High-Temperature Gear Materials

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QUESTION #1

What gear material is suitable for high-temperature (350 – 550° C), high-vacuum (10 –8 torr), clean-environment use?

Expert response provided by Dr. Philip Terry:

From time to time, general questions arise concerning the maximum temperature at which gear materials can operate — or specific questions about what material is suitable for a specific — usually elevated — temperature. When faced with these questions, gear metallurgists and material technologists usually look at the limits imposed by virtue of the previous thermal processing of the gear materials. Gears are rated (that is, the ability of the gear teeth to carry Hertzian contact stresses and bending loads) as a function of the hardness of the material and, in particular, the surface hardness of the tooth.

The hardness of gear steels is typically achieved by through-hardening (quenching and tempering), nitriding or carburizing.

In the production of through-hardened gears, the part is taken to a high temperature to austenitize the material, and then quenched in oil, water or other cooling medium to produce a hard, martensitic, metallurgical structure finally tempered to impart toughness and ductility. The tempering temperature is typically in the range 900 to 1,150°F. Following this final temper, any exposure to temperatures at or close to the selected tempering temperature will reduce the hardness of the material and, consequently, lower the load-carrying capability of the material when used for gearing.

Nitriding is also typically performed in the region of 900°F, and so material intended to be nitrided is normally tempered at around 950°F to avoid over-tempering during the nitriding process. Nitrided gears are, therefore, constrained to running temperatures below 900°F to prevent softening in service.

The highest hardness material used in industrial gears and therefore the gears with the greatest load carrying capability are those which are surface hardened by carburizing. However the final tempering temperature used on carburized gears immediately prior t°Finishing is in the region of 375°F, and although carburized gears have the highest known load capacity, this low tempering temperature restricts the temperature at which they can be used to around 300°F.

Below is a summary table based on ensuring that gear hardness does not drop as a result of exposure to high temperature in service based on a maximum temperature 50°F below the final temperature used on the material during thermal processing.

Temperature limits for gear materials	
Process Temperature Limit	**°F**
Through-hardened	850
Nitrided	850
Carburized	300

The values shown in the table are typical levels; if details of a specific heat treatment cycle are known, and higher final temperatures are used, the limits can be raised to within 50°F of the actual temperature. Similarly, if a specific service temperature needs to be accommodated, lower limits can be imposed on the tempering temperature to ensure that parts will not soften due to over-tempering in service.

The temperatures quoted here are for the commercial alloys most frequently used for gear manufacture; other more specialized alloys exist which have been specifically designed for higher temperature applications such as the Pyrowear family of alloys for carburized parts. Some of these alloys are tempered after carburizing at 550°F, thus extending their range of application up to 500°F.

The comments in this article refer to the temperature limits of the steel base material of gears, and do not discuss the issue of temperature limitations for gear lubricants, which need to be evaluated separately.

Dr. Philip Terry was born and educated in the U.K., receiving in 1972 his doctorate in materials science/fracture mechanics. He has decades of metallurgy-and-materials experience in various design and managerial capacities at companies such as British Steel Corp., Cameron Iron Works, and, for 15 years until his retirement in 2011—Lufkin Industries. Terry has also been an invaluable AGMA member over the years, having served on or chaired many of its materials- or heat treat-related committees. He currently serves as the standing U.S. representative on ISO TC 60 WG 14 – Metallurgy. Terry is now *un-retired,* working as an independent consultant specializing in material selection, heat treatment, welding-and-fabrication, and failure analysis *(Philip.terry@orange.fr).*

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