Wear Protection for Gears

Frederick J. Teeter & Manfred Berger

Several trends in mechanical engineering are leading to greater surface stress on components and thus to unacceptable wear. These trends include greater stresses due to increased power densities; the need to maintain high precision of components throughout their service life; and the environmental imperative to reduce use of lubricants and additives.

In gearing, the trend is characterized by a rise in power density. In other words, high torques are being transmitted through small systems. In addition, gears often have to run with poor lubrication. Gear wheels may therefore suffer various kinds of damage, depending on load and peripheral speed (see Fig. 1).

As peripheral speed increases, the viscosity and thickness of the lubricant film decrease as a result of the higher temperature. If the lubricant film ruptures, seizure occurs on the tooth flanks. At low peripheral speeds, no continuous lubricant film forms between the tooth flanks. The surfaces come into direct contact (mixed friction) and abrasion occurs. In the pitting region (where tiny pits are formed on the tooth flank), a load-bearing lubricant film is present; the load capacity is governed by the compressive strength of the gear surface. Prolonged rolling contact produces fine cracks, which start at roughness valleys or inclusions and lead to the detachment of particles from the surface. Small pits (Fig. 2) are created on the tooth flanks.

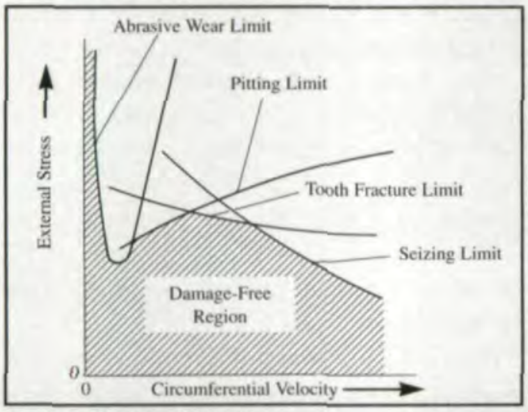


Fig. 1 — Working limits of gears.

Fig. 2 — Pitting on the flanks of gear teeth.

To cope with these varying stresses and meet the need for economical mechanical parts, gears have been made of plastic, medium, low-carbon steels (such as 1020 and 1030), heat-treated steel, induction-hardened steel, nitrided steel and case-hardened steel. The load-carrying capacity increases in this order, but so does the cost of the gears. In particular, the regrinding of hardened gears is expensive.

Factors governing gear life and reliability include not only the material and the stress level, but also the design and the lubrication. There are limits on these factors because of typical service conditions (e.g., slow running) and design constraints such as small volume and target weight.

Protective coating that can be precisely deposited would be desirable as a way of meeting the more and more stringent requirements on heavily loaded gears. Even for high stresses and poor lubrication environments, such coating can provide long-term surface protection in service.

Conventional coatings, such as electrolytic hard chrome and dry lubricant films based on MoS_2, often are not adequate to satisfy these requirements. A new coating made of amorphous carbon with tungsten carbide inclusions (referred to as a WC/C coating) has proved its worth in situations where all other surface coating systems fail.

WC/C Coating

This WC/C coating (BALINIT C) is applied by a PVD (Physical Vapor Deposition) process—more precisely, by reactive sputtering. In this process, the coating material is expelled from targets (WC plates) in a high vacuum by ion bombardment and deposited on the parts being coated.

This high-vacuum technology makes it possible to obtain coating properties that cannot be

Frederick J. Teeter
is the marketing director for Balzers Tool Coating, Inc., North Tonawanda, NY.

Manfred Berger
is the product manager for Balzers-Liechtenstein.

imparted under an atmosphere (thermal spraying) or with gases or baths (nitriding, galvanizing). These properties include:

• Controlled material composition. Amorphous carbon films have the lowest friction of all hard surfaces.

• Extreme precision. PVD coatings are only a few µm thick. They replicate workpiece surfaces exactly, thereby eliminating the need for subsequent machining.

• Maximal load-carrying. High-vacuum deposition avoids contamination of all kinds. As a consequence, there is a metallurgical bond to the substrate, leading to high coating adhesion and load-carrying capability (PVD coatings such as TiN are traditionally employed on severely stressed tools).

Technical data of the WC/C (BALINIT C) coating are as follows:

• Hardness 1000 Hv 0.05
• Coefficient of friction 0.1–0.2 (vs. 0.6–0.7 for steel)
• Coating thicknesses 1–4 µm
• Coating temperature Max. 250°C (480°F)
• Oxidation resistance 300°C (572°F)
• Color Black/gray

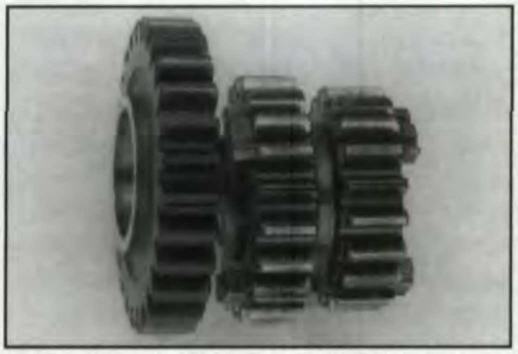


Fig. 4 — Wear of motorcycle gear after oil leakage during a race. Right: uncoated. Left: WC/C-coated.

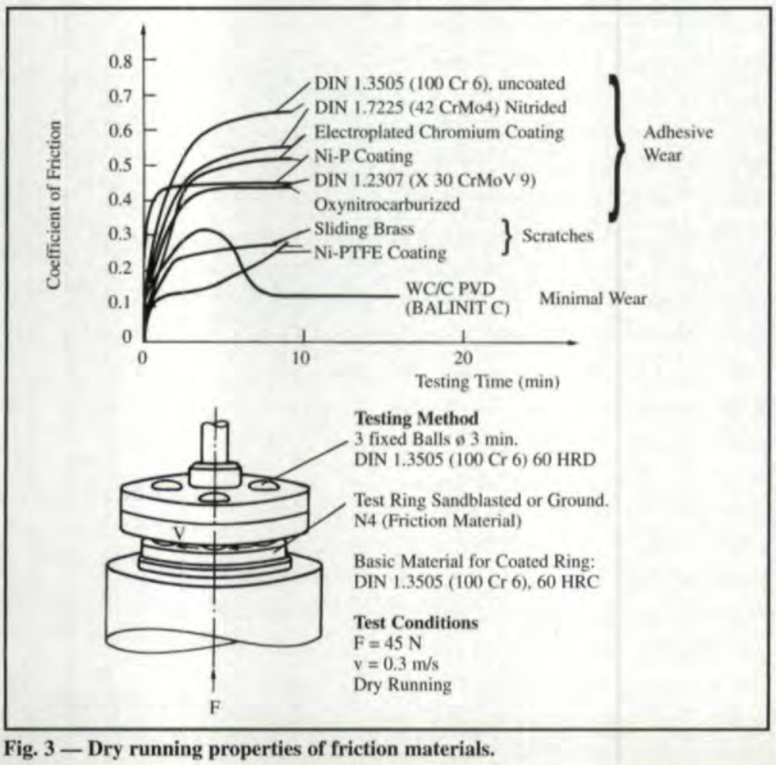


Fig. 3 — Dry running properties of friction materials.

As far as optimal wear protection is concerned, the key combination of properties offered by the WC/C coating is low friction with high hardness.

The sliding properties of the WC/C coating are not attained by conventional surface treatments, such as nitriding, nitrocarburizing or chemical nickel-plating, or by bronzes. This point is seen particularly in the dry friction behavior of these surfaces. Fig. 3 shows the results from a model dry friction test. In this test, hardened steel pins slide on disks of various materials or on various surfaces. While the bronze disk does exhibit low friction, it experiences severe wear in the form of scoring; the hard materials or surfaces, on the other hand, develop high coefficients of friction or display seizure (cold welding) after a short time in the test.

None of these surfaces yield both low friction and wear resistance. Only the WC/C coating exhibits low friction with virtually no wear. This good frictional behavior in the model test also leads to outstanding results in practical gear applications.

Gear Coating in Practice

Motorcycle Gears. Gears for motorcycle transmissions experience high stresses due to high speeds and limited volumes; they are fabricated from case-hardened steels. Application of the WC/C coating to these gears results in enhanced reliability and emergency running reserves. Fig. 4 compares uncoated and coated gears from a motorcycle after a race in which an oil leak developed. Normally, seizure occurs very quickly in such cases. Because the most severely stressed gears had the WC/C coating, the machine was able to finish the race. The coated gear, shown on the left in Fig. 4, has almost no wear in contrast to the uncoated ones.

Concrete Mixer Gears. The case-hardened sun wheel of a concrete mixer gear, which runs slowly under load, was in danger of seizure, since no adequate lubricant film was formed. The WC/C coating prevented premature seizure and enabled the transmission to perform in this special mode. A slow-running model test provided clear confirmation of this capability. The wear rate on the coated gear pair stabilizes at a very low value (Fig. 5).

Motor Control Actuator. Actuating mechanisms for throttle valve controls in car and truck engines cannot be lubricated because electronic components are located nearby. A dry lubricant film of MoS_2 does not provide sufficient wear protection. Hard, low-friction WC/C coating gives long-term protection for this unlubricated actuator.

Bevel Gear Actuator. A bevel gear actuator for aircraft landing flaps is subject to severe tribological stress because of the high forces and low sliding speeds. Even with nitriding, inspection and maintenance intervals were too short. The WC/C coating, which has a much lower coefficient of friction than nitrided surfaces, made it possible to institute acceptable inspection intervals.

Highly Stressed, Fast-Running Gears. If a continuous lubricant film is formed, the service life is limited by the pitting load capacity. With the WC/C coating, load capacity gains of 10–15% for case-hardened gears (Fig. 6) and as much as 30–40% for heat treated gears are seen. As a result, gear loads can be increased or smaller gears can be used for given loads. Coating makes it possible to use a less costly class of materials in a given application where ground and case-hardened gears otherwise would have to be employed. The cause of the increased load capacity in coated gears is that the coating becomes smoother when the gears run together and thus reduce local surface pressure.

Worm Gear Drives. Wear problems are especially severe in worm gear drives because of the kinematic situation (high proportion of sliding contact, low speed). In most cases, bronze worm wheels have to be used to prevent seizing. But these gears are soft, so that abrasion in service makes it necessary to replace them relatively often. Worms made of medium, low-carbon steel also wear easily. The use of case-hardened and ground worms is a costly alternative. The WC/C coating leads to solutions in two directions:

- Precision Drives. Precise positioning (for example, fixture positioning in machine tools) cannot be attained on a long-term basis with rapidly wearing bronzes. Case-hardened worms and worm gears do not have low enough friction, so they seize prematurely. Application of the WC/C coating to worms and worm wheels made of steel protects against both seizure and abrasion.
- Substitution of Case-Hardened Worms. If a conventional pair of a low-carbon steel worm and bronze wheel does not offer adequate wear resistance (Fig. 7), a worm of case-hardened steel is used. This makes the drive appreciably more costly. In many cases (such as a vertical-lift table, for example), a low-cost worm of heat-treated or low-carbon steel can be coated with WC/C. In this way, the friction behavior is improved and gearing costs are drastically cut.

The WC/C coating is an ideal treatment for gear materials. Not only does it offer a solution for extreme load situations, but it also can be used to boost performance or reduce weight, or it can provide an alternative to expensive materials.

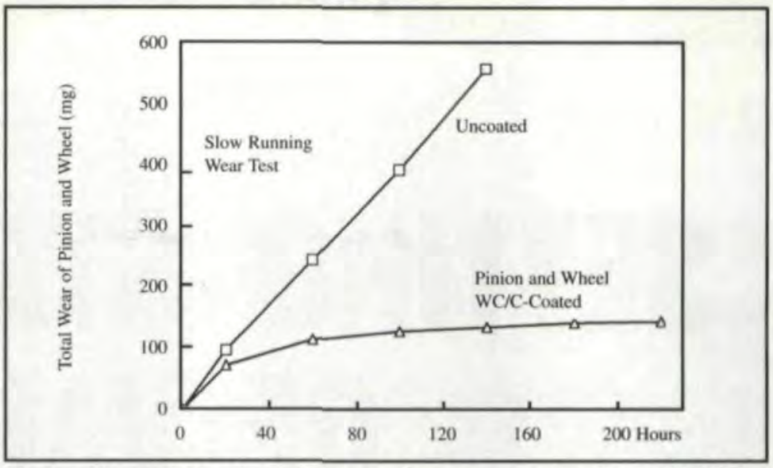


Fig. 5 — Wear test for a slow running gear for a concrete mixer. Stress: 2180 MPa. Sliding velocity: 0.04 m/s.

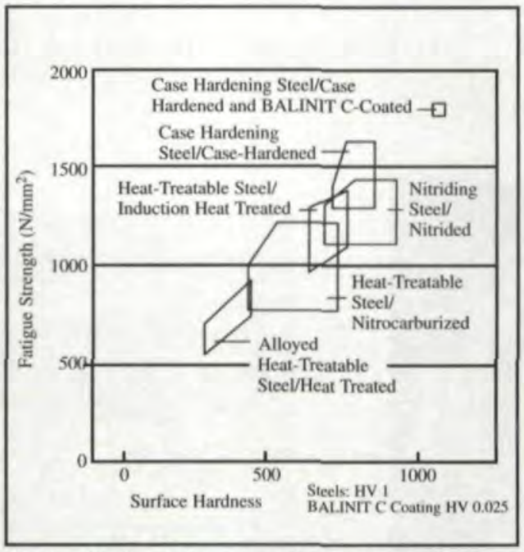
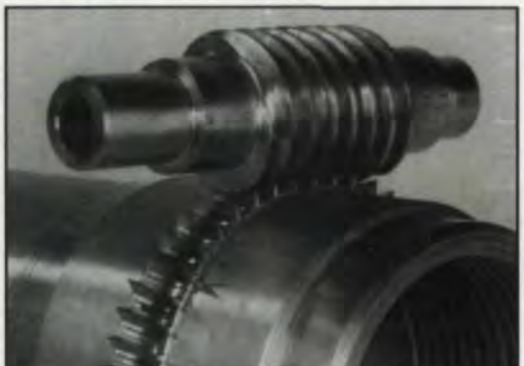


Fig. 6 — Surface fatigue strength of materials for gears.



Worm Material	Cost of worm, related to the cost of low-carbon steel worm
low-carbon steel	1
case hardened steel, ground	6
low-carbon steel, WC/C-coated	1.5
heat treated steel, WC/C-coated	4

Fig. 7 — Wear of conventional worm gears and cost of alternative materials.

Tell Us What You Think...
If you found this article of interest and/or useful, please circle **206**.

For more information about the product described in this article, please circle **207**.