

When conducting a complete failure analysis, tooth cracks are often found to be a culprit. The following installment discusses why this happens, and how it can be avoided.

Cracks originating in the surface of the tooth flank are due to Hertzian stressing at a depth relative to the maximum Hertz shear stress. The Hertz law provides the radius of contact between a sphere of elastic material and a surface in terms of the sphere's radius, the normal force exerted on the sphere, and Young's modulus for the sphere's material.


In addition to the two principally recognized failure modes, namely contact fatigue and tooth root bending fatigue, has been added TIFF (Tooth Interior Fatigue Failure). The crack initiation is at mid height on the tooth and slightly below the case-core boundary. The failure is created by constant residual tensile stresses in the tooth interior resulting from the case hardening process, combined with alternating stresses that arise when the gear functions as an idler. It is estimated that when the gear is to be used as an idler, the risk of a TIFF failure increases 20 percent. This type of failure can also appear at loads below those that are required for tooth root bending fatigue.

Residual stresses are created by operations such as plunge grinding that can selectively heat the surfaces. Grinding cracks are the inevitable result of excessive heating of the localized areas of the tooth flank due to the grinding operation itself. This manufacturing problem is extremely costly, as it occurs in one of the final operations. When a localized area becomes heated the surrounding harder and stronger regions restrict the material's ability to expand. When the residual stress exceeds the strength of the tempered steel, cracks will result. Unfortunately there are occasions when these cracks do not make

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an appearance until the gear is placed in service. A stress relieving temper that is applied after grinding will reduce the possibility of cracks in service. The cracks due to grinding extend into the lower layers of the hardened case until the residual stress pattern is balanced. The grinding process by its very nature has the tendency to set up a residual stress in the ground surface. The depth of this stress is dependent on the grinding wheel's fineness. The cracks can also be formed under severe grinding conditions in unhardened tooth flanks. The cracks are not very deep (0.005") and appear as a series of parallel cracks or in a "chicken wire" mesh pattern. These cracks, however, can initiate and lead to stress risers, eventually leading to actual tooth breakages. The structural damage usually will occur at the tooth tip. When the tooth root is also being ground, extra material is being removed, and this increases the likelihood of burning. Nital etching is used in many industrial applications to inspect for the structural damage that might have

resulted from the grinding operation. The method is quick and relatively simple, but it will only detect B- and D-class damage. Different grinding processes create different distributions and intensities of the structural damage. AGMA Standard 2007-C00 "Surface Temper Etch Inspection after Grinding" is the recognized document for the inspection. However, even such detailed inspection is not foolproof.

A more recent development that is known as "magnetic rubber inspection" has been modified to detect crack lengths as small as 0.006", and maximum depths to an accuracy ± 0.002 inch. In the mid 1980s the Barkhausen noise inspection method for detecting grinding damage was first developed. The method is simple to use and can reduce product failure to zero percent. An important paper by Wojtas et al, "Detection of Thermal Damage in Steel Components After Grinding Using the Magnetic Barkhausen Noise Method," was presented in Hannover in September 1998. The paper explains that damage may commence with a partial relaxation of desirable compressive stresses at temperatures below 500°C. As temperatures increase to nearly 600°, B-class thermal damage known as re-tempering burn occurs. This overtempering results in a reduction in surface hardness and the onset of tensile stresses. When temperatures increase beyond 720°C D-class thermal damage is created, which is considered to be a rehardening burn. The tooth flanks and/or root may then consist of very hard and brittle material with surrounding areas of B-class burn "soft" material. The residual stresses will also be compressive in some areas and highly tensile in other places. 

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