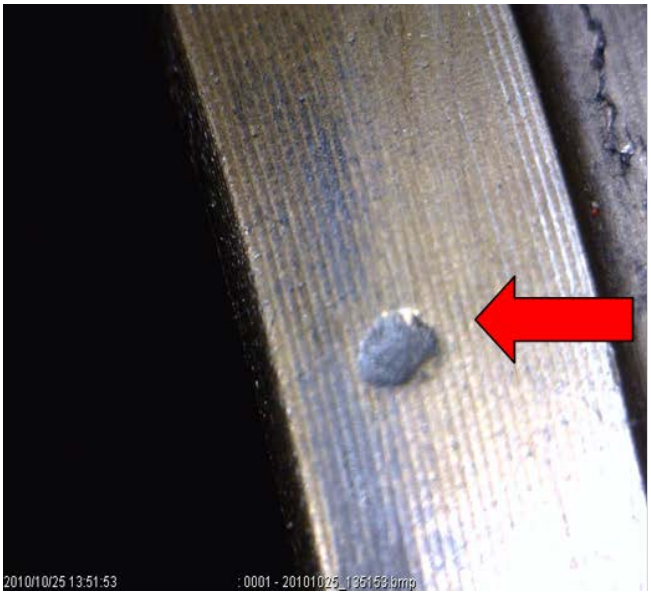
The impressions on the liner flange are from trapped foreign material between the liner flange and the cylinder head.

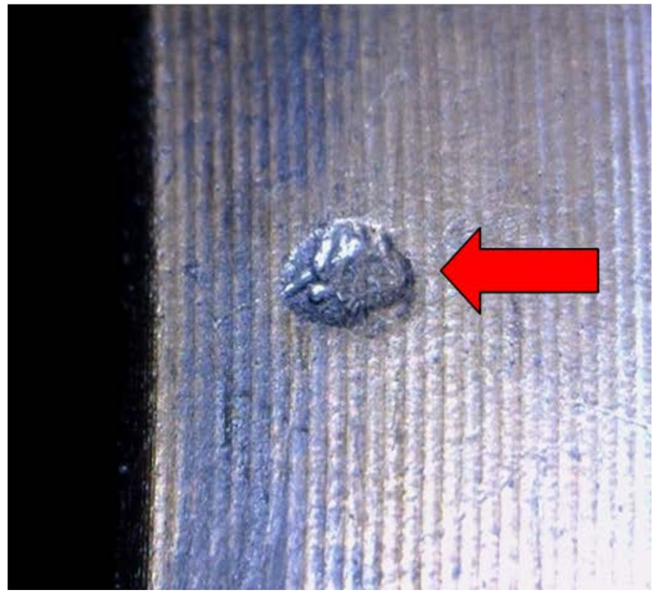


Foreign material trapped between the liner flange and the block surface.



The impressions on the liner flange are from trapped foreign material between the liner flange and the cylinder head.





F. <u>The effects of poor cooling system maintenance</u>

The pitting caused coolant to leak into the cylinder.

Corrosion shortens engine life and damages cooling system components. The complaint sent in with this liner was leaking liner seals.

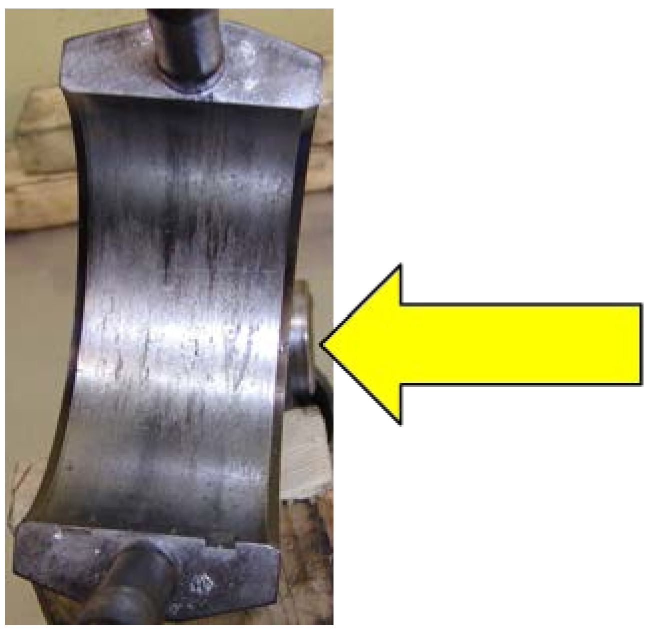
Rust causes poor heat transfer and engine overheat.

4.5 CONNECTING RODS

A. <u>Cylinder kit failure from lack of proper lubrication</u>

The first two pictures show the spun connecting rod bearings.

The next picture shows the lower part of the connecting rod that holds the rod bearing. Note the rod is not drilled for an oil feed hole to the piston pin.

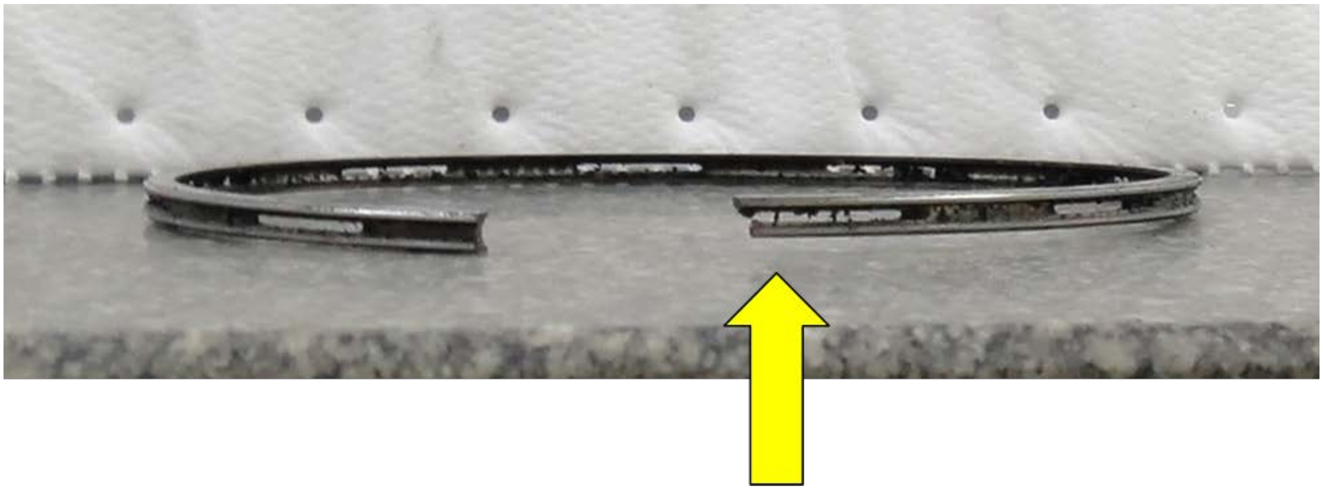


The connecting rod was not up dated at time of overhaul to the recommended drilled rod. The rod bearing failure was caused by lack of proper lubrication.

4.6 PISTON RINGS

A. <u>Broken oil control ring caused by assembly error</u>

The following picture shows the broken oil control ring positioned on a granite flat surface. Note the upward bend on the broken side of the ring.



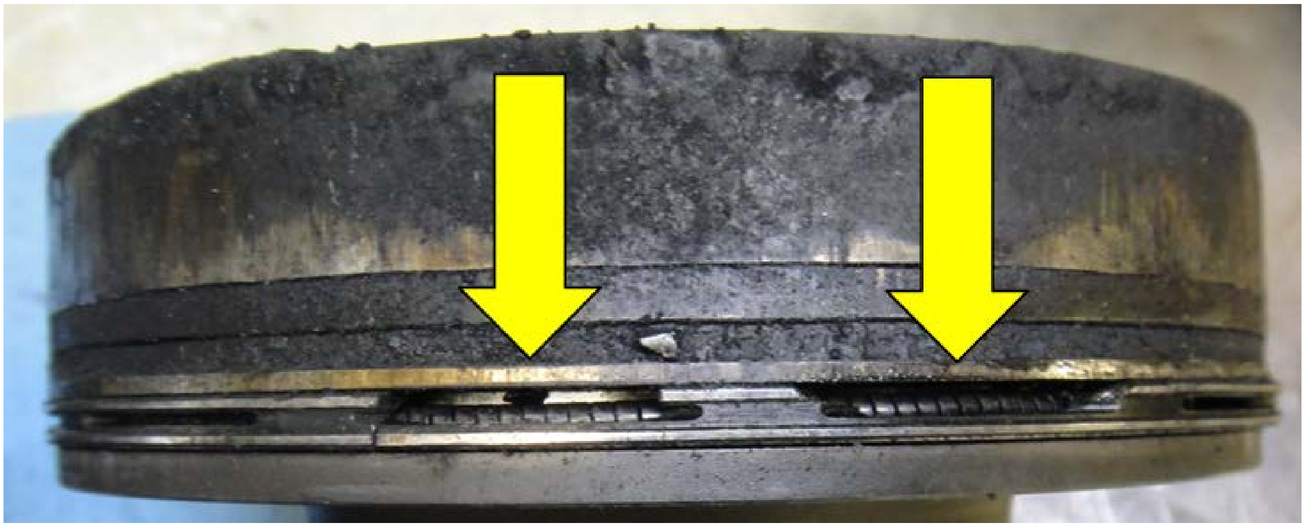
The cause of failure would be the ring not being sufficiently compressed and was damaged during installation.

B. <u>High crankcase pressure caused by rings not installed correctly</u>

Rings not installed correctly allow a combustion path to the crankcase causing high crankcase pressure "blow by" and loss of power.

C. <u>High oil consumption caused by broken oil control ring</u>

The picture shows the oil control ring broken in several areas (yellow arrow). The most likely cause of failure would be the ring was damaged during installation.

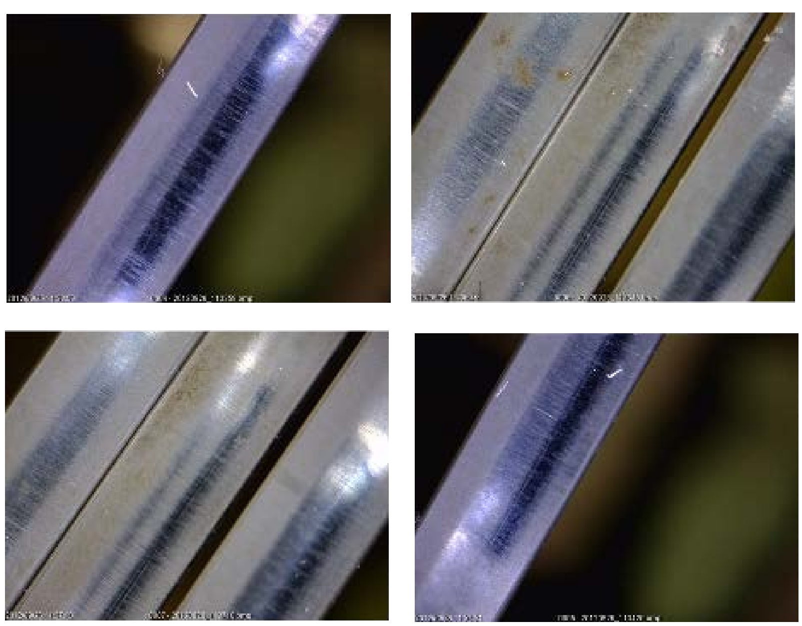


D. <u>Ring failure caused by abrasive contamination</u>

Claim: Excessive oil consumption.
Observations-4 ring sets were examined for possible cause of excessive oil consumption. The top compression ring and intermediate rings were examined under magnification. During the inspection process, noticeable vertical scratching of the ring faces was found. Scratching of the ring faces will cause incomplete sealing of the power cylinder and can cause excessive oil consumption.

Possible causes of this type of condition:
1) Leaks in the air intake system.
2) Abrasives in the engine oil.
3) Poor cleanliness during assembly.

No manufacturer defects were observed in the inspection process.



4.7 PISTON PIN RETAINERS

A. <u>Piston pin retainer improperly installed</u>

The pin retainer came loose and severely damaging cylinder kit.

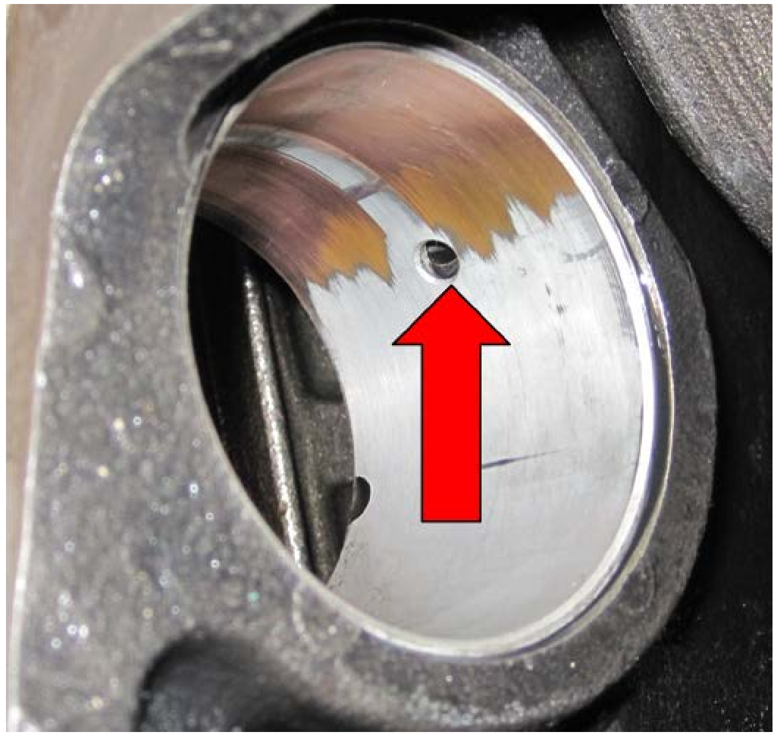
5.1 CAMSHAFT BEARINGS

A. <u>Camshaft bearing journal wear caused by uneven bearing support</u>

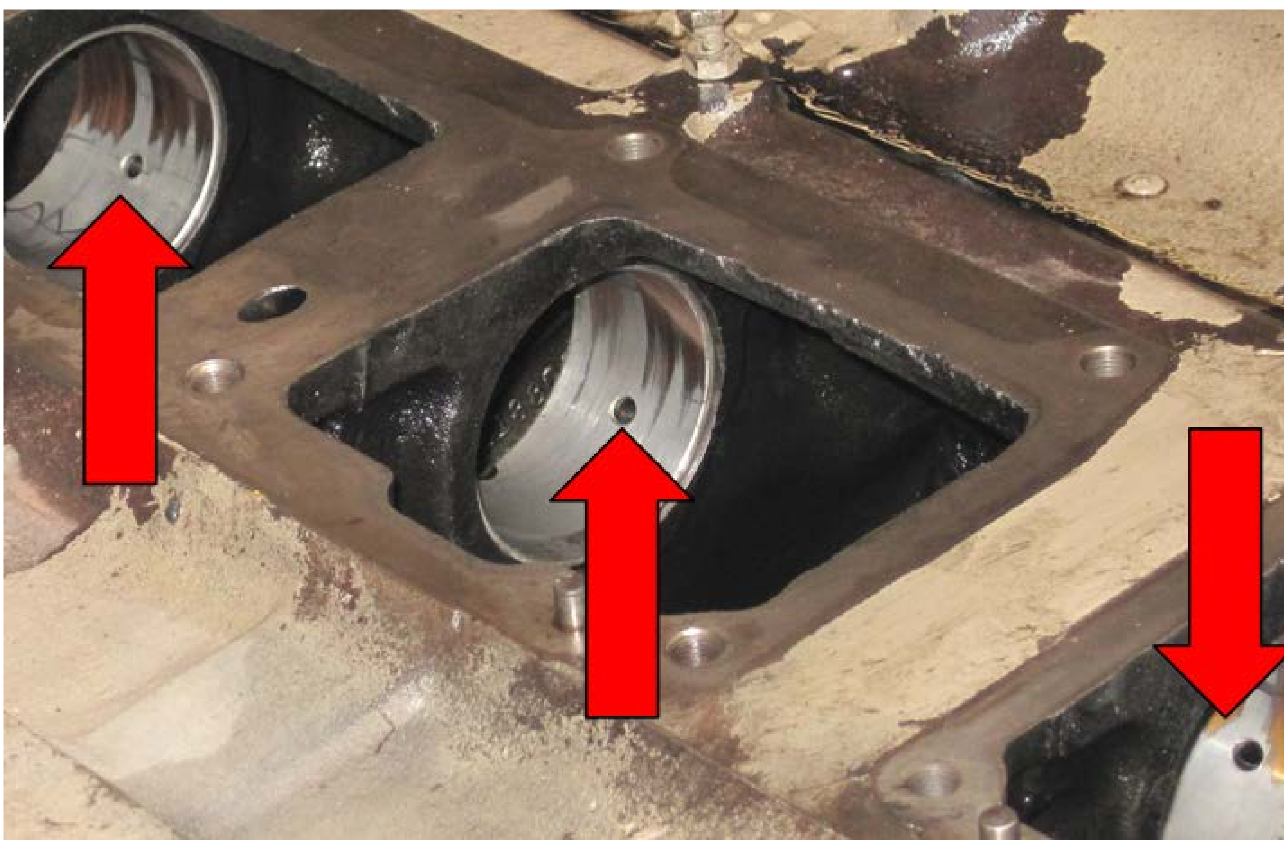
Bearings require the proper support, alignment and fit to function properly. The O.D. of the bearing below shows very little fitment marks to the block bearing bore (yellow arrow). The bearing was measured and found to be in specification on the O.D. and I.D. indicating the camshaft-bearing bore in the block was most likely oversize. The wear marks on the inside of the cam bearing further shows uneven wear most likely from distortion. Excessive clearances allow the camshaft to flex and do not allow for proper lubrication and support.

B. Camshaft failure caused by improperly installed bushings

The picture shows a failed bearing due lack of proper lubrication. The bearing in the second picture has some premature wear, but note the arrow points to a partially covered oil hole.



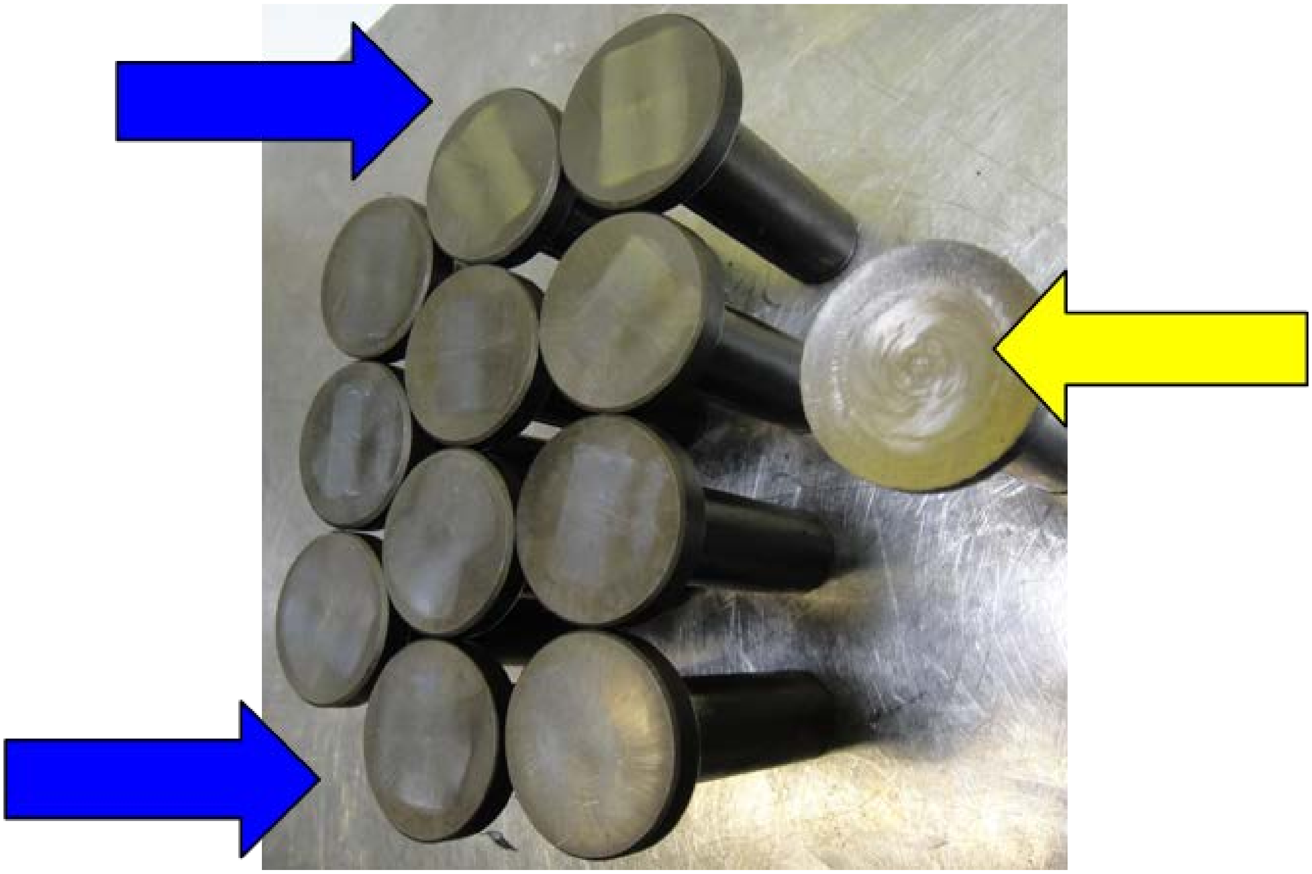
The next picture shows all the oil holes are partially blocked.



The cause of the failure is improper installation of the cam bushings. The partially blocked oil holes do not allow for proper lubrication.

C. <u>Camshaft failure caused by lack of lubrication</u>

The first picture shows the wear pattern on tappet to camshaft lobe contact area (blue arrow). The yellow arrow points to the only tappet that has been rotating, note circular pattern.

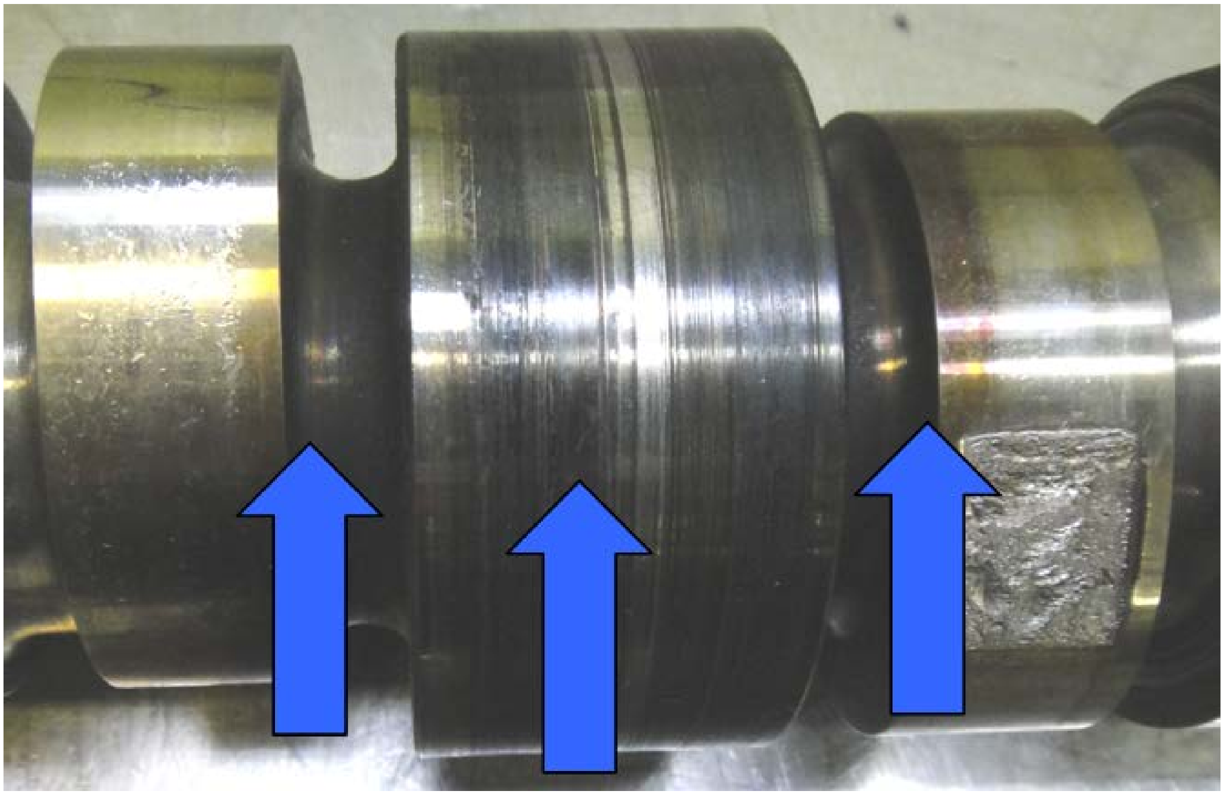


The next two pictures show the wear on one of the lobes of the camshaft.

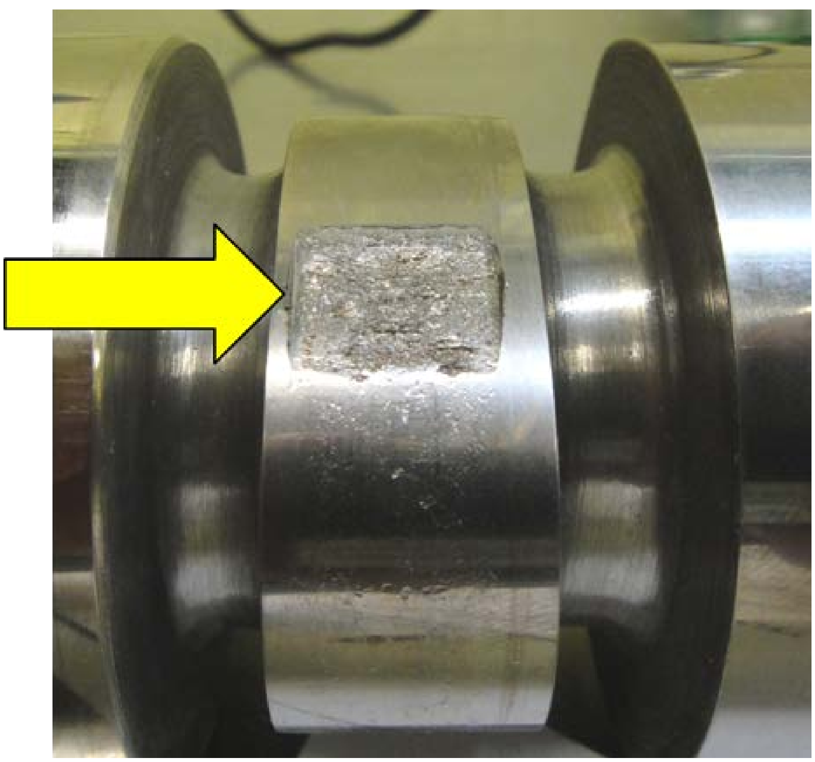
The cause of failure is lack of proper lubrication and tappets not rotating.
On a flat tappet engine, the camshaft must be pre-lubed before starting. Other possible causes of failure could be worn or damaged tappet bores.

D. <u>Camshaft failure due to the lack of proper lubrication</u>

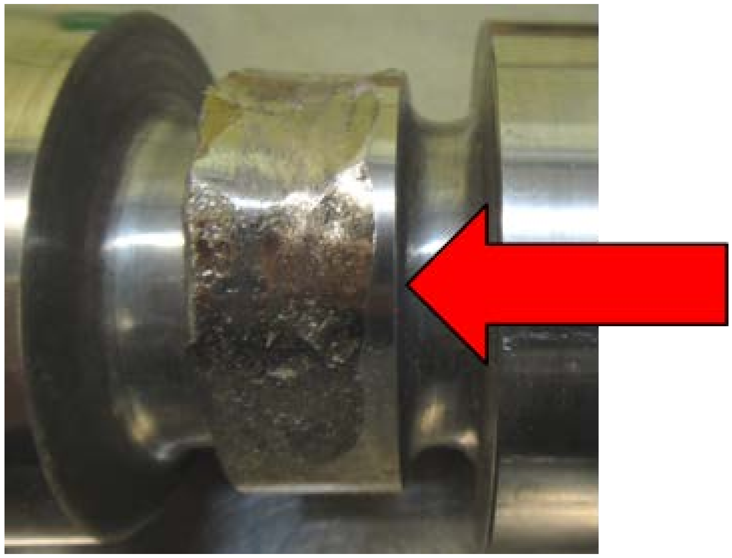
The first picture shows a bearing journal blackened from lack of proper lubrication, also note discoloration extending to surrounding shaft (blue arrow).



The next picture shows galling on valve lobe (yellow arrow).



The final picture shows a lobe that is severely gouged from a follower that has turned sideways (red arrow).

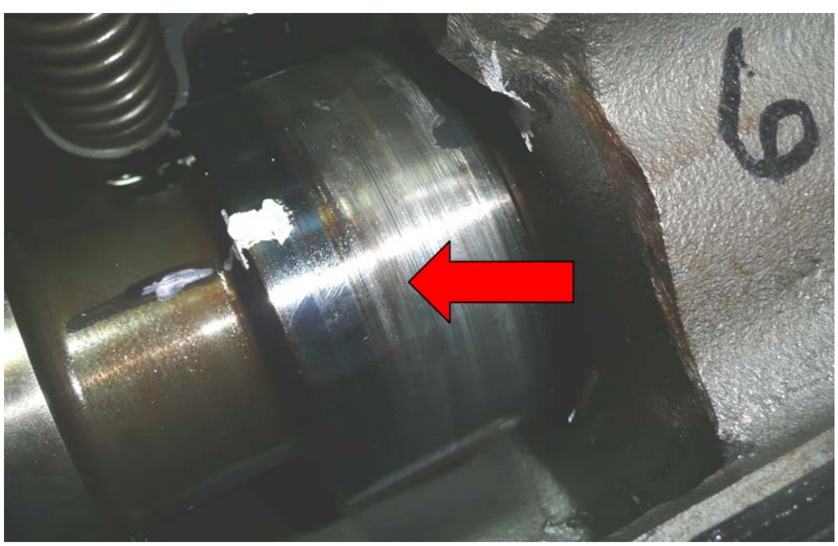


There are two areas where the correct amount of lubrication is required to allow the camshaft and the cam follower rollers to wear normally. The first area is between the pin and roller; the second is between the camshaft lobe and roller. The friction between the cam lobe and the follower comes from the normal loading due to the combined cylinder pressure and the valve spring force. A rolling contact is necessary to minimize friction. If there is a lack of lubrication galling will start to occur.

Galling is defined as material transfer as a result of two surfaces coming into direct contact after penetrating through the lubricating film. Typically, the roller material transfers to the cam surface. Once the surfaces encounter galling, the load carrying capacity of the system is greatly reduced. The breakdown progresses to spalling caused by high contact fatigue stress. Continued running eventually causes the lobe to disintegrate as seen in the above pictures.

E. <u>Camshaft failure from misalignment</u>

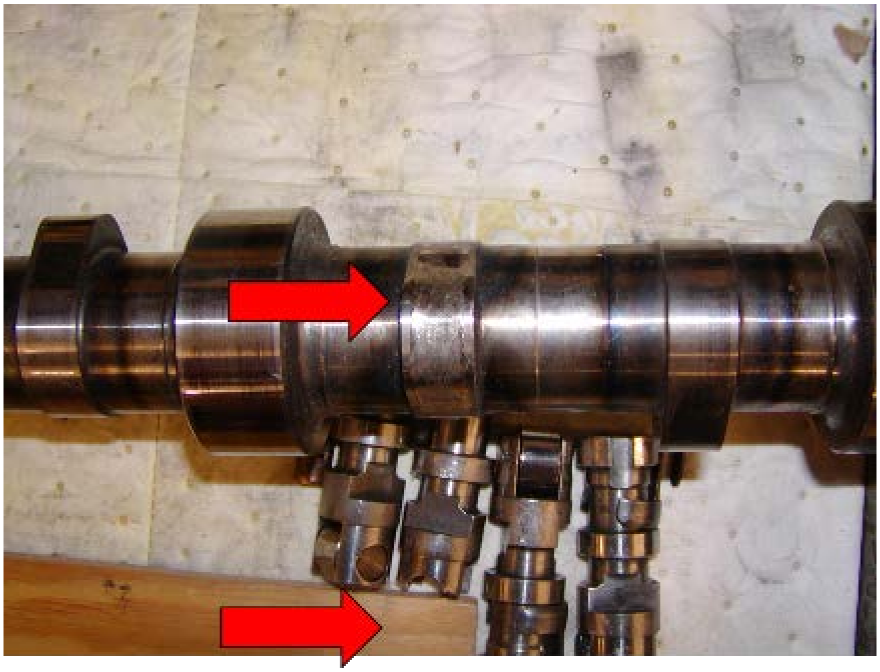
The following picture shows the bearing was subjected to severe over heat, note the discoloration of the bearing material.

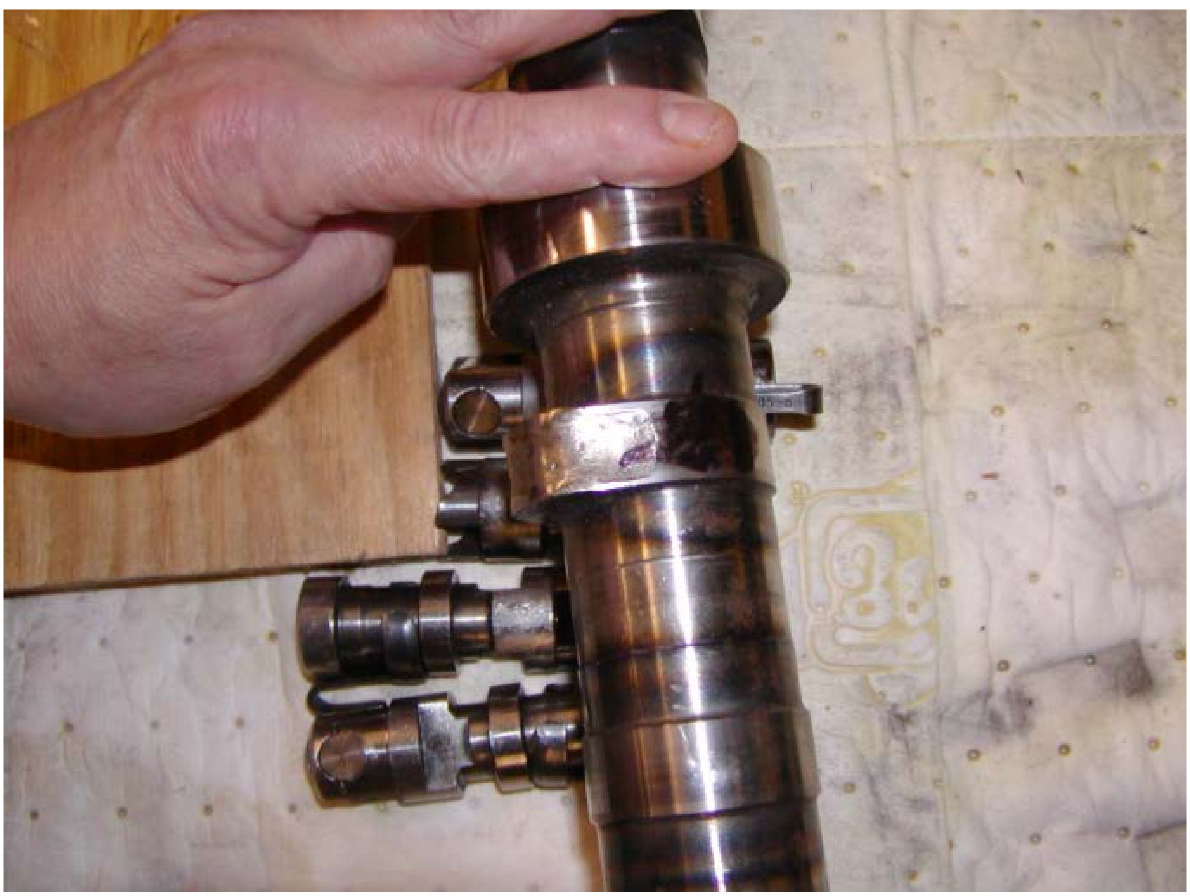


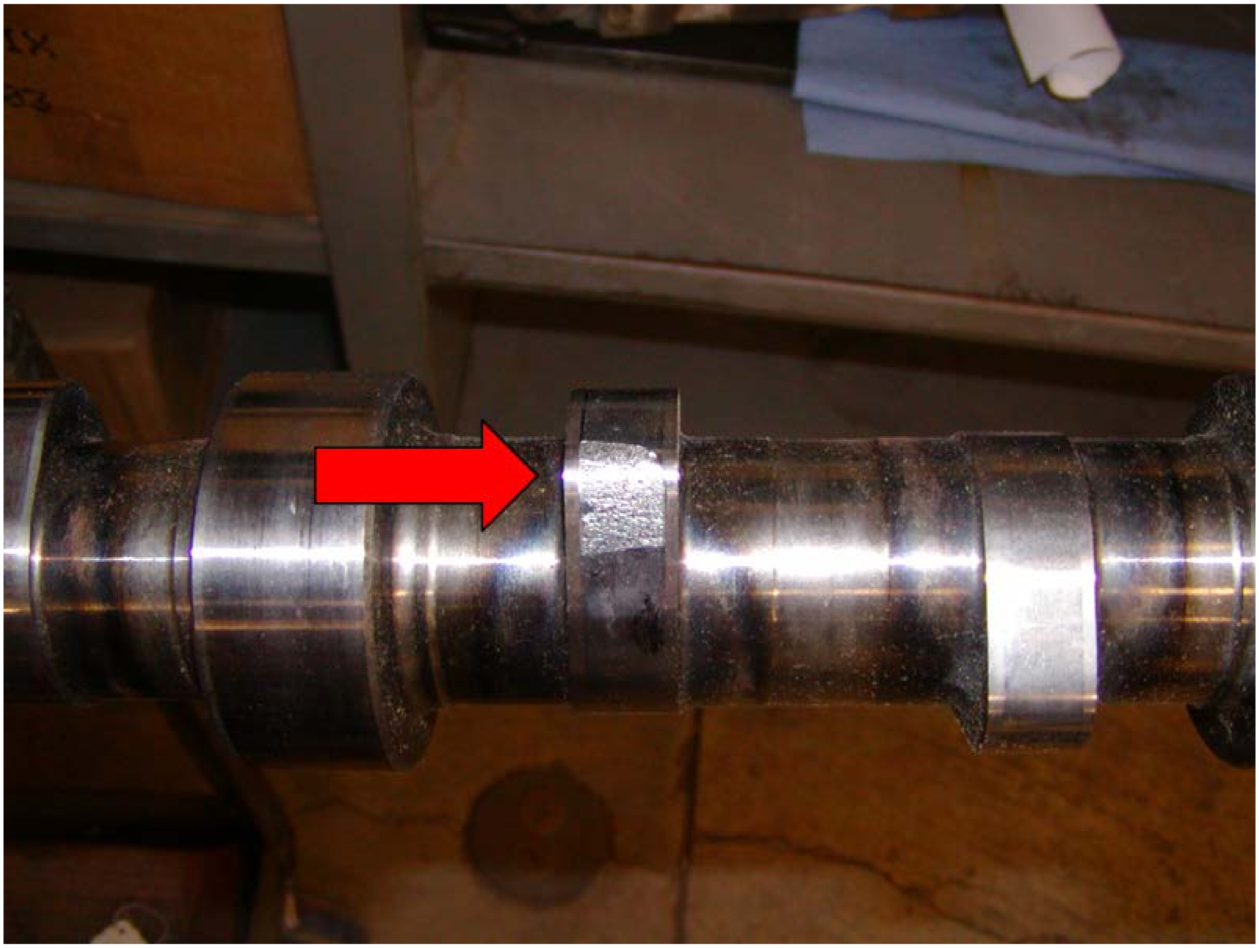
This type of failure is caused by misalignment, contamination or lack of proper lubrication.

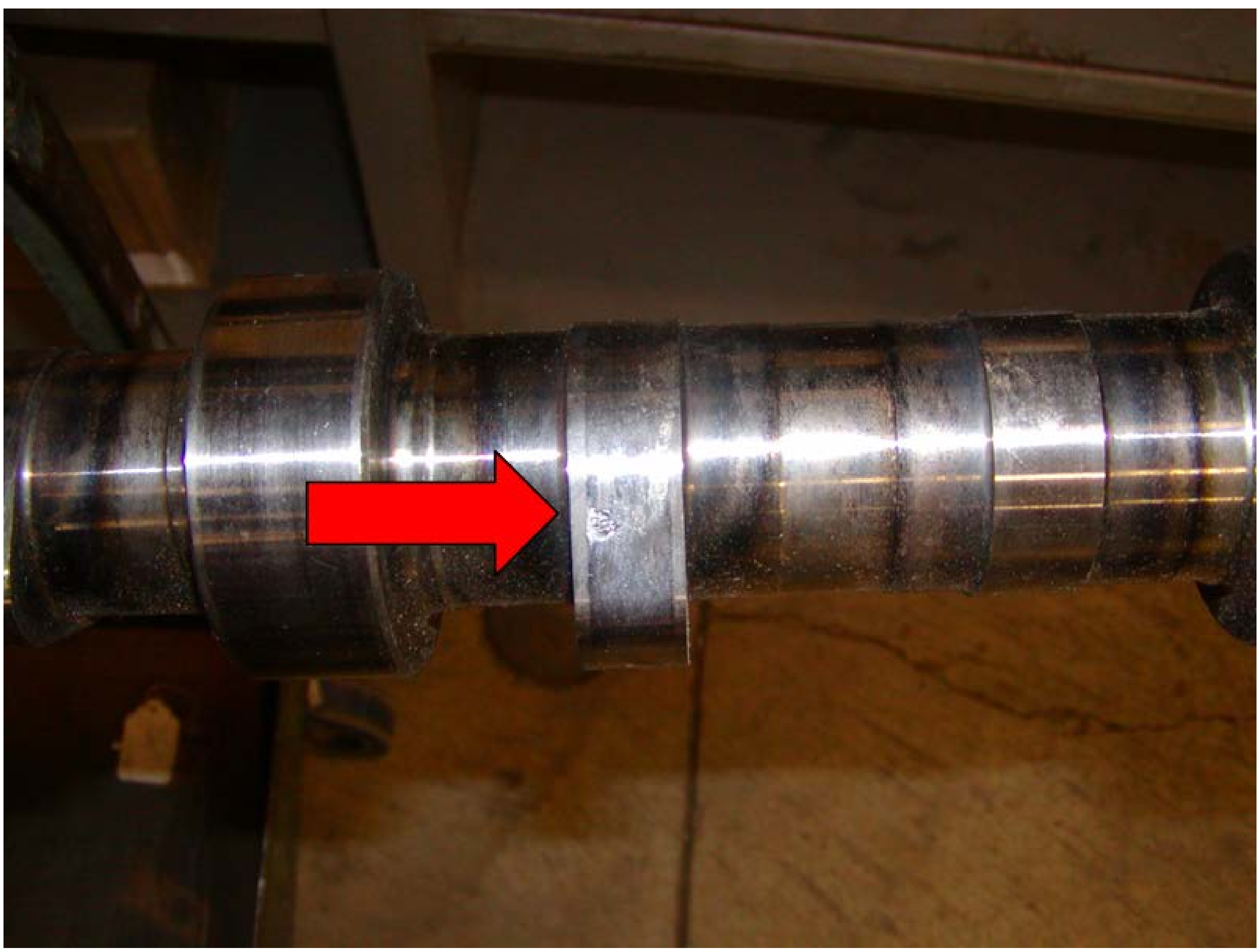
F. <u>Engine over speed damage to camshaft and followers</u>

The following pictures show different degrees of damage to the leading and descending sides of the camshaft lobes. This is caused by the downward impact of the lifter roller after it was instantly separated from the top of the cam lobe. This type of damage is caused by engine over speed.



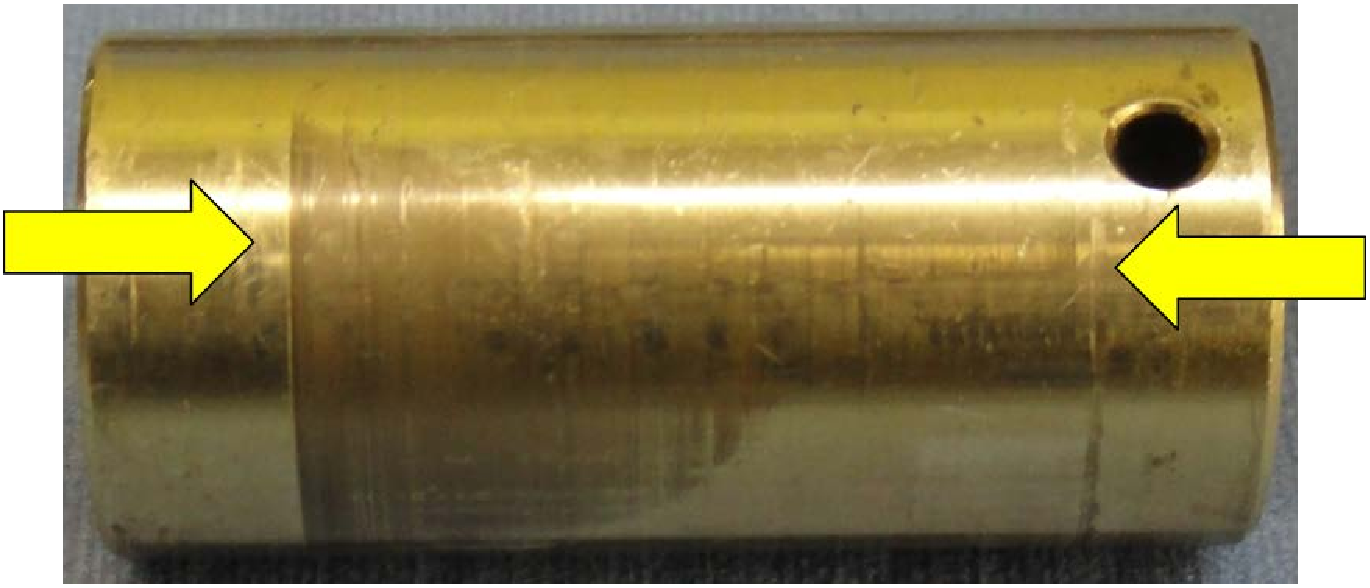




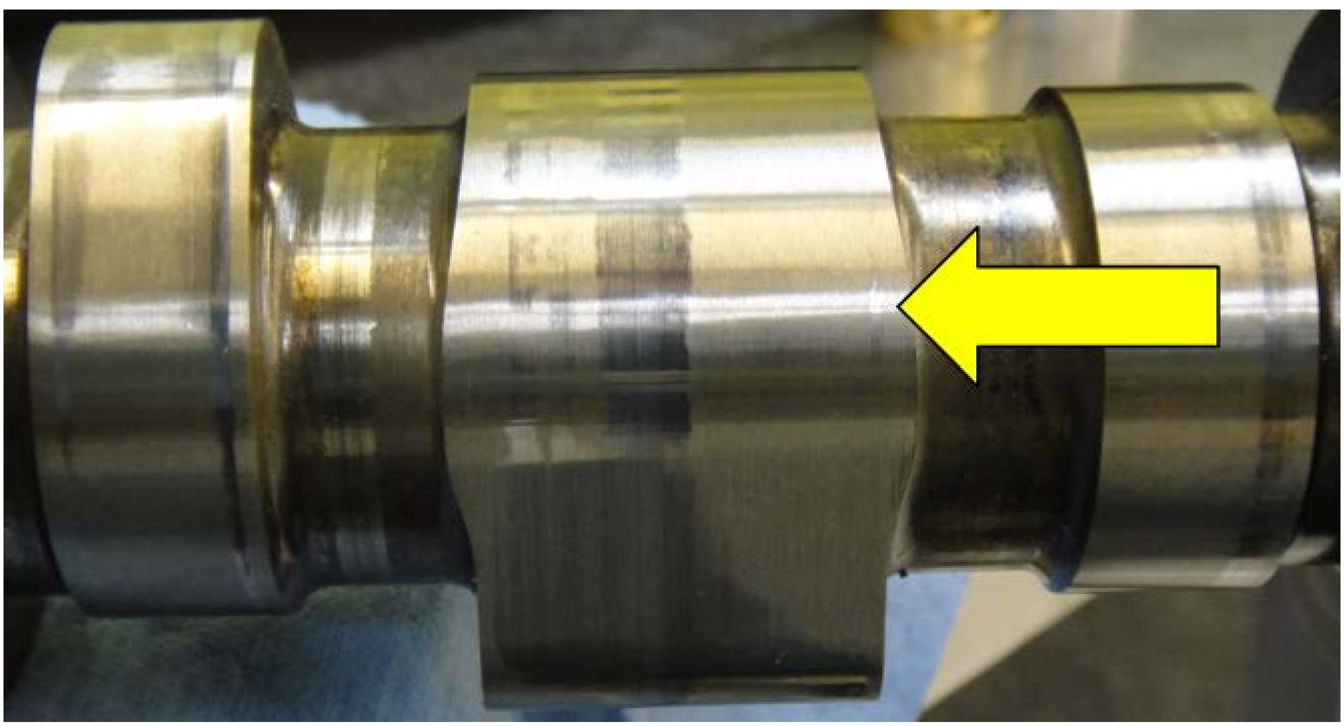


G. Rocker arm failure caused by mechanical fatigue

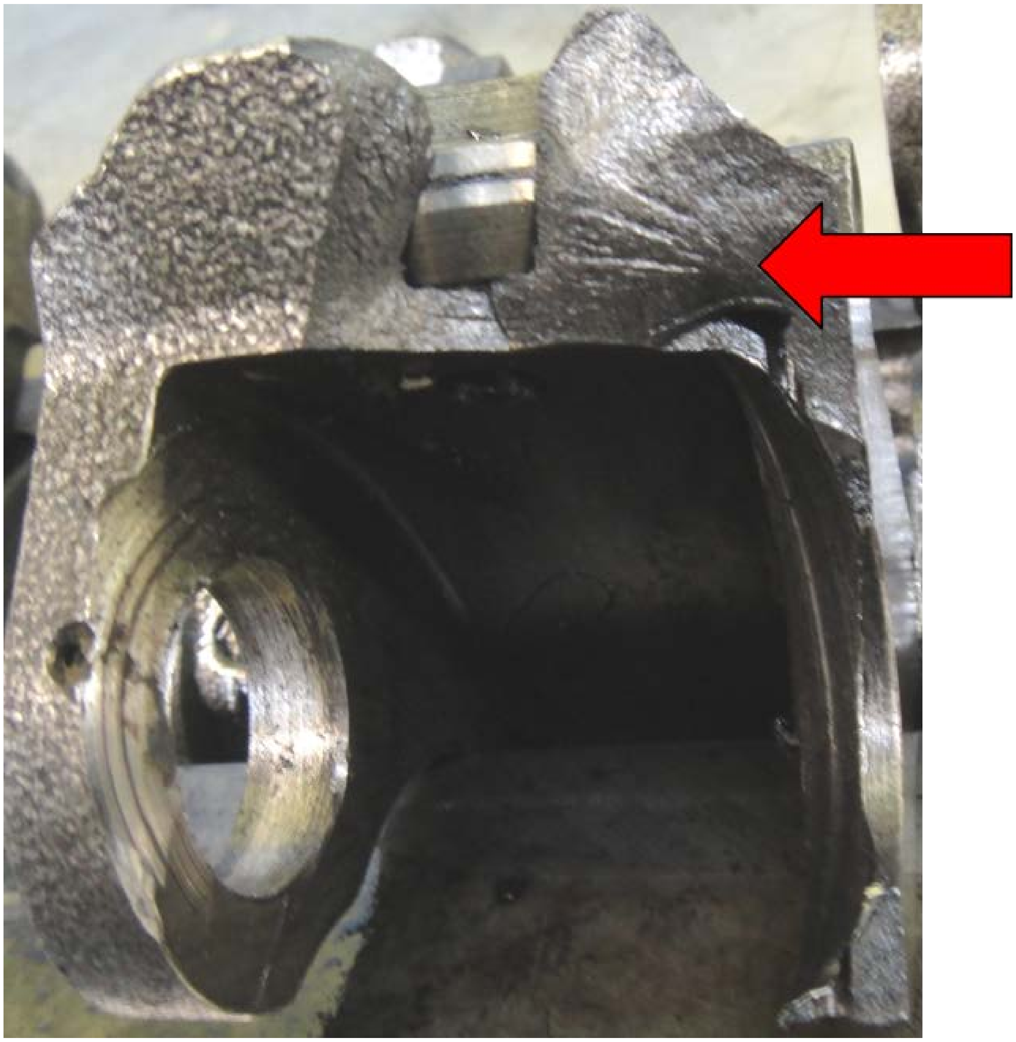
The picture below shows the wear on the pin from the adjacent rocker lever roller. Note: the one-sided wear indicating the roller was not loaded evenly. The rollers and camshaft lobes were not running parallel to each other, indicating a distortion in the camshaft or rocker box.



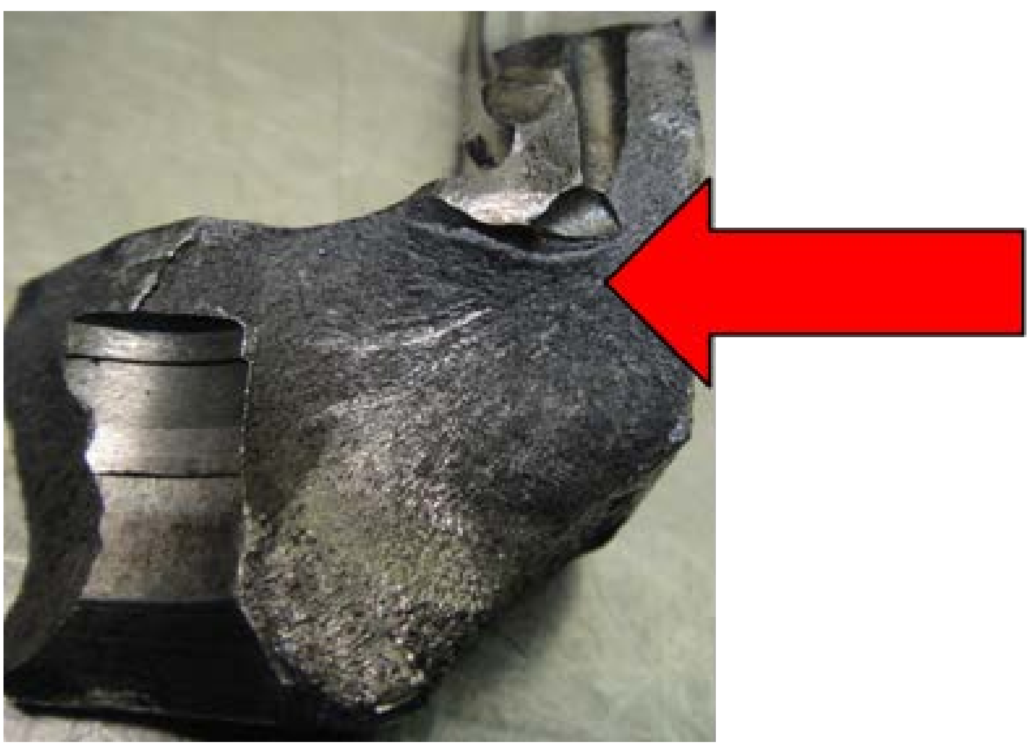
The next picture shows uneven wear patterns on the camshaft reflecting the wear pattern in the previous picture of the pin.



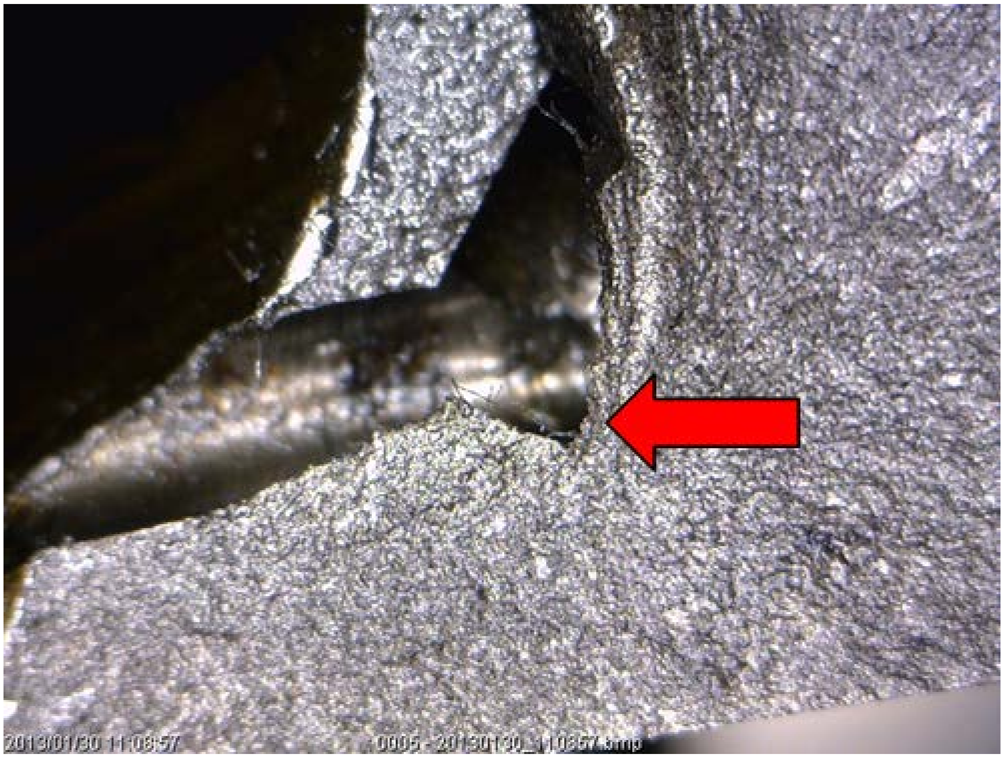
The next three pictures show the fractured surface area of the failed rocker lever. Note beach mark lines in surface pointed out by the red arrow.



The beach mark lines in the picture are on the mating part of the failed rocker lever.



The final picture at 500X magnification shows the stress riser which started the fracture in the rocker lever.

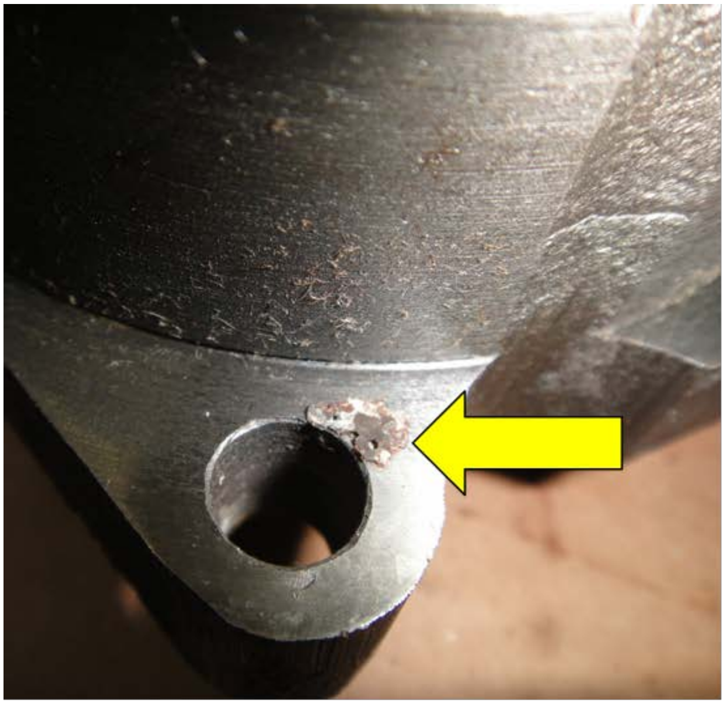


The fracture initiated at one location and propagated across the rocker lever until final failure occurred. The rocker lever failed due to mechanical fatigue. The presence of visual beach marks and microscopic striations characterize the progressions of fatigue cracks. These characteristics are present on the fracture surfaces of the rocker lever as shown in the above picture. The most likely root cause of failure is a stress riser in the rocker lever causing the failure of the rocker lever.

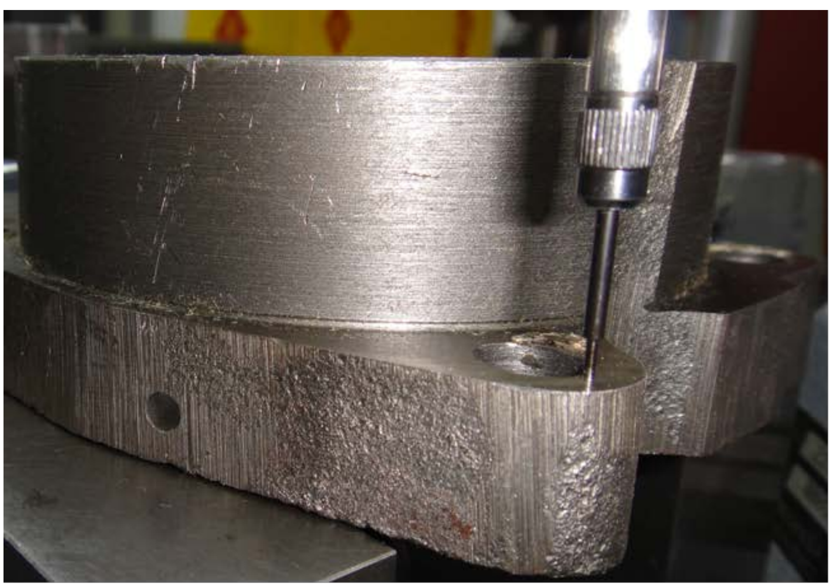
6.1 OIL PUMPS

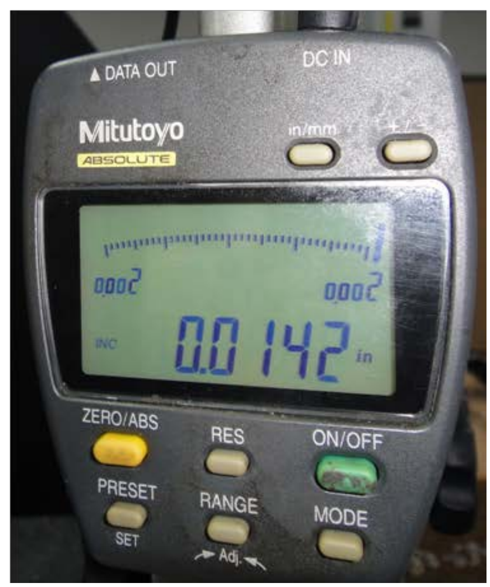
A. <u>Oil pump failure caused by improper installation</u>

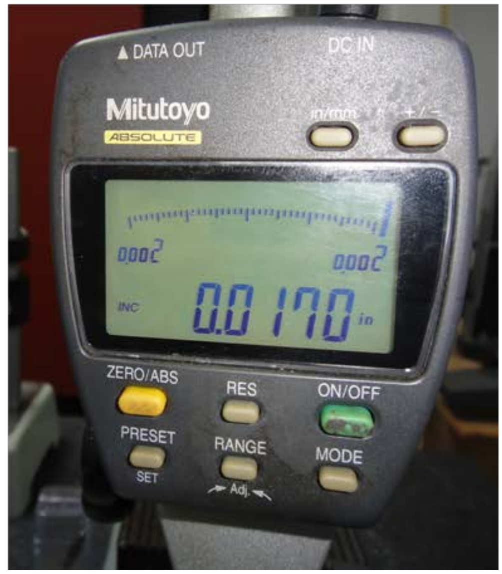
The pictures show the surface area where the pump interfaces with the block. Note the buildup of lock tight in these locations indicating presents of a gap.



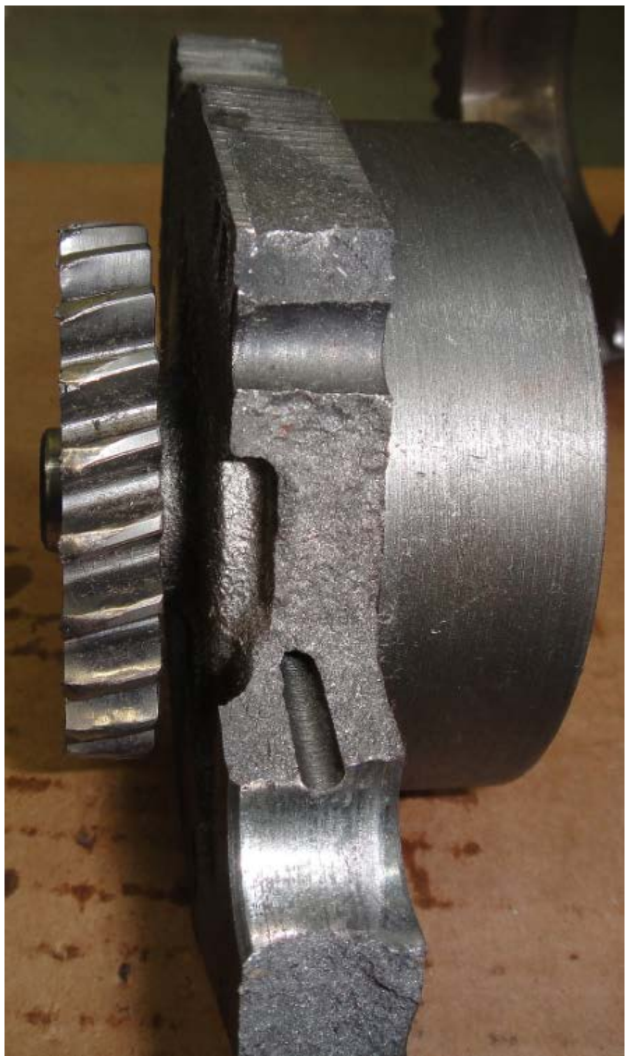
The following four pictures show the height of the hardened material from the mating area of the pump in the two locations show above. Note: the thickness differences.







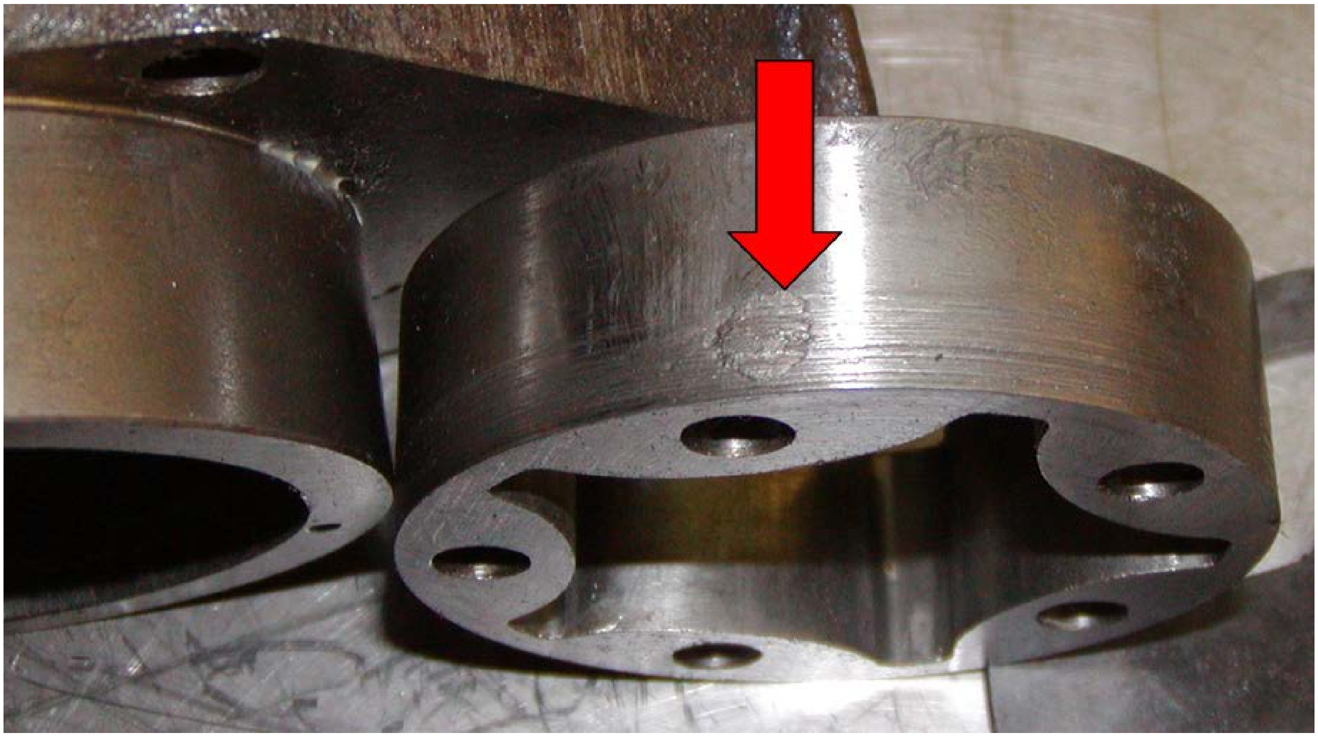
The final picture shows the broken area of the pump. No inclusions were found and no indication of overheat.



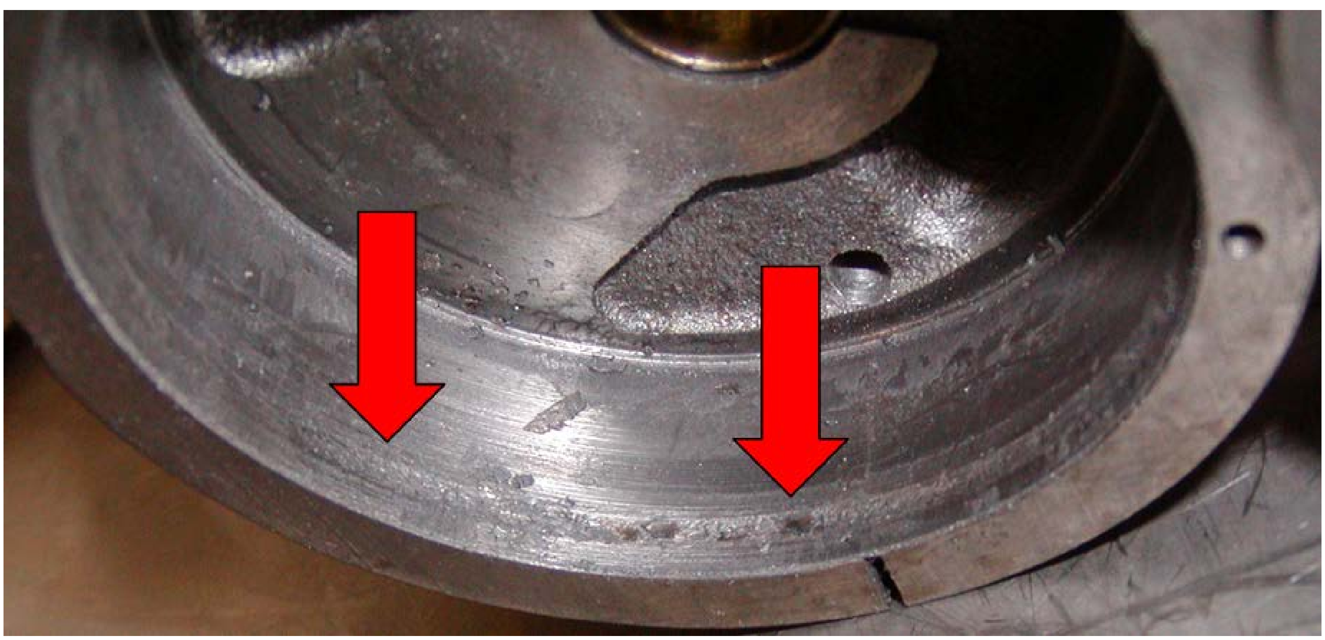
The break area of the housing showed no inclusions or flaws. Backlash was not an issue as there is no indication of overheat. The most likely cause of failure is a bending break of the pump housing occurring when the retaining bolts side loaded the housing causing it to crack. This in turn allowed the driven gear shaft to come loose and bind and break the crankshaft gear.

B. <u>Oil pump failure due to contamination</u>

The red arrow points to where foreign material came to rest on the driven rotor.

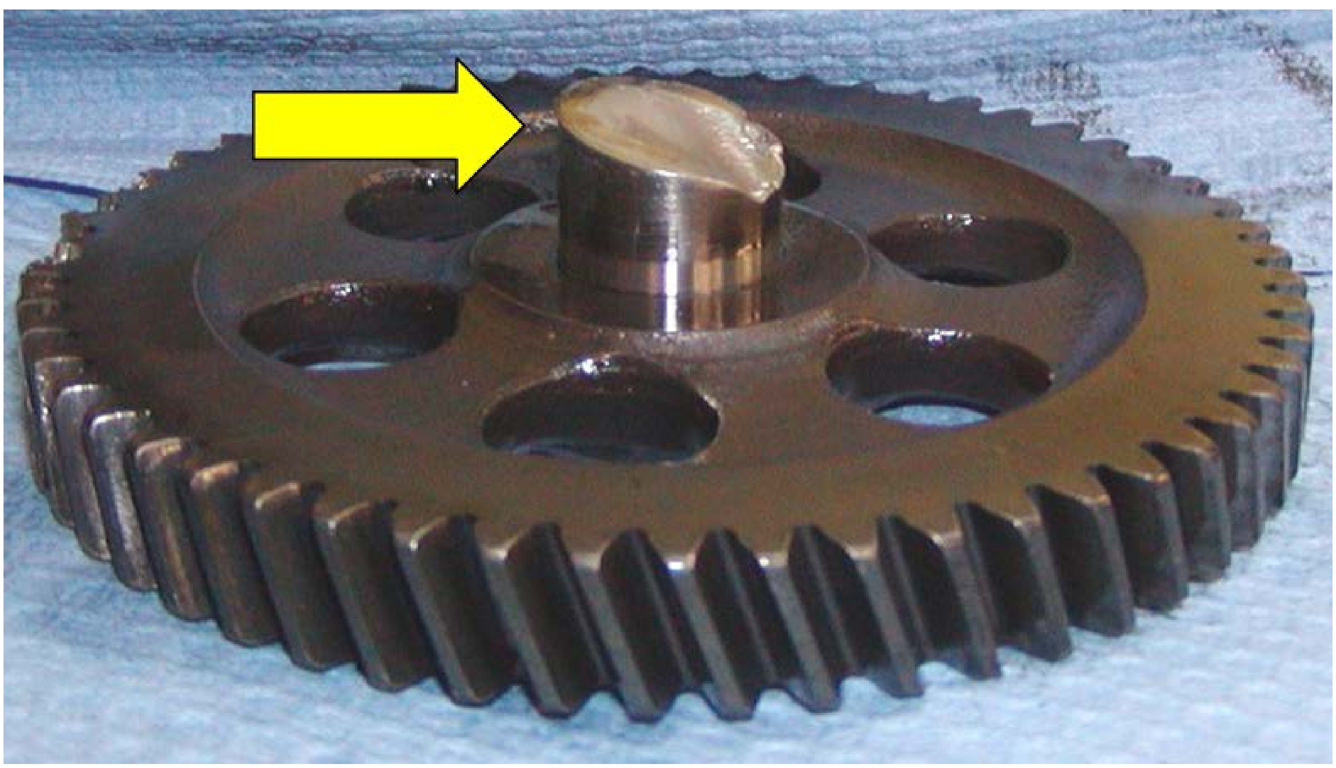


The inner surface of the housing shows where the foreign material channeled the pump housing.

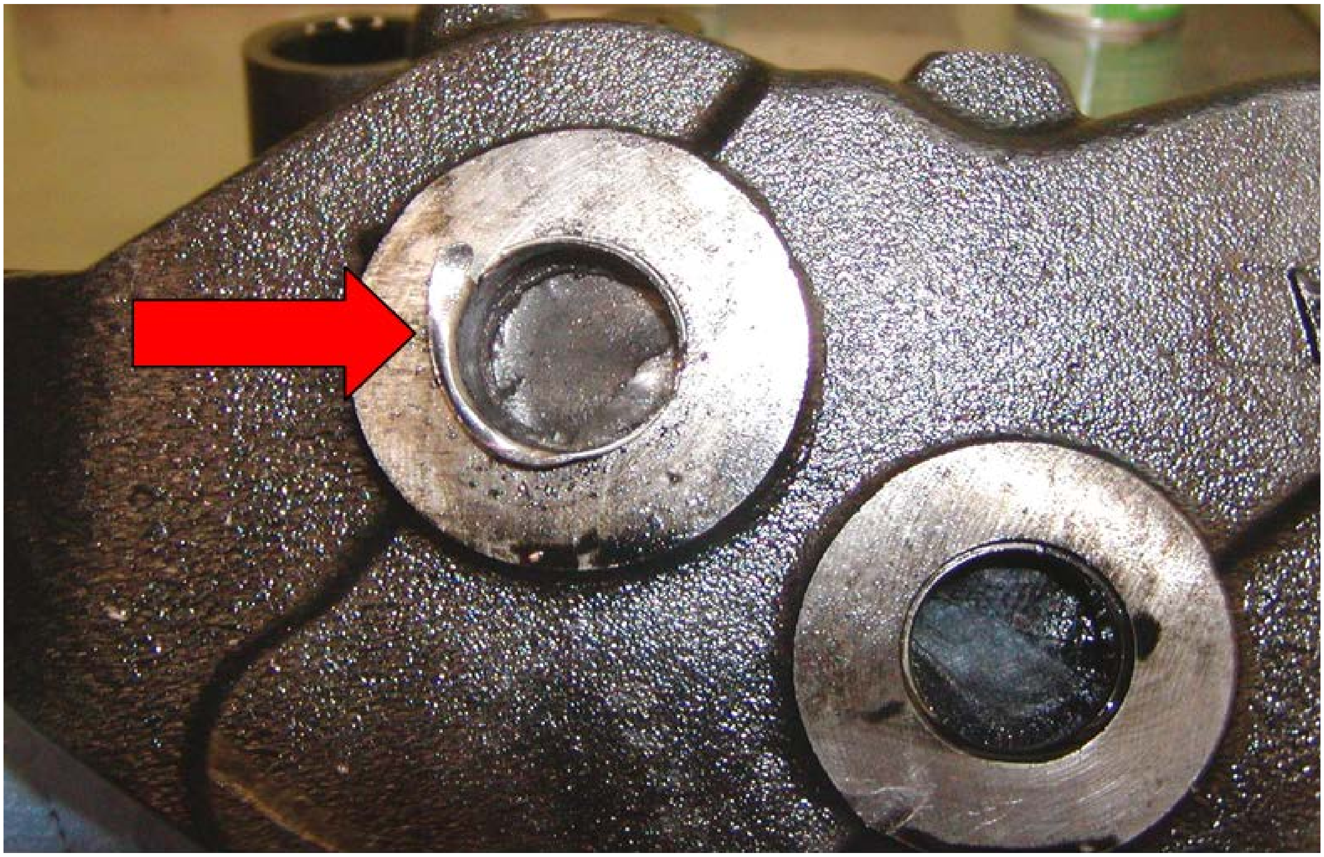


C. Pump failure due to improper installation procedures.

The pictures show an end view of the broken shaft and a side view of the shaft. Note angle of break.



This shows the shaft bushing has failed in the pump housing with the internal part of the shaft stuck in it. The red arrow is pointing at the failed bushing.



The bushing failed from insufficient lubrication caused by excessive side loading. A shaft that breaks at or near a 45 degree angle indicates it has been under excessive torsional stress, a twisting break. The fact the bushing failed from side loading, one would expect a clean shaft break. However, when the shaft seized in the bushing the force of the engine twisted the shaft and caused the break to be torsional. The root cause of the pump failure was determined to be the pump was not shimmed properly and the gears did not have sufficient backlash.

6.2 PISTON COOLERS

A. <u>Piston cooler failure caused by contamination in the oil system</u>

Contamination left in the oil system from an engine overhaul plugged the piston cooler and caused the cylinder kit to seize from over heat. The material in the picture below the cooler was determined to be gasket material.

7.1 PISTON SEIZURE QUICK REFERENCE

Quick Reference Guide

Piston seizures will only occur when metal-to-metal contact between the piston, rings to liners exists. Thermal expansion and/or lack of lubrication are the primary causes for seizures. Piston seizures can be, but are not limited to, one or a combination of the following operational or serviceable conditions:

I. Causes for piston burning, crown erosions, crown overheating, crater cracking, thermal fracturing and nibbling:

1. Defective, contaminated, or incorrect injector
2. Incorrect or improperly calibrated injection pump
3. Early injection timing
4. Intake restriction
5. Exhaust restriction
6. Inoperative or incorrect turbo
7. Inoperative or misdirected oil spray jet
8. Lugging
9. Overloading
10. Incorrect rack settings
11. Inoperative and/or misadjusted governor
12. Use of ether

II. Causes of Four point scoring and either side of pin bore and piston skirt overheating:

1. Overheated cooling system
2. Low coolant level
3. Loss of coolant flow
4. Stuck thermostat
5. Water pump impeller spinning on shaft
6. Lack of crown cooling by the lube oil (spray jets)
7. Incomplete combustion (fuel washdown)
8. Defective or contaminated injector
9. Improper cold start and/or hot shutdown procedures
10. Inoperative radiator louvers if applicable
11. Defective pressure cap
12. Damaged or broken impeller
13. Air pocket at water pump
14. Plugged radiator
15. Plugged radiator cooling fins (bugs, paper etc.)
16. Coolant leaks
17. Inoperative or damaged piston cooling jet
18. Low oil pressure

III. Total piston scoring and/or seizure causes:

1. Progression from four point scoring (refer to list 2)
2. Counterbore or receiverbore distortions (out-of-round)
3. Pinched or rolled liner o-rings/crevice seal
4. Counterbore not concentric with block deck
5. Progression from ring scuffing
6. Use of silicone in o-ring/crevice seal groove area (form-a-gasket)
7. Grease or oil in o-ring/crevice seal groove prior to installation
8. O-ring contamination prior to installation (swelling)

9. Lube oil contamination (abrasives)
10. Air born contaminates (abrasives)
11. Bent or twisted connecting rod
12. Overloading
13. Lugging
14. Detonation
15. High air intake temperature and/or restriction
16. Exhaust restriction
17. Overfueling
18. Incorrect injection timing
19. Incorrect rack settings
20. Inoperative and/or incorrect turbo
21. Incorrect compression ratio
22. Air / Fuel ration imbalance
23. Incorrect fuel cetane rating
24. Incorrect oil classification

IV. Center skirt scuffing, elliptical cold/round when warmed causes:

1. High RPM before operating temperature
2. Engine load before operating temperature
3. Lack of skirt to liner clearance
4. Dry starts when prelube is required
5. Particle abrasive present

V. Causes for piston crown damage, foreign material or other:

1. Progression from ring scuffing
2. Progression from distortion seizure
3. Turbo compressor failure
4. Debris entering intake system
5. Installation debris
6. Valve failure - valve-impact
7. Incorrect installation of pin bushing, lack of retention might cause rod eye bushing to rotate
8. Malfunctioning and/or misadjusted jake brake
9. Incorrect jake brake usage
10. Extreme detonation
11. Excessive ether
12. Cold operation
13. Fast timing
14. Cyclic loading
15. Leaking injector

Conclusion:

A thorough examination of the four major systems will aid in the investigation process.
The four major systems are as follows:

► AIR INTAKE / EXHAUST SYSTEM
► FUEL SYSTEM
► COOLING SYSTEM
► LUBRICATING SYSTEM

The examination should also include operational hazards and repair practices.

7.2 REASONS FOR OIL CONSUMPTION

Reasons for Engine Oil Consumption

What is excess oil consumption

All engine manufacturers have specific acceptable levels of oil consumption - what the expected oil consumption should be as part of normal operating conditions. These levels of oil consumption help define what is excessive in a given engine.

Engine, Age, and Oil Consumption

Oil consumption changes as the engine ages. Typically, a new engine will have a "break-in" period which might experience a higher level of oil consumption.

The increased oil consumption falls off after the engine breaks in. As the engine ages and gets toward the end of its life cycle oil consumption tends to rise again.

Heavy Loads, Extreme Conditions, Increased Demand

There are many other factors effecting oil consumption. Pulling heavy loads and operating in mountainous terrain will tend to cause an increase in oil consumption.

The harder a diesel engine works the more oil it will consume. Idle time also must be taken into consideration. If the engine is constantly idling you will consume more oil.

Viscosity Effects Oil Consumption

Changing the viscosity of your engine oil can also make a difference in oil consumption. Changing from a 15W-40 to a 10W-30 will have a slight increase in oil consumption due to having a slightly lighter viscosity oil in the engine.

Proper Oil Change Intervals

Extending oil change intervals beyond reasonable limits can also lead to excessive oil consumption.

Impact of Low Oil on The Engine

When an engine is consuming an excessive amount of oil and constantly running a gallon or more below the recommended level, the engine is putting excessive stress on the oil left in the engine.

Additives in the oil are going to be consumed at a faster rate if the engine is run with a low oil level thus reducing the life of the oil.

Deposits and Lost Performance

Additional problems can occur if the engine is burning oil. Carbon deposits will form on the valves and in the combustion chamber.

If oil is getting into the combustion chamber it can cause deposits to form on the top of pistons. Burning oil also will cause deposits on the exhaust valves. With these deposits the engine will not have the proper airflow which will result in a loss of power and overall engine performance.

What causes excess oil consumption

Under normal operating conditions, excess oil consumption is generally a mechanical problem.

Technically Speaking

Oil is consumed in one of two ways: It is either burned or is leaked

Leaking

In a significant number of instances where oil consumption is a problem it turns out to be a leak issue. Either the valve cover gasket is leaking or one of the main seals is leaking. The pan gasket can also cause the leak.

Burning

The quality of the oil being used can have an impact.
If the engine is using a higher quality oil, the piston ring and ring belt areas will tend to stay clean. If these areas remain clean and free of carbon deposits less oil will be consumed. When the ring areas get dirty and covered with carbon the rings cannot move freely. The engine will start to have a higher oil consumption rate.

Oil Consumption - Troubleshooting

Before reviewing the reasons why oil consumption occurs, it should be noted a degree of consumption should be anticipated in all engines. What is considered normal or acceptable will vary from one engine application to the next. For large diesel engines used in over the road trucking applications, many manufacturers are not concerned until consumption reaches one gallon oil per 10,000 miles of operation.

Improper Break-In Procedure

When a cylinder is new the inner wall surface is not smooth. The objective of the break-in procedure is to rub off any high spots, both on the cylinder wall and the piston rings, so the rings can create a tight gas seal for normal operation. This requires the piston ring to break through the oil film and allow a certain amount of metal-to-metal contact between the components. Once this matching has occurred the break-in is considered to be complete and very little contact will occur thereafter.
Lubricating oil is there to prevent metal-to-metal contact, but the process described above requires a break the oil film. Low power settings and the use of improper lubricating oils can prevent this process from occurring.

Bore Glazing

A glazed cylinder bore occurs when the honing pattern on the liner is filled with varnish or lacquer, so oil is not able to fill the pattern causing overheating and damage.
The use of incorrect oils or mixing additives in the lube oil during break-in creates the risk of a higher film-strength which will prevent the piston rings from penetrating the oil film and therefore the necessary abrasion on the cylinder wall will not occur. Secondly, the frictional process creates unusually high surface temperatures on the cylinder wall and this can cause the additives in the oils to form a glaze in the honing groves on the surface of the cylinder wall. When a cylinder is manufactured, a cross-hatch hone is used to score a diamond pattern into the surface of the liner; this is necessary to allow an oil film to be held on the surface of the cylinder wall and lubricate the piston during operation. If this glazing of these honing grooves occurs before the break-in period is complete then the piston ring will not seal properly. The cylinder wall will no longer have the surface groves necessary to carry lubricant and the combination will result in a poor gas seal and high oil consumption. The only way to remove such a glaze is by re-honing the cylinder wall or replacing the liner. Successful break-in requires the correct use of adequate power settings. High power settings mean high combustion pressures which, due to the piston ring design, forces the piston ring out to penetrate the oil film. This is the key to the break-in process. Lightly loaded engines can also lead to problems with bore glazing.

External Oil Leaks

Some of the many points where external leaks occur may include: oil lines, crankcase drain plug, oil pan gasket, valve cover gaskets, oil pump gasket, fuel pump gasket, timing cover and camshaft bearing seal. No possible source of leakage should be neglected because even a very small leak will cause extremely high oil consumption. For example, it has been estimated a leak of one drop of oil every 20 feet is approximately equal to a loss of one quart every 100 miles. The best way to check for external leaks is to road test the vehicle with a large piece of light colored cloth tied under the engine. Oil on the cloth will indicate a leak which should be traced back to its source.

Front or Rear Crankshaft Oil Seals

Worn front or rear crankshaft seals almost always result in oil leakage. This can only be determined when the engine is operated under load conditions. Crankshaft seals should be replaced when worn because a slight leak will result in extremely high oil consumption just as it would with an external oil leak.

Worn or Damaged Main Bearings

Worn or damaged main bearings throw off an excessive amount of oil which flows along the crankshaft and is deposited into the cylinders. The amount of oil used increases rapidly when bearing wear increases. For instance, if the bearing is designed to have 0.0015 inch clearance for proper lubrication and cooling, oil throw off will be normal as long as this clearance is maintained and the bearing is not damaged in any way. However, when the bearing clearance increases to 0.003 inch, the throw off will be five times normal. If the clearance is increased to 0.006, the throw off will be 25 times normal. When the main bearings throw off too much oil, the cylinders are usually flooded with more than can be controlled by the piston and rings. This causes burning of the oil in the combustion chamber and carboning of the piston and rings.

In a conventional, full-pressure lubricated engine a large loss of oil at the main bearings may starve the downstream connecting rod bearings of lubrication to such an extent, especially at low speeds, insufficient oil may be thrown on the cylinder walls. This will cause the pistons and rings to wear to such an extent they will not be able to control the oil at high speeds. The effect of main bearing wear will be high oil consumption.

Worn or Damaged Connecting Rod Bearings

Clearances on connecting rod bearings affect the throw off of oil in the same proportions as mentioned for main bearings. In addition to, the oil is thrown more directly into the cylinders. Worn or damaged connecting rod bearings flood the cylinders with such a large volume of oil the pistons and rings are overloaded and some oil escapes past them to the combustion chamber and causes high oil consumption. Insufficient bearing clearance can also produce piston, ring and cylinder damage as well as damage to the bearing itself.

Worn or Damaged Camshaft Bearings

Camshaft bearings are generally lubricated under pressure. If the clearances are too large, excess oil will be thrown off. Large quantities of this oil may flood valve guide and stem areas resulting in increased oil consumption.

Worn Crankshaft Journals

Worn crankshaft journals will have the same effect on oil consumption as worn bearings. When they are worn out-of-round they cannot be set up with round bearings to give uniform oil clearance. A bearing fit to the larger dimension of a worn journal will be loose at the smaller dimension and throw off many times the proper amount of oil. Journals which are out-of-round, rough or scuffed should be reground and fitted with undersize bearings of the correct size.

Tapered and Out-of-Round Cylinders

In slightly tapered and out-of-round cylinders, the oil can be controlled by the pistons and rings. However, with increased taper and out-of-roundness, satisfactory oil control becomes more difficult to maintain. The increased piston clearances permit the pistons to rock in the worn cylinders. While tilted momentarily, an abnormally large volume of oil is permitted to enter on one side of the piston. The rings, also tilted in the cylinder, permit oil to enter on one side. Upon reversal of the piston on each stroke, some of this oil is passed into the combustion chamber.

For each revolution of the crankshaft, the pistons make two strokes - one up and one down. When an engine is running at 1500 R.P.M. the rings in tapered and out-of-round cylinders are changing their size and shape 3000 times per minute. Consequently, at high speeds, the rings may not have time to conform perfectly to all worn parts of the cylinders on every stroke. Whenever this occurs, the engine consumes higher amounts of oil due to what is commonly referred to as oil pumping.

Distorted Cylinders

Cylinders which are distorted so they are out of shape - not from wear, as described under "Tapered and Out-of-Round Cylinders", but from other causes, such as unequal heat distribution or unequal tightening of cylinder head bolts - present a surface which the rings may not be able to follow completely. In this case, there may be areas where the rings will not remove all of the excess oil. When combustion takes place, this oil will be burned and cause high oil consumption.

Clogged "PCV" Valve

The main purpose of the PCV (positive crankcase ventilation) valve is to recirculate blow-by gases back from the crankcase area through the engine to consume unburned hydrocarbons. Blowby is a mixture of air, fuel and combustion gases forced past the rings on the combustion stroke. The PCV system usually has a tube leading from the crankcase to the intake manifold. Vacuum within the engine intake manifold pulls blowby gases out of the crankcase into the combustion chamber along with the regular intake of air and fuel.

A valve can become clogged with sludge and varnish deposits and trap blowby gases in the crankcase. This degrades the oil, promoting additional formation of deposit material. If left uncorrected, the result is plugged oil rings, oil consumption, rapid ring wear due to sludge buildup, ruptured gaskets and seals due to crankcase pressurization, oil thrown out around the filler cap and consequent rough engine operation.

Honing Abrasive

If cylinder honing or glaze breaking is performed on an engine, cleaning instructions should be carefully followed to prevent metal fragmentation or abrasive damage to the rings' seating surfaces.

After honing thoroughly wash cylinder walls with soapy water and a scrub brush and oil immediately thereafter, or swab cylinders with No. 10 oil and carefully wipe clean. Repeat until all evidence of foreign matter is removed. In either method used, a white cloth wiped on the surface should remain clean.

Note: Do not use gasoline or kerosene to clean the cylinder walls after honing. Solvents of this nature will not remove the grit from the cylinder wall and often carry particles of abrasives into the pores of the metal. Failure to properly clean the cylinder walls will leave abrasives causing rapid wear and ring failure resulting in elevated oil consumption.

Worn Ring Grooves

For piston rings to form a good seal, the sides of the ring grooves must be true and flat - not flared or shouldered. The rings must have the correct side clearance in the grooves. Normally, automotive ring groove side clearance should not exceed .002-.004. As the pistons move up and down, the rings must seat on the sides of the grooves in very much the same way valves must seat to prevent leakage. New rings in tapered or irregular grooves will not seat properly and oil will pass around behind the rings into the combustion chamber. Worn grooves are usually flared or tapered causing increased side clearances which permit more than the normal amount of oil to pass the rings into the combustion chamber. Excessive side clearances also create a pounding effect by the rings on the sides of the piston grooves. This promotes piston groove wear and, if the condition is not corrected, breakage of rings lands may occur.

Cracked or Broken Ring Lands

Cracked or broken ring lands prevent the rings from seating completely on their sides and cause oil pumping by a process similar to the description above in "Tapered and Out-of-Round Cylinders". In addition, they also lead to serious damage of the cylinders and complete destruction of the pistons and rings. Cracked or broken ring lands cannot be corrected by any means other than piston replacement>replace pistons as soon as there is the slightest indication of a crack.

Worn Valve Stems and Guides

When wear has taken place on valve stems and valve guides the vacuum in the intake manifold will draw oil and oil vapor between the intake valve stems and guides, into the intake manifold and then into the cylinder where it will be burned. If this condition is not corrected when new piston rings are installed, an engine is likely to use more oil than it did before because the new piston rings will increase the vacuum in the intake manifold. When gum or deposits on the valve stems are removed - a procedure recommended when overhauling an engine - the seal previously formed will be removed and leakage will be more pronounced. This is particularly true on overhead valve engines where loss of oil may occur on the exhaust valves as well as on the intake valves. High oil consumption caused by too much valve guide clearance which requires replacement of the valves. Use of a permanently bonded valve stem seal will give added insurance against oil leakage on complete engine overhauls or on valve jobs.

Bent or Misaligned Connecting Rods

Bent or misaligned connecting rods will not allow the pistons to ride straight in the cylinders. This will prevent the pistons and rings from forming a proper seal with the cylinder walls and promote oil consumption. In addition, it is possible a bearing in a bent rod will not have uniform clearance on the crankpin. Under these conditions, the bearing will wear rapidly and throw off an excessive amount of oil into the cylinder.

Worn or Improperly Fit Wrist Pins

The use of worn or improperly fitted wrist pins or the installation of the wrong pins, as in the case of rifle drilled rods where oil is forced to the wrist pins under pressure, can cause such an excessive throw off of oil onto the cylinder walls the piston rings may not be able to control it. This will not only result in the direct loss of the excess oil but also in the formulation of carbon which will clog the oil passages and cause the rings to become stuck in the grooves.

Wrist Pins Fit Too Tight

Wrist pins fitted too tight at both ends prevent the pistons from expanding and contacting freely under the repeated heating and cooling encountered in engine operation. The piston distortion results in scuffing or scoring, which inevitably leads to blow-by and high oil consumption.

Clogged Oil Passages

After an engine has been in service for an extended period of time the oil passages in piston rings and pistons will likely become clogged from carbon or an accumulation of foreign matter in the oil. The passages are designed for carrying oil - in excess of the amount needed for lubricating the cylinders - back to the crankcase. When the passages become clogged, oil may be trapped in areas reducing the indicated level of oil within the engine. It may also pool in areas such as above the valve guides, which can further promote consumption.

Clogged passages in the rifle drilled rods or any clogged oil line will starve the engine of lubrication, promote wear and lead to high oil consumption. To avoid clogging of oil passages, the same precaution should be taken as recommended in "Pistons Rings Stuck in Grooves". Initial side clearance is not applicable in this case.

Unequal Tightening of Main Bearing Bolts or Connecting Rod Bolts

Unequal tightening of main bearing bolts or connecting rod bolts will throw the bearing bores out-of-round enough to shorten bearing life and to cause an abnormally large throw off of oil from the bearings. The effect on oil consumption is described in "Worn or Damaged Main Bearings" and "Worn or Damaged Connecting Rod Bearings". When bearing bores are originally machined the bolts are tightened to the manufacturer's torque. A torque wrench must be used to insure roundness of the bearing bores whenever the bolts are tightened after having been removed and reinstalled. Unequal tightening of connecting rod bolts may also cause connecting rod distortion, with results similar to those described in "Bent or Misaligned Connecting Rods".

Unequal Tightening of Cylinder Head Bolts

The strains developed by unequal tightening of cylinder head bolts may cause serious cylinder distortion and result in oil pumping as mentioned in "Tapered and Out-of-Round Cylinders" and "Distorted Cylinders". When re-installing a cylinder head, a torque wrench should always be used on the head bolts. The engine manufacturer's instructions should be followed for the torque readings and the sequence in which the bolts are tightened.

Cooling System Maintenance

Rust, scale, sediment or other formations in the water jacket and radiator, or corrosion of the water distributing tube, will prevent a cooling system from performing its duties efficiently. This is likely to cause cylinder distortion with a direct loss of oil as mentioned in "Tapered and Out-of-Round Cylinders" and "Distorted Cylinders".

A defective cooling system causes overheating of the engine with the possibility of developing localized hot spots in some of the cylinders. This may also lead to scuffing and scoring of cylinders, pistons and rings which results in high oil consumption.

Dirty Oil

Failure to change the oil at proper intervals or to take proper care of the oil filter may cause the oil to be so dirty it will promote clogging of the oil passages in the piston rings and pistons. This will increase the oil consumption as described in "Clogged Oil Passages". Dirty oil will also increase the rate of wear on bearings, cylinders, pistons and piston rings. All of these worn parts will contribute to a further waste of oil.

Too Much Oil in Crankcase

Due to an error in inserting the oil dip stick so it does not come to a seat on its shoulders, a low reading may be obtained. Additional oil may be added to make the reading appear normal with the stick in this incorrect position which will actually make the oil level too high. If it gets so high the lower ends of the connecting rods touch the oil in a pressure lubricated engine or the dippers go too deep into the oil in a splash lubricated engine, excessive quantities of oil will be thrown on the cylinder walls and some of it will work its way up into the combustion chamber.

High Engine Vacuum

Engine vacuum has increased in modern engines because engine rpm, valve overlap and compression habits have also increased with these models. Some of the late model engines will draw as high as twenty five inches of vacuum on deceleration, as compared to twenty inches in older engines. This high vacuum characteristic has made it necessary for the development of an oil ring to seal both (top & bottom) sides of the ring grooves and eliminate oil from passing around the back and sides under high vacuum or deceleration. Such vacuum could be the main cause of smoking and oil consumption so it is important to use a side sealing piston ring when required by the application.

Worn Timing Gears

Worn timing gears can cause the valves to be out of time with the crankshaft. The large amount of backlash, which is caused by this wear, will prevent proper engine adjustment because timing may vary from one revolution of the crankshaft to another. When the valve and piston motions are not synchronized, extremely high oil consumption may result. This will be caused by excessive vacuum which draws large quantities of oil into the combustion chamber where it will be burned.

Piston Rings Fit with Too Little End Clearance

When fitting new rings sufficient end clearance is required to allow for expansion due to heat. Normal gap clearance in automotive engines with cast iron rings usually runs .003-.005 per inch of bore diameter. The rings will heat more rapidly and will operate at a higher temperature than the cylinder because they are exposed to the direct heat of the burning gases from the combustion chamber. The cylinder walls are kept at a lower temperature by the water in the water jacket. This means the rings expand more than the cylinder and this expansion must be allowed for by use of a gap - known as end clearance - between the two ends of each ring. If sufficient end clearance is not provided, the ends of the rings will butt while the engine is in operation.

Butting will cause scuffing and scoring of rings and cylinders which leads to oil consumption. If the engine is allowed to be used for continued operation, especially under heavy load, scoring will become more severe. The ends of the rings will be forced inward, away from the cylinder wall, and a space opens up between the rings and the cylinder. This provides a direct path for hot gases from the combustion chamber to burn the oil on the cylinder and greatly increases the oil consumption of the engine. Severe cases of butting may also cause ring breakage, with the same results as described in "Worn or Broken Piston Rings". Excessive ring end clearance leads to increase oil consumption as well.

Worn or Broken Piston Rings

When piston rings are broken or are worn to such an extent the correct tension and clearances are not maintained, they will allow oil to be drawn into the combustion chamber on the intake stroke and hot gases of combustion to be blown down the cylinder past the piston on the power stroke. Both of these actions will result in burning and carboning of the oil on the cylinders, pistons and rings.

Broken rings are especially damaging because their loose pieces with jagged ends are likely to cut into the sides of the piston grooves. This causes land breakage which results in the complete destruction of the piston assembly. Instead of reinstalling worn rings during engine overhaul, it is always advisable to replace them. New rings have quick-seating surfaces which enable the rings to control oil instantly, unlike rings which have been used in the past. Used rings, even those only slightly worn, will still have polished surfaces which will not seat-in properly and will lead to excessive oil consumption.

Piston Rings Stuck in Grooves

Oil cannot be controlled by piston rings which are stuck in their grooves. Every effort should be made to prevent rings from becoming stuck.

First, rings should be installed with sufficient side clearance to enable them to remain free while the engine is working under load at normal operating temperatures.

Second, every precaution should be taken at the time of assembly to ensure all parts of the engine are clean of any dirt particles which might cause the rings to stick.

Third, a good grade of oil should be used to lessen the possibility of carbon or varnish.

Fourth, the oil should be kept clean by regularly scheduled oil changes and proper care of the oil filter.

Fifth, every precaution should be taken to keep the engine from becoming overheated from any cause.

Late Valve Timing

Late valve timing will keep the intake valve closed too long after the intake stroke has started, and will increase the vacuum in the cylinder. The high vacuum will have a tendency to suck oil up past the piston and rings into the upper part of the cylinder where it will be burned.

Oil Pressure Too High

An incorrect oil pressure setting or a faulty relief valve may cause the oil pressure to be too high. The result will be the engine will be flooded with an abnormally large amount of oil in a manner similar to worn bearings.

Oil Viscosity

Refer to the engine owner's manual for the proper oil viscosity to be used under specific driving conditions or ambient temperatures. Use of oil with lighter than prescribed viscosity can lead to higher than normal oil consumption.

Lugging Engine

Lugging is running the engine at a lower RPM in a condition where a high RPM (more power/torque) should be implemented. This causes more stress loading on the piston and can lead to increases in engine oil consumption.

Leaking Turbocharger Seal

A leaking turbocharger seal will draw oil into the combustion chamber where it will burn and form carbon deposits which contribute to further oil consumption as they interfere with proper engine function.

Restricted Air Intake

Excessive restriction in the air intake system will increase engine vacuum and can increase oil consumption as noted in "High Engine Vacuum". A heavily plugged air filter would be one example of this situation.

7.3.1 TURBOCHARGER OVERVIEW

Definition

A turbocharger **(Figure 1)** is a radial fan pump driven by the energy of the exhaust gases of an engine. Turbochargers consist of a turbine and a compressor on a shared shaft. The turbine is a heat engine in itself. It converts the heat energy from the exhaust to power, which then drives the compressor, compressing ambient air and delivering it to the air intake manifold of the engine at higher pressure, resulting in a greater mass of air entering each cylinder.

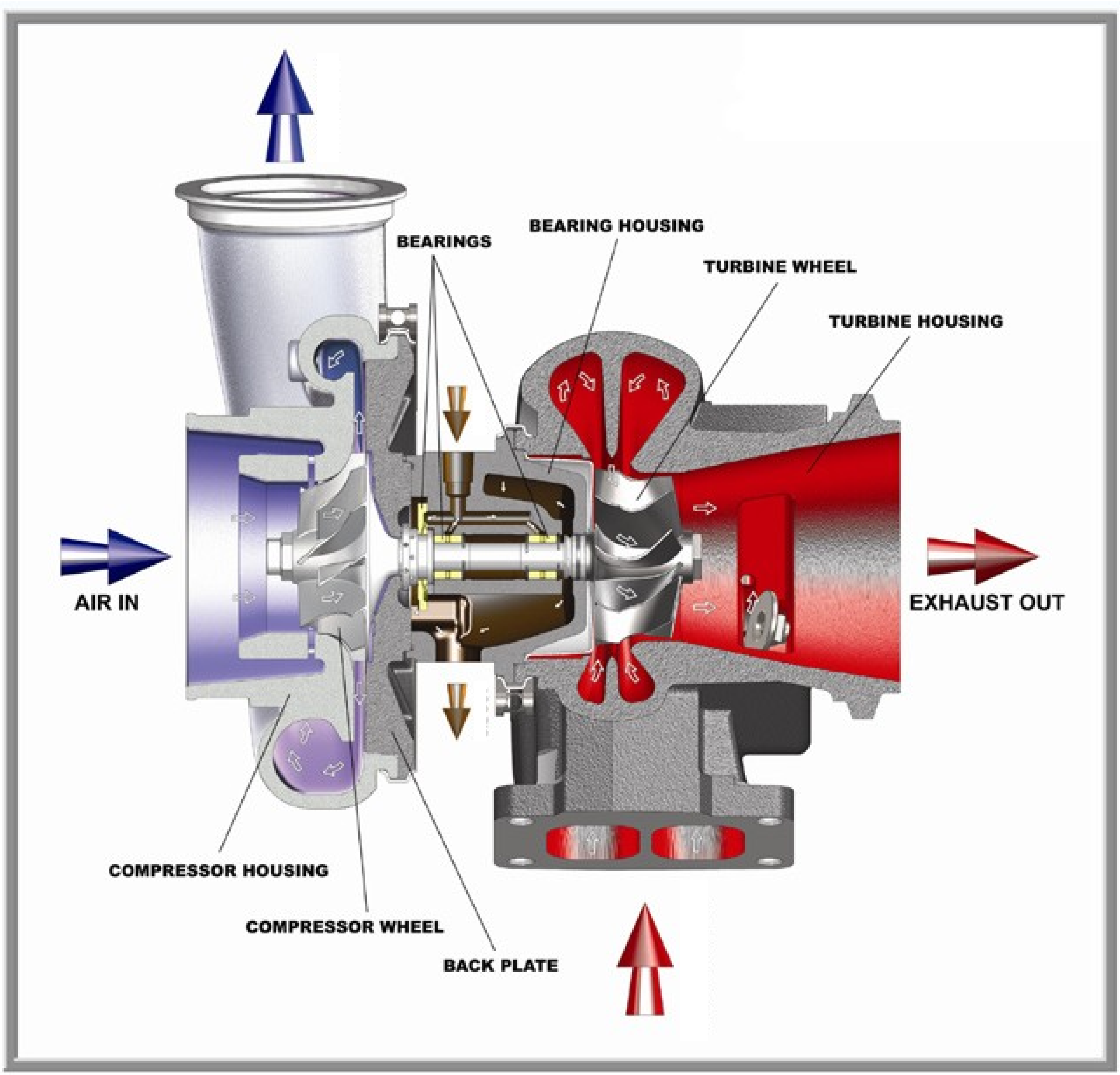


Figure 1: Diagram of Air & Oil Flow through a Turbocharger

Objective & Benefits

The objective of a turbocharger is to improve upon the size-to-output efficiency of an engine by solving one of its cardinal limitations. A naturally aspirated automobile engine uses only the downward stroke of a piston to create an area of low pressure in order to draw air into the cylinder through the intake valves. This ability to fill the cylinder with air is its volumetric efficiency. Because the turbocharger increases the pressure at the point where air is entering the cylinder, a greater mass of air (oxygen) will be forced in as the inlet manifold pressure increases. The additional oxygen makes it possible to add more fuel, increasing the power and torque output of the engine while reducing emissions.

Structure of a Turbocharger

A typical turbocharger assembly consists of the components shown in **Figure 2**. There are many variations of this assembly with minor differences. Some turbocharger assemblies will contain supplementary components such as a ball bearing cartridge, a variable nozzle turbine (VNT) assembly, or a wastegate. If you encounter questions regarding any of these supplementary components please contact Rotomaster for technical assistance.

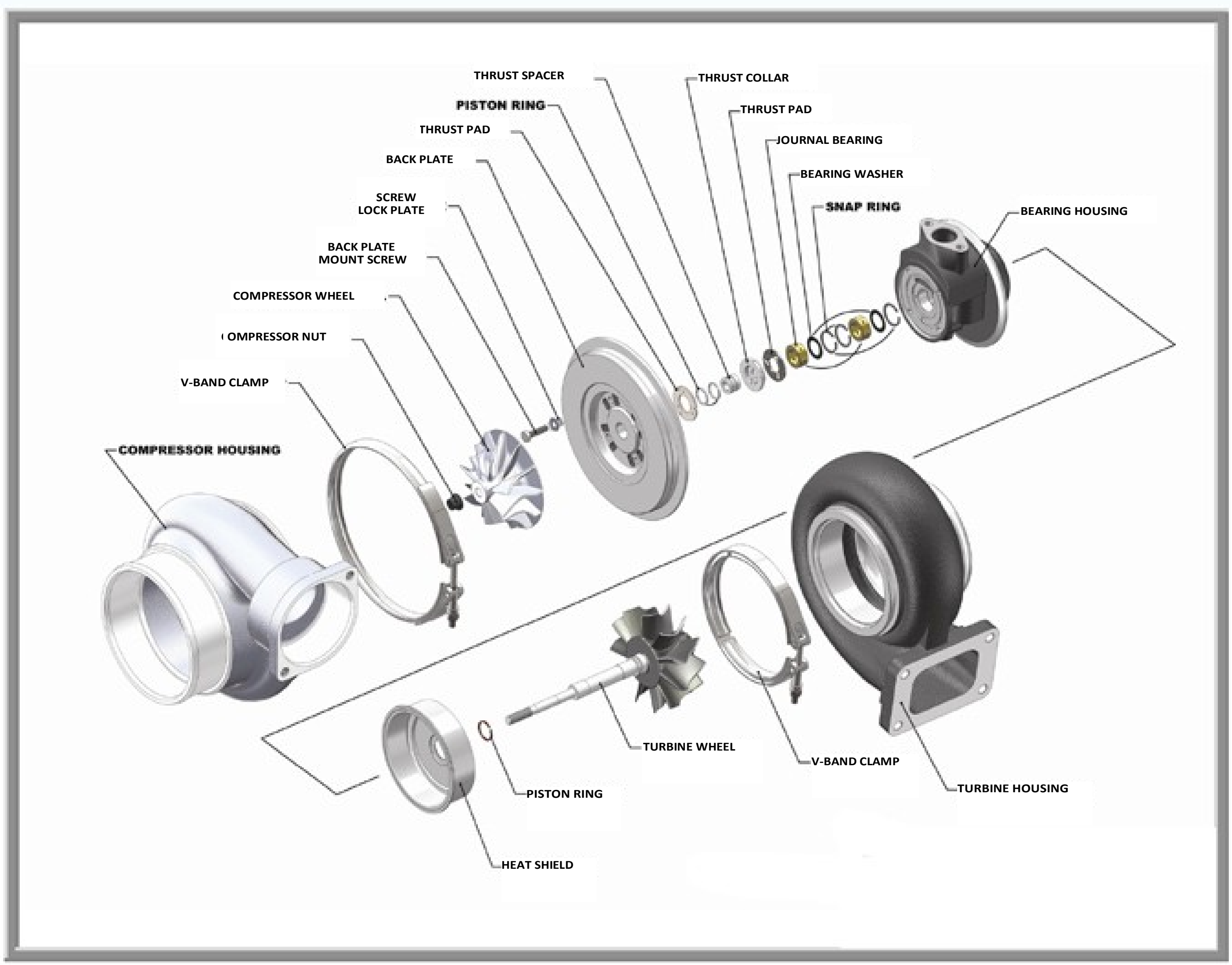


Figure 2: Typical Turbocharger Exploded View

7.3.2 MAINTENANCE AND TEARDOWN PROCEDURES

Periodic Maintenance & Inspection

In most cases, the damage severity of turbocharger failure can be greatly reduced by performing routine inspections during normal vehicle maintenance. Start by removing the turbine and compressor housings and inspect the state of the wheels and housings. If there are no abnormalities, do not disassemble further but rather inspect the bearings by manually turning the wheel assembly. The wheels should turn freely without any hindrance. You can also place a dial gauge on the wheel assembly to measure the axial play. If this play exceeds the maintenance standards in the service manual, the turbo should be removed and fully inspected.

Teardown Procedure

Start by performing a visual inspection of all components prior to removal. It is a good practice to keep detailed notes and take pictures of any visible abnormalities throughout this procedure. These notes will aid in the analysis, comparison to future cases, and also provide excellent feedback to the customer.

A typical teardown procedure is shown below **(Figures 3 to 6)**. Do not clean the components until they have been carefully inspected for oil blockages causing a lack of lubrication. Label the journal bearings as they are removed to aid in bearing analysis (Compressor Side and Turbine Side).

Figure 3: Remove Housings

Figure 4: Remove Wheels

Figure 5: Remove Back Plate

Figure 6: Remove Bearings, Washers, Etc.

7.3.3 COMMON CAUSES FOR TURBOCHARGER FAILURE

This section will discuss the four primary causes for turbocharger failure. It is important to note that when a turbocharger fails for any reason, there is almost always secondary (and often more severe) damage caused by the resulting shaft motion. You must look passed the obvious damage to locate the root cause. Note that some "cause of failure" descriptions contain very similar indicators so be sure to read through all prior concluding your analysis.

Lack of Lubrication / Contaminated Oil (Causes over 40% of Failures)

The lubrication system plays a vital role in extending the life expectancy of a turbocharger by lubricating, cooling, and cleaning the bearings. The shaft and bearings must "float" on a constant, clean film of oil to prevent direct contact with each other which will result in damage. Any lack of oil flow or foreign contaminant (i.e. dirt, sand, or metal shavings) in the oil will cause excess wear and/or scaring on the bearing surfaces. This wear will often increase the clearances between rotating components resulting in excess "shaft motion". A large amount of "shaft motion" is detrimental to the life of a turbocharger.

Common causes of lubrication failure:

- Low engine oil pressure/level
- Obstructed oil supply or drain lines
- Improper weight of oil
- Contaminated oil
- Fast starts in cold weather
- Hot shutdown **(Figure 7)** - Engine is shutoff at high rpm/temp; instant oil flow loss causing overheating
- Engine Blow-by

A. External Lack of Lubrication:

- Occurs when anything exterior to the turbocharger is affecting the oil flow (supply or drain lines, engine blow-by, etc.).
- All thrust & journal bearings as well as the turbine shaft will show signs heat discoloration **(Figure 8)** as well as wear from the resulting shaft motion. The wear will appear smooth or "wiped" **(Figures 9 & 10)** and should not have any significant scaring **(Figures 11 & 12)**.
- **Unwarrantable:** The cause of this failure is external to the turbocharger.

B. Internal Lack of Lubrication:

- Visible when one or more, but not all, of the bearings show the above mentioned wear. This indicates that only one of the oil feed lines have been blocked from either contaminated oil (see below) or a manufacturers defect.
- **Warrantable:** If there are no signs of contaminated oil.
- **Unwarrantable:** If there are signs of contaminated oil or "coking" of the oil caused by overheating.

C. Contaminated Oil:

- Occurs when abrasive material such as dirt, sand, or metal shavings enters the oil passages. This is generally easy to notice as the bearings and connecting components will show abnormal grooves and scratches **(Figures 11 & 12)**. This may also cause a lack of lubrication failure as noted above.
- **Unwarrantable:** The cause of this failure is related to the installation or oil quality within the vehicle.

Figure 7: "Hot Shutdown"
Turbine Wheel Shows Visible Bearing Pattern and Heat Discoloration

Figure 8: Turbine Shaft Lack of Lubrication Turbine Wheel Shows Visible Heat Discoloration and Smeared Wear

Figure 9: Journal Bearing Lack of Lubrication

Left = New Bearing; Right = Smooth Wear & Heat Discoloration

Figure 10: Thrust Bearing Lack of Lubrication

Left = New Bearing; Right = Smooth Wear & Heat Discoloration

Figure 11: Journal Bearing Contaminated Oil

Visible Scaring on Inner and Outer Diameters

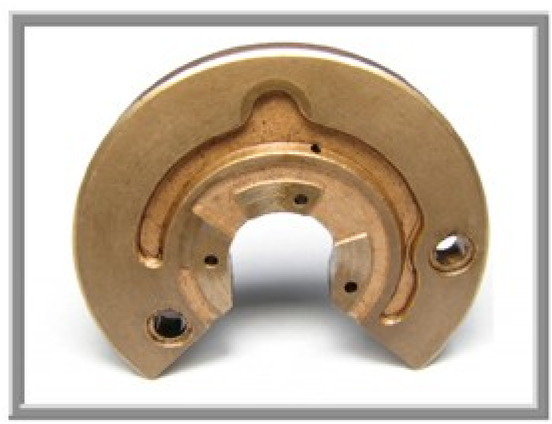


Figure 12: Thrust Bearing Contaminated Oil

Visible Scaring on Pads

Foreign Material in Exhaust or Air Inlet

Foreign particles (i.e. Screws, nuts, sand, metal power, broken air filters, etc.) entering the turbine or compressor stages will damage the rotating turbine or compressor blades. Both wheels are accurately balanced to perform at extremely high operating speeds required by their application. If either wheel is damaged in any way, the rotating assembly will no longer maintain its balanced state which will result in severe shaft motion causing almost every component of the turbocharger to fail.

In many cases, this is the most obvious damage to recognize as the compressor or turbine wheel will often show severe damage without removing the housing **(Figure 13 & 14)**. However, in some scenarios, this is a gradual erosion of the wheel from fine particles such as sand or dirt. In this case, the wheel will display small pits across the vanes or minor wear on the inducer tips.

Although rare, this failure may also be caused by the compressor wheel lock nut loosening off and entering the compressor vanes **(Figure 18)**. This failure originates from assembly if the lock nut was not tightened to the specified torque setting or the Loctite® compound was not applied.

- **Warrantable:** If the compressor wheel lock nut is the visible cause of failure.
- **Unwarrantable:** If caused by any other foreign material external to the turbocharger.

Figure 13: Compressor Wheel Foreign Material

Severe Damage to the Vanes on the Wheel

Figure 14: Turbine Wheel Foreign Material

Severe Damage to the Vanes on the Wheel

High Exhaust Temperature

Excessive temperature in the exhaust system will cause the lubricating oil to "coke" in the bearing housing drain annulus at the turbine end **(Figure 15)**. This causes oil leakage into the turbine housing. Coke and carbon deposits will be visible and eventually damage the back of the turbine wheel and cause abnormal wear on the thrust bearing. High exhaust temperatures can also erode **(Figure 16)** and crack **(Figure 17)** the turbine housing and/or bearing housing. Excessive heat discoloration of the turbine shaft is usually visible. The piston ring in the turbine side of the bearing housing will often appear relaxed if it has been submitted to these high temperatures.

High exhaust temperatures can originate from several operating conditions shown below:

- Incorrect fuel ratio (high fuel setting)
- Insufficient air supply caused by a plugged air cleaner, etc.
- A leak in the intake manifold or piping
- Excessive exhaust restrictions
- Plugged aftercooler core

- **Unwarrantable:** Unless incorrect compressor or turbine housings were assembled originally.

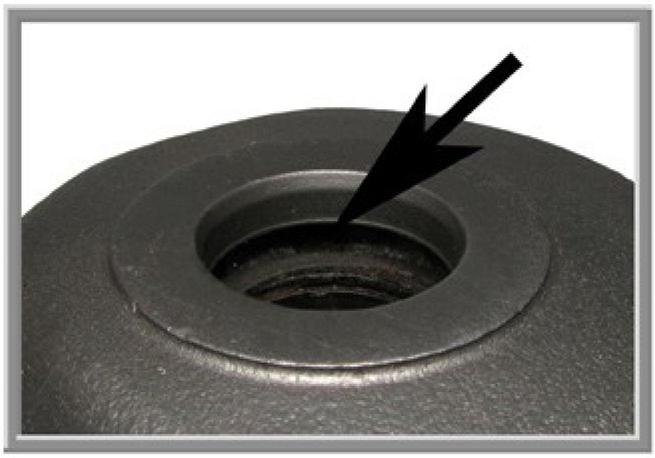


Figure 15: Bearing Housing High Exhaust Temp

Blocked Drain Annulus from Oil Coking

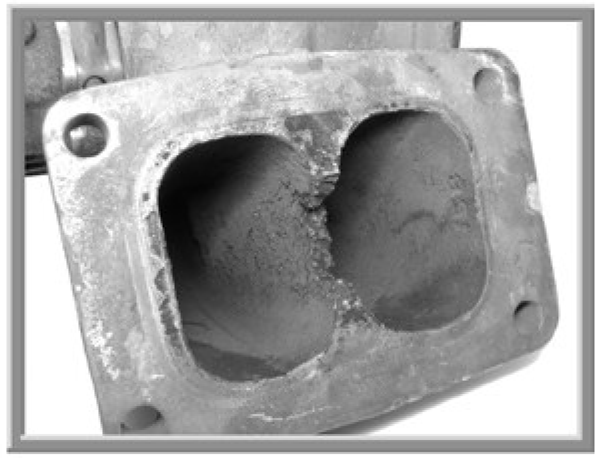


Figure 16: Turbine Housing High Exhaust Temp

Erosion of Web Caused by High Temperatures

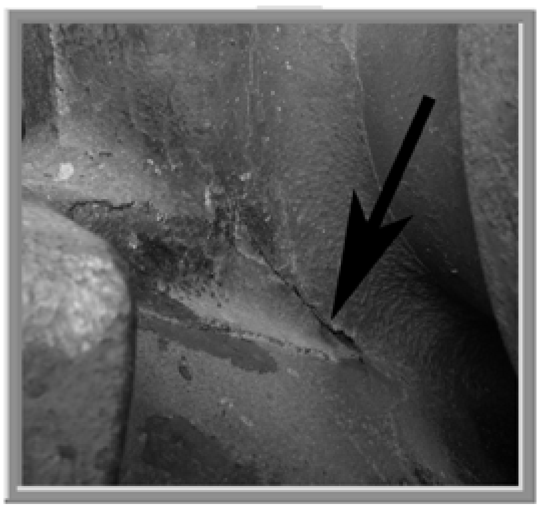


Figure 17: Turbine Housing High Exhaust Temp

Cracked Housing Caused by High Temperatures

Defective Workmanship or Material

While these occurrences are rare, the visible evidence is often easy to recognize. Some examples are displayed and explained below.

- **Warrantable:** If the defects originate from the manufacturer.
- **Unwarrantable:** If the defects originate from the installation.

Figure 18: Compressor Wheel Lock Nut Failure

Nut is missing, foreign object damage to vanes

Figure 19: One Sided Wear on Compressor Housing

Can be caused by improper manufacturing or assembly

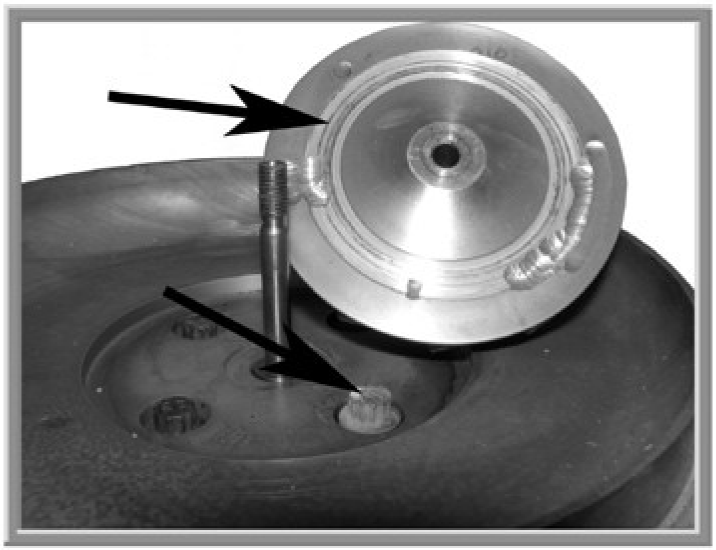


Figure 20: Back Plate Bolt Loosened and Contacted Back of Compressor Wheel

Can be caused by improper assembly (No Loctite®)

Common Failure Diagrams

Below and on the next page are four examples of Turbocharger failure due to improper installation or vehicle systems **(Unwarrantable)**.

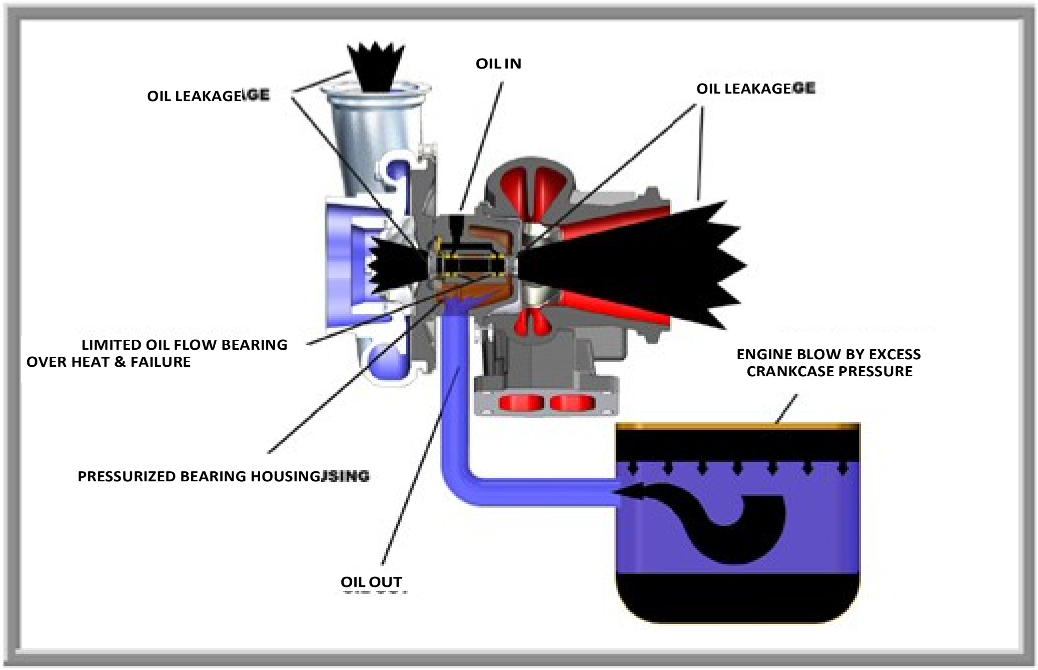


Figure 21: Engine Blowby

Increased crankcase pressure causes flowing oil to squeeze out of the piston ring gaps and also reduces the amount of oil to the bearings causing failure

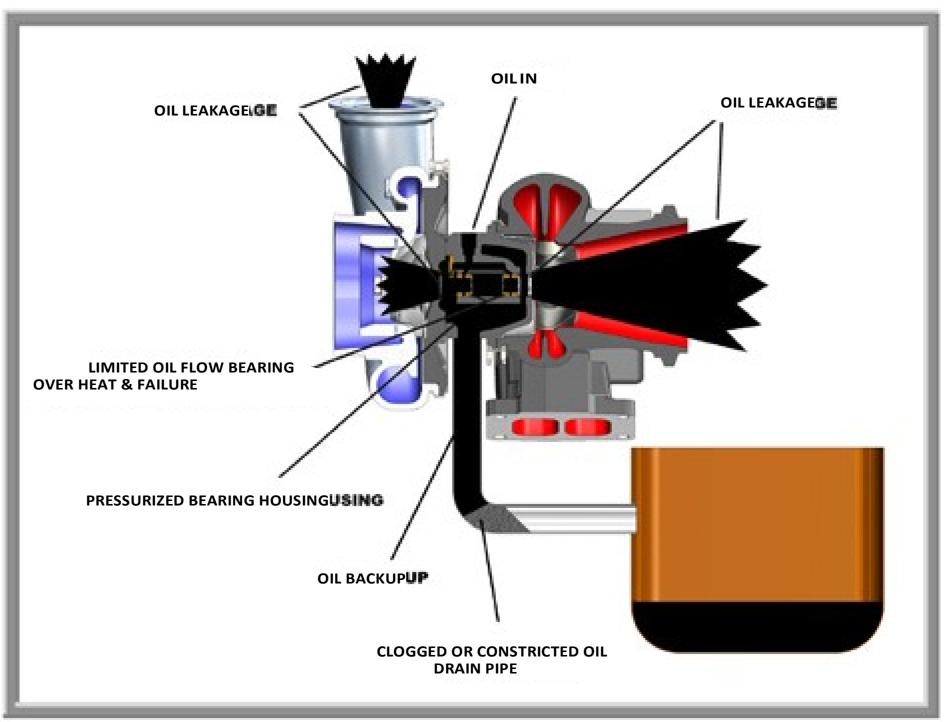


Figure 22: Clogged Oil Drain Pipe

Oil cannot flow and pressurizes the drain area causing oil leakage and bearing failure

Common Failure Diagrams (Continued)

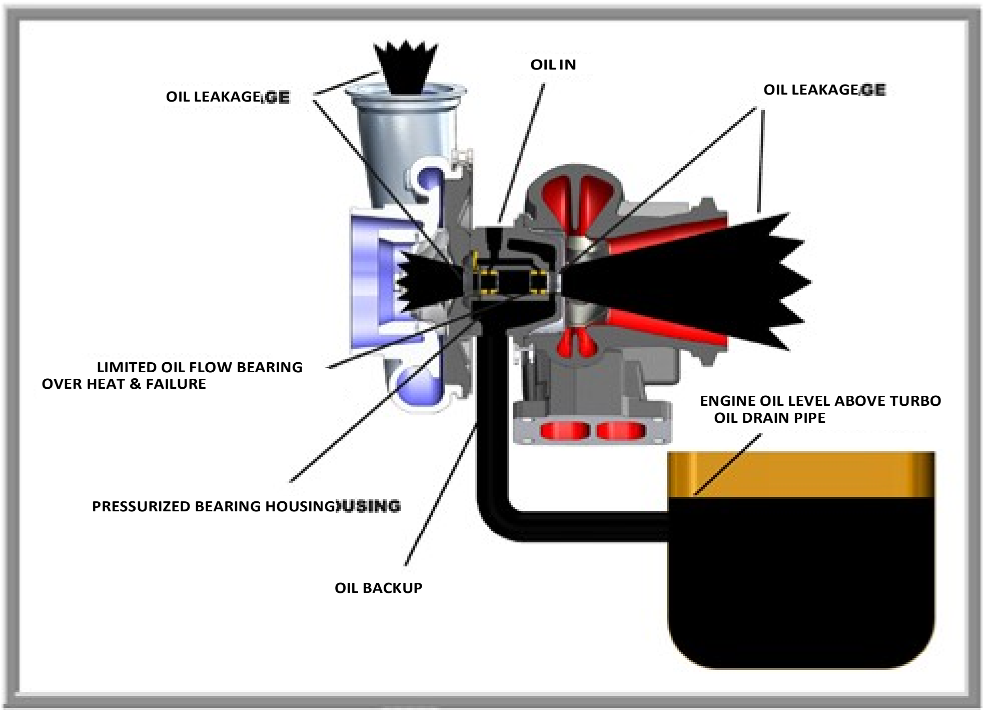


Figure 23: Oil Level Too High

Minor pressure in the crank case will prevent oil from flowing which pressurizes the drain area causing oil leakage and bearing failure

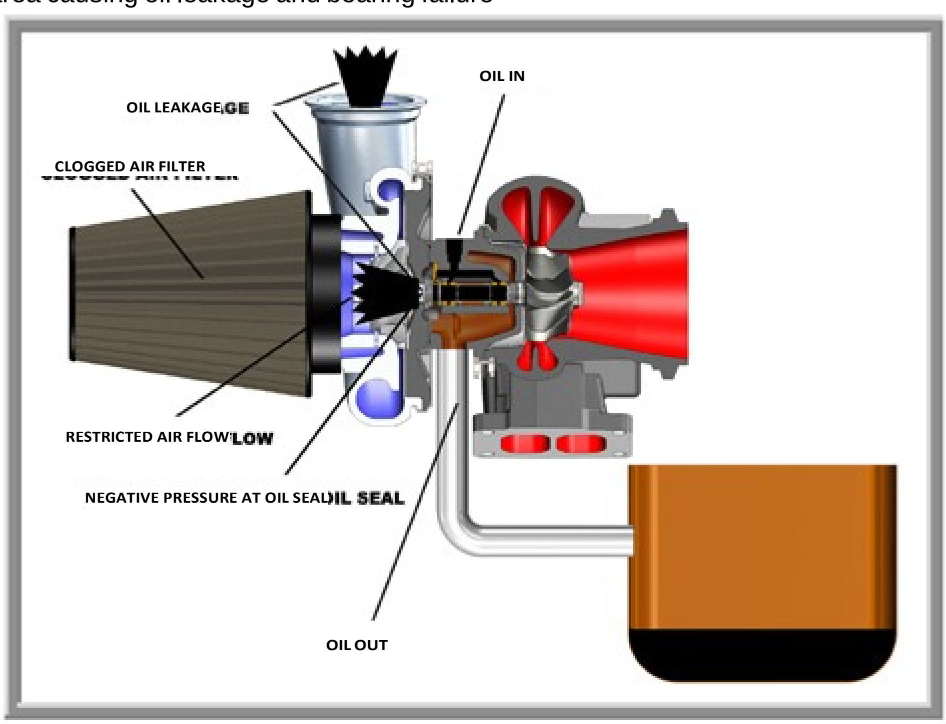


Figure 24: Clogged Air Filter

Reduced air flow in the compressor inducer will create high vacuum pressure which will suck oil into the compressor side of the turbocharger

7.3.4 INSTALLATION, SUMMARY, AND WARRANTY REPORTING

Before a New Turbocharger is Installed

It is important to inform the customer of the analysis results. In most cases, the cause of failure originates from either an installation error (foreign material, etc.), improper vehicle systems (oil lines, etc.), or improper operation of the vehicle (hot shutdown, etc.). Ensure the cause of failure is fixed and/or the customer is educated about the cause of failure prior to installing a new turbocharger to avoid a repeat failure.

Summary

There are many factors that can greatly reduce the life of a turbocharger. This text was designed to serve as an educational guide to improve our customer's knowledge. In most cases, turbochargers fail due to improper use or maintenance by the end user. It is hoped that better informing our customers will reduce the time required to get this information to the end user and also reduce costs related to warranty returns.

Please contact Interstate-McBee toll free at 1-800-321-4234 if you have any questions regarding this text or if you encounter a failure which is not discussed or difficult to determine the root cause.

Warranty Reporting Process

We encourage our customers to understand that there can be long delays and costs related to warranty returns. Customers must first call to obtain a RGA # prior to sending a failed turbocharger to Interstate-McBee. To aid in the analysis process, we ask that customers supply as much of the information shown below as possible.

Customers are to supply the following information if a turbocharger is returned for further analysis:

Example Turbocharger Warranty Report	RGA #:	
	Date:	

Customer Information					
Customer:		Contact Name:		Invoice #:	
Phone #:		Fax #:		E-Mail:	

Product Information					
Part #:		Model #:		Serial #:	
Install Date:		Failure Date:		Hours in Operation:	

Description