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Fatigue test results of surface hardened components to evaluate a two layer approach for strength assessment

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Abstract

In the automotive industry, forged steels are commonly used for powertrain components such as gears, axles or crankshafts. In order to minimize wear and increase fatigue strength, these mechanical engineering parts are usually surface-hardened. The surface heat treatment leads to a significant change of the local material properties in the heat effected zone of the surface area.

This paper addresses an effective two-layer model for evaluating fatigue strength of surface hardened components based on local stresses. Hence, one layer represents the induction-hardened surface and the second characterizes the base material. The aim of this elaborated method is a more reliable computational estimation of fatigue life among other assessments based on technological benefit factors for components designed for the high cycle fatigue (HCF) regime by taking into account local material properties, defects and residual stresses.

In order to verify the presented method and to determine the local manufacturing process-dependent fatigue strength, specimens are extracted from highly stressed component areas considering forged grain structure. The sample notch shape represents typical notch types in mechanical engineering parts regarding form factor, stress gradient and highly stressed volume. The idea behind the fatigue tests is to study material samples exhibiting a comparably minor residual stress condition in both hardened and unhardened condition to separate the cause variables residual stresses, strength of base material and martensitic phase on fatigue strength. Compared to the unhardened base material, the fatigue tests at different stress ratios revealed higher fatigue strength within low and high cycle fatigue of the martensitic material.

Considering these input data in combination with the fatigue strength of each material section, the layer approach enables a more reliable local fatigue assessment among other fatigue evaluation methods based on technological benefit factors.

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Keywords: fatigue strength, surface-hardened components, residual stresses

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Present automotive products within continuous development process are subjected to the claim of consistent vehicle light weight design[1]. Hence the declaration of component safety has a high priority. In the automotive industry highly-stressed structural parts such as gears, axles or shafts are usually surface-hardened with the aim of minimizing wear and pitting[2] and increasing fatigue strength[3]. In comparison to weight-critical or package limited design changes surface-hardening achieves efficiently an ascending fatigue strength[4]. Thermochemical surface-hardening techniques[5, 6] causing further strength enhancement due to heat treatment are e.g. nitriding, case and induction hardening[7]. Within the heat affected zone processes of microstructure transformation and development of compressive residual stresses[8] occur. As depicted in Fig. 1 crack initiation beneath the surface layer according to different mean stress sensitivies of martensitic structure and base material at stress ratio $R = -1$ is possible. Mentioned effects regarding the different hardening processes are taken into account within fatigue design guidelines[9]. For ensuring an appropriate computational fatigue design this paper evinces a two layer material approach considering different material properties of the surface-hardened layer and the subjacent core material. A forged crankshaft with induction hardened main and conrod bearing areas is considered. Latter areas possess a martensitic structure as a result of the induction hardening process. Small-scale round specimens are extracted from crankshafts and uniaxial fatigue tests for both layers incorporating varied specimen hardness are pursued. As base material a AFP steel is used, which is common for forged and induction hardened components.

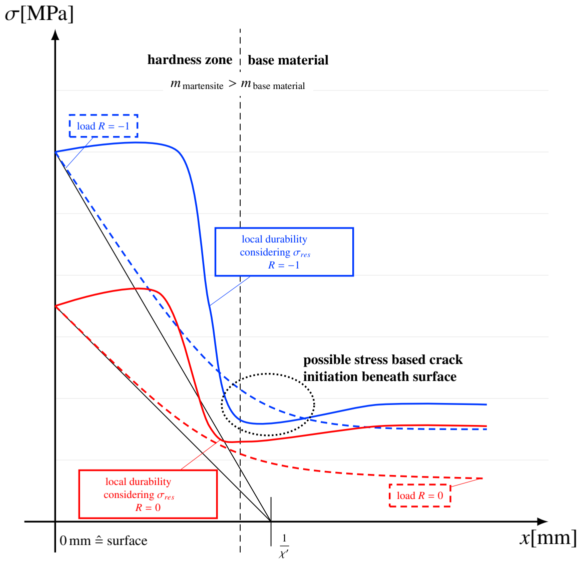

Fig. 1. Mechanical load vs. mechanical durability of surface hardened components

Nomenclature

σ_{res}	residual stresses [MPa]
α	angle of notch [°]
D,d	diameter [mm]
r_1	radius unnotched specimen [mm]
r_2	radius notched specimen [mm]
L	specimen length [mm]
R	stress ratio [−]
k	slope [−]
σ_a	nominal stress [MPa]
σ_m	mean stress [MPa]
N	load cycle [−]