EVIDENCE AND ANALYSIS OF THERMAL STATIC STRAIN AGING IN THE DEFORMED SURFACE ZONE OF FINISH-MACHINED HARDENED STEEL

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After heat treating of formed workpieces, finish machining of the hardened steel, e.g. by turning, milling, cutting, grinding and honing, polishing or lapping, represents the last manufacturing step in the standard production cycle of machine elements. By this final shaping, functional surfaces of adjusted roughness and optimized profile for good wear resistance and fatigue strength are fabricated. Crack-inhibiting compressive residual stresses built up by efficiently cooled mechanical material removal in the plastically deformed edge zone further improve the lifetime, e.g., of Hertzian loaded parts like rolling bearings, camshafts or cogwheels. The practically most important finishing operation of grinding is applied to ensure best surface quality and dimensional accuracy of complexly shaped components. Metal removal involves high plastic deformation work. Glide and intersection processes raise the dislocation density and produce lower energy substructures, such as multipoles. In hardened steel, where grinding generates residual stresses of up to about –500 MPa on the surface, the X-ray diffraction (XRD) line broadening thus simultaneously decreases slightly in the plastically strained edge zone. These considerations suggest that subsequent heating is suitable to stabilize the mechanically formed energetically favorable dislocation configuration by the development of interstitial carbon Cottrell atmospheres, which should enhance the fatigue resistance.

The temperature and time dependence of post-machining thermal treatment (PMTT) is investigated on the example of ground and honed through hardened SAE 52100 rolling bearing steel. The associated microstructural stabilization is expressed in a large XRD line width decrease on the surface. The measured kinetics of isothermal PMTT can be modeled by rate-controlling carbide dissolution that represents the source of carbon for dislocational segregation. The corresponding reduction in line width follows an Arrhenius-type time-temperature relationship. The superimposed decrease due to thermal recovery occurs much slower so that both effects are separable. Static strain aging is also verified by the formation of a slight white etching surface layer. Temper carbides in the outermost material are cut or deformed by the grinding process. The tendency of these damaged nanosized particles to dissolve and release carbon is high since the surface energy increases with curvature. Reheating below the martensite tempering or bainite transformation temperature prevents hardness loss by post-tempering. The narrow edge zone of about 10 μm thickness, which is mechanically affected by grinding and subsequently thermally refined by reheating, represents the highest loaded region of the steel, for instance, in case of dense raceway indentations or under boundary lubrication and mixed friction. Such surface-critical service conditions occur, e.g., in the majority of bearing, cogwheel or camshaft applications. Accelerated rig tests of finished balls under poor lubrication provide an increase of the lifetime by a factor of about two due to PMTT. This result indicates practical potential of the simple low-cost reheating treatment for certain operation conditions in the surface failure mode of rolling contact fatigue.