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'Thermal Fracture'

Recently, I have dealt with cases where thermally induced fracture has either occurred or been alleged. Arguments raised in connection with these matters have illustrated a misunderstanding of the role of temperature in the fracture of metallic components. Contrary to what is frequently stated, overheating of engine cylinders and other large metallic parts is not often the cause of fracture. Fracture is normally caused not by heating but by cooling. Cooling usually follows heating and it is therefore the case that fracture often follows an episode of unusual heating. But in undertaking a serious technical investigation one must be clear how and why this is.

A crankshaft bearing overloaded or inadequately lubricated may overheat. As the shaft rotates more or less swiftly the rise of temperature is uniformly distributed around the bearing journal. Being subject to direct frictional effects, the surface of the journal will heat the most, but the increasing temperature will also seep inward to heat the thick core of the shaft.

Figure 1 - Pattern of hairline crankshaft cracks revealed by dye penetrant.

It is commonly appreciated that all engineering metals expand when heated. As metal is heated the atoms move apart. In the case of steel, the linear expansion coefficient 'α' = $12 * 10^{-6}/^{o}C$, which is to say that for every increase in temperature of $1^{o}C$ a bar of steel will expand by about twelve millionths of its original length.

If a steel bearing surface is heated by, say $300^{o}C$, the layer of metal at the surface would expand by about four thousandths of its original circumference. For a 500mm diameter bearing this would be an increase of about 5.6mm. The heated shaft and bearing surface would expand freely. Any constraint to expansion arising from a difference in temperature between the shaft surface and the interior would tend to induce a compressive stress in the surface, whereby the crystals and molecules are squeezed together, the very opposite of what is required to cause a fracture.

When a heated bearing is noticed by the operator the engine will usually be stopped. As the crankshaft comes to a halt, some part of the overheated journal will be in static contact with a cooler section of the fixed bearing housing. This part of the crankshaft will be cooled relatively quickly. For every degree of cooling the metal will shrink according to coefficient α and the cooled outer section will be stretched over the still hot and expanded inner layers of steel. This reverses the stress regime and induces tensile 'hoop stress' in the surface. This stress will be much more severe than the mechanical stresses resulting from normal engine operation and it is common for cracks to occur in the hardened outer material layers. As the term implies, 'hoop stress' mimics the stress pattern in the steel hoops applied to hold the staves of a traditional barrel together and cracks caused by this stress are easily recognised by their location and the fact that they run parallel to the axis of the shaft. Usually, such cracks are shallow and 'hairline' but very sharp at the ends. Because of this they form perfect starting points for the development of fatigue cracks if the engine is kept in service.

Thermal cracks are also discovered in engine pistons, cylinder liners and cylinder heads. Here, they are most often caused by 'thermal fatigue'. Cyclical heating and cooling repeats, possibly many times, the simple one-off process normally responsible for crankshaft cracks.

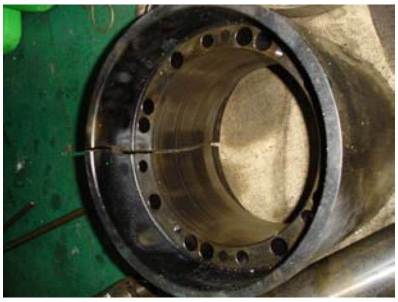

Figure 2 - Severe fracture of piston skirt caused by thermal hoop stress.

The levels of thermal stress generated are potentially more severe than the mechanical operating stresses but in common with repetitive mechanical stress, each cooling part of the thermal cycle induces tensile load. Repeated tensile load is responsible for the initiation and propagation of fatigue cracking. In deciding whether, for example, a cylinder liner has been fractured by thermal or mechanical stress it is instructive to take note of the orientation of fracture. As with the crankshaft, thermal fracture only occurs when metal sections are constrained against shrinkage as they cool from a high to a low temperature. The direction of the stresses, and therefore of fractures, are decided by the directions in which constraint is possible. In the case of a cylindrical cylinder liner constraint is only possible in the circumferential sense, not linear. Therefore, as cracks always form perpendicular to the line of action of the stress causing them, thermal cracks in a cylinder liner are generally orientated axially. Careful consideration of the component geometry is required to diagnose more complex shapes such as cylinder heads.

This series of occasional Technical Notes is intended as a service to the enlightened lay reader and to explain marine engineering issues which are topical or which appear from time to time as issues in maritime disputes.

Alex Sinclair is an independent consulting marine engineer with over 26 years experience of casualty investigation, arbitration and litigation. A full CV is available at www.ajsinclair.com.