Additives: Anti-Wear vs. Anti-Scuff Is One Better?

QUESTION

While I have read a reasonable amount of the literature on the pros and cons of anti-wear and anti-scuff additives, I find that the more I read, the more confused I become. I could use some clarity in my life. Can you help?

Expert response provided by Robert Errichello and Angeline B. Cardis.

Anti-Wear and Anti-Scuff Additives

The natural oxide layer that forms on metals when they are exposed to the atmosphere is the simplest wear protection. Unfortunately, under boundary lubrication, the oxide layer is easily removed under light load, resulting in the risk of metal-to-metal contact.

Anti-wear and anti-scuff additives affect lubricant performance by controlling wear and friction characteristics under boundary lubrication conditions. A properly formulated gear lubricant contains additives that protect gear tooth surfaces at both low and high temperatures. The additives function by one of the following mechanisms:

- Physical adsorption
- Chemical adsorption
- Chemical reaction

Physical adsorption. Lubricants with polar additives, such as long-chain fatty acids, adsorb to the oxide layers on metal surfaces to form a layer of molecules that reduces friction and wear. These additives are effective at low loads and low temperatures, but lose their effectiveness at temperatures between 80°C and 150°C — depending on the type of additive. They are called lubricity additives and are often used in lubricants for worm gears.

Chemical adsorption. Lubricants with additives such as tricresylphosphate (TCP) or zinc dialkydithiophosphate (ZnDDP) that chemically bond to the oxide layers or metal surfaces provide anti-wear protection that is more durable than that provided by physical adsorption. They are effective at moderate loads and moderate temperatures up to about 200°C. Beyond this temperature, the chemically adsorbed films desorb or are rubbed off and have limited load capacity.

Chemical reaction. Lubricants with anti-scuff additives are designed to react with the parent metal surfaces to provide protection under severe loads and high temperatures where the oxide layers and chemically adsorbed anti-wear films on metal surfaces are disrupted. Anti-scuff additives contain at least one chemically reactive nonmetal such as sulfur or phosphorus that readily reacts with exposed metal surfaces to form a tribofilm with low shear strength. These sacrificial films reduce friction and wear and help prevent scuffing by forming solid films on gear tooth surfaces and inhibiting true metal-to-metal contact. The films of iron sulfide and iron phosphate have high melting points, allowing them to remain on the gear teeth even at high contact temperatures up to about 700°C. The formation and loss of the tribofilms are determined by competition between the opposing processes of chemical reactivity with the metallic surfaces and mechanical removal of the tribofilms caused by the sliding action of the gear teeth. This constitutes a form of mild corrosion, and if the additives are too chemically reactive, they can promote chemical wear and polishing. They can also react unfavorably with other gearbox components such as seals and bearing cages. Therefore, lubricant and additive manufacturers are careful to limit additive reactivity to avoid excessive corrosion.

Distinction between anti-wear and anti-scuff additives. Anti-wear and anti-scuff additives are designed to provide protection over a broad spectrum of operating conditions; both act to protect against adhesive wear that ranges from mild to severe. Mild adhesive wear is confined to the oxide layers of gear tooth surfaces and it always occurs with as-manufactured gear teeth. If the gears are properly run-in, the asperities are smoothed, the wear usually subsides with time, and the wear is considered normal. At the other extreme, scuffing is severe adhesive wear, and it can cause catastrophic damage. Since anti-wear and anti-scuff additives both act in similar ways, it is best to classify them in terms of their activation temperature. Anti-wear additives become effective at relatively low temperatures and become ineffective at moderate temperatures; anti-scuff additives become effective at relatively high temperatures and remain on gear tooth surfaces until they are rubbed off or melt at relatively high temperatures. Therefore, the choice between anti-wear and anti-scuff additives depends on the gear application. Anti-wear additives such as TCP and ZnDDP might be adequate for high-speed, lightly loaded gears that are not subjected to shock loads, whereas slow-speed, highly loaded gears that are subjected to shock loads might require anti-scuff additives such as those containing sulfur and phosphorus — alone, or in combination. In many applications, lubricants with both anti-wear and anti-scuff additives are required to protect against the full range of adhesive wear, but care should be taken to avoid aggressive chemistry that can result in polishing wear, micropitting, or degradation of other components.

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