

The Optimal High Speed Cutting of Bevel Gears – New Tools and New Cutting Parameters

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American Gear Manufacturers Association



TECHNICAL PAPER

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

High speed carbide dry cutting went through an evolution with respect to speeds and feeds and the kinematic relationship between cutting blade and work, which eventually resulted in many improvements, available today. The dependency of many important parameters upon the particular situation of a certain job makes it often difficult for a manufacturing engineer to establish an optimal cutting scenario.

For many years, the question of three face sharpened versus two face sharpened blades has been discussed, but it never really was a question of how many faces were sharpened, but rather how flexible the geometry of the major surfaces, that form the cutting edge could be adjusted to the particular situation of a certain job. The expression "certain job" includes next to the cutting method: face hobbing or face milling, generating or non-generating, also the basic parameter of the gear set design as well as the blank material and its crystal structure. The second significant aspect of the three face sharpening is the all around coating, that is required if the protecting layer of coating was removed due to the grinding of front face and side relief surfaces.

An analysis of the different parameters and their influence to the performance of the cutting process, allows establish five, nearly independent areas of attention:

- Blade geometry and placement in the cutter head
- Cutting edge micro geometry
- Surface condition of front face and side relief surfaces
- Speeds and feeds in the cutting process
- Kinematic relationship between tool and work (climb or conventional cutting, vector feet)

This paper presents explanations and guidelines for optimal high speed cutting, depending on cutting method, part geometry, blank material and manufacturing environment, which also help to choose the right blade system to give the manufacturing engineer detailed information to support the effort of optimizing cutter performance, tool life and part quality.

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Introduction

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on cutting method, part geometry and manufacturing environment, which also help to choose the right blade system to give the manufacturing engineer detailed information to support the effort of optimizing cutter performance, tool life and part quality.

Cutting Tool Material

The preferred tool material for dry cutting processes is extra fine grain carbide. Carbides are cemented, sintered composite materials of tungsten carbide (WC) and one or more metallic binding elements. The best experience in dry cutting of bevel gears have been gained in applying K-grade (ISO designation) carbides which only contain the single binding element cobalt (Co). Depending on the cutting depth it has been found that a cobalt content of 12% shows the best cutting results for larger size gears and a cobalt content of 6% is advantages for small size jobs.

The lower contents of cobalt increases the hardness and the wear resistance of the cutting tool but makes it more brittle which increases the risk of cutting edge chipping. The higher contents of cobalt enhances the toughness of the tool, which reduces the wear resistance. **Figure 1** shows two diagrams which indicate fracture toughness and wear resistance as function of the cobalt contents [1]. The best compromise for different work piece materials and jobs from automotive to truck size is evident by a composite from 10% cobalt and 90% tungsten carbide.

The diagrams in Figure 1 show with their different color graphs the influence of the grain size with respect to toughness and wear. The extra fine grain sintered structure delivers the best overall performance compared to finer as well as courser structures materials. The excellent cutting experience with extra fine grain materials is also a result of the high sintering quality with low variation in composite density and a highly homogeneous structure as a result of the sintering process of extra fine grain carbide particles.



Figure 1: Fracture toughness and wear resistance of carbide

Cutting Tool Coating and Cutting Edge Rounding

The purpose of cutting tool coating in the area of chip forming action is to provide a surface layer with high hardness and low surface roughness. This protects the carbide cutting edge and surroundings from chemical reactions and isolates the basic substrate from the chip flow with respect to wear and temperature.

It seems to be a basically different task to protect the cutting edge of a two face sharpened blade vs. the cutting edge of a three face sharpened blade. The three face sharpening requires an all around coating which delivers a cutting edge that is formed by a coated front face as well as a coated side relief sur-

face including top relief area and also covering the clearance side surface.

The blade that is only coated on the front face (two face sharpened blade as shown in **Figure 2**) has a protection on the front face where the surface stress from chip forming is the highest and where the chips are being molded to their final form with a high relative surface speed. The unprotected side relief surface has a continuous sliding contact with the flank surface of the work. The individual parameters of a particular cutting process will make the difference between high contact forces that lead to rapid wear and cutting edge chipping or a result in a negligible side relief wear with an un-chipped appearance of the cutting edge [2].

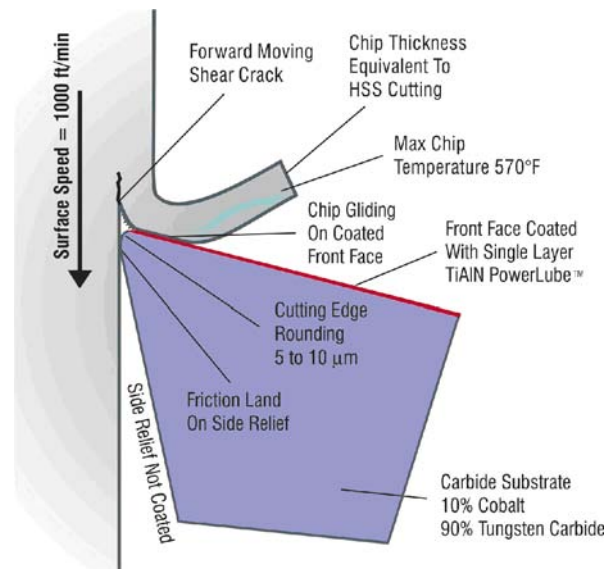


Figure 2: Chip removal mechanics

The edge rounding radius dimension and the micro blend between edge rounding and front face coating are the key parameters to achieve low cutting forces, optimal plasticization and chip shearing action. The optimal edge rounding radius for today's high speed dry cutting for only front face coated blades lies between 5μm and 10μm. **Figure 3** shows on the left side a device for edge rounding of carbide blades with permanent front face coating. The nylon bristles of a rotating brush contain aluminum oxide. The brush traverses sideways while it is rotating with a circumferential velocity vector that is lined up in the 3mm to 7mm interference zone between cutting edge and brush with the direction of the cutting edge. The photographs on the right side of Figure 3 show the cutting edge before edge

rounding and to the right after rounding. The upper section in the photographs with the darker color is the coated front face, the light colored stripe is the cutting edge and the area below is the side relief surface. The influence of edge rounding is evident by the reduced micro craters and the smoother transition between the cutting edge and the coating.

At the beginning of carbide dry cutting operations the best cutting results were obtained using a TiAlN coating with a composition of 50% Titanium and 50% Aluminum-Nitride. Both, single and multi layer coatings were tested in many cutting trials. Today, the commonly used and highest performing coatings are derivatives of a single 10µm thick layer of TiAlN with the trade names AlNite® and TiAln-X. The coating table in **Figure 4** gives an overview of some physical properties of coatings in use today

for chip removing operations [1].

Work Piece Material and Structural Treatment

Gears in industrial gear boxes and automotive/truck transmissions are generally manufactured from carburizing steels which provide a hard and highly durable surface and a core with high toughness after case hardening. Commonly used materials for the manufacturing of bevel gears are:

- AISI 5117 or ISO 16MnCr5 tensile strength 600 N/mm²
- AISI 3215 or ISO 18CrNiMo6 tensile strength 800 N/mm²
- AISI 4119 or ISO 20MoCr4 tensile strength 700 N/mm²

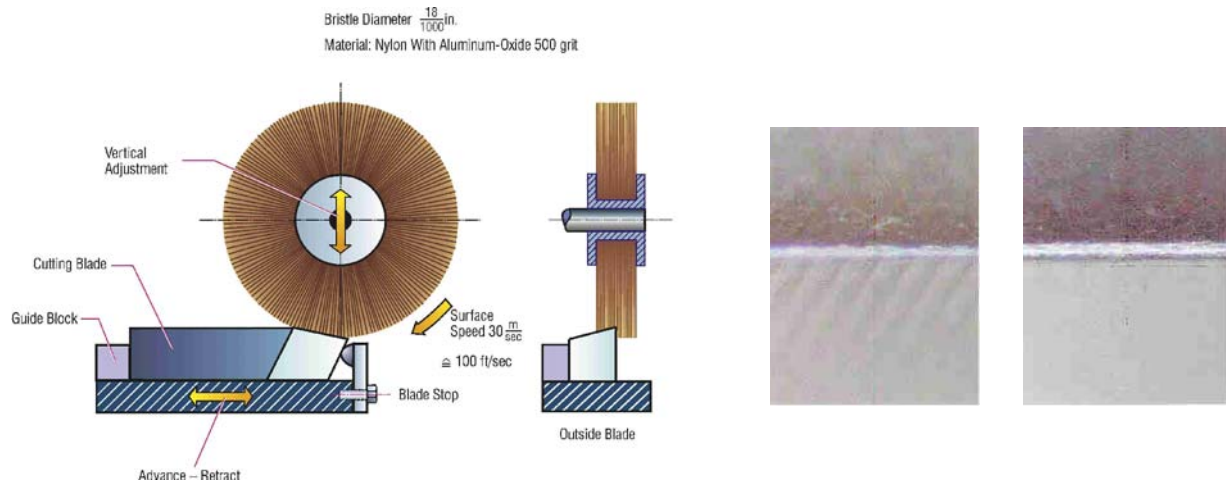


Figure 3: Edge rounding device and cutting edge before and after rounding

	TiN	TiCN	AlNite®	AlNite® X TiAlN-X	TiAlN- X.CEED	TiAlN- +WC/C	AlCrN	nAlCo
	Balzars BALINIT® A	Balzars BALINIT® B	Balzars BALINIT® Futura Nano	Balzars BALINIT® X.TREME	Balzars BALINIT® X.CEED	Balzars BALINIT® HARDLUBE	Balzars BALINIT® ALCRONA	Platit
Hardness (HV.05)	2300	3000	3300	3500	3300	3000	3200	4590
Coefficient of Friction (against steel, dry)	0.4	0.4	0.30- 0.35	0.4	0.4	0.15-0.20	0.35	0.45
Maximum Service Temp	600°C 1112°F	400°C 752°F	900°C 1652°F	800°C 1472°F	900°C 1652°F	800°C 1472°F	1100°C 2012°F	1200°C 2192°F
Coating Color	Gold	Blue- Grey	Violet- Grey	Violet- Grey	Blue- Grey	Dark Grey	Blue- Grey	Violet- Blue
Coating Structure	Mono- layer	Multi- layer	Nano	Mono- layer	Mono- layer	Multi- layer	Mono- layer	Nano

Figure 4: Table with commonly used Physical Vapor Deposition (PVD) coating types