Advantages of Titanium Nitride Coated Gear Tools

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Abstract

A brief introduction to the subject of Thin Film Coatings and their application to gear hobs and shaper cutters is followed by a detailed description of the Chemical Vapor Deposition Process and the Physical Vapor Deposition Process. Advantages and disadvantages of each of these processes is discussed.

Emphasis is placed upon application engineering of coated gear tools based on laboratory and field test results.

Recommendations are suggested for tool design improvements and optimization of gear cutting operations using coated tools. Productivity improvements potentially available by properly utilizing coated tools are considered in terms of both tool cost and machining cost.

Introduction

Gear cutting tools are among the most complex and costly tools used in the metal working industry. This is especially true of the more accurate tools which normally require form grinding of the critical gear tooth form generating surfaces. Because the tools are expensive, as well as the gear cutting operation itself, means have long been sought to improve tool life and to increase the productivity of the gear cutting process. Many methods have been applied in the past to obtain these ends including, special designs of the gear tools, use of higher alloy high speed steels, and various coating or treatment methods which were applied to the tool surfaces in an attempt to increase their wear life. These methods have included various nitriding processes, chrome or nickel or other plating processes, as well as others, which may even have fallen within the realm of black art. There have been some processes which have proven viable for certain unique or special applications. In these cases, significant improvements have been obtained and the methods have been economically justified. However, most proposals which appeared to yield significant life or productivity improvements in a laboratory or closely controlled production environment have not, in fact, proven to be practical manufacturing alternatives for use on gear tools in the long run.

Titanium nitride (TiN) coatings have been successfully applied to carbide inserts since 1969. The chemical vapor deposition (CVD) process, which is a high temperature process, has been applied to carbide inserts used in turning, boring, and milling applications and proven highly successful. The high temperature required by the CVD process does not distort, nor does it change the carbide substrate, therefore, the process had proven applicable to carbide inserts. This high temperature method had not been applied until recently to high speed steel gear cutting tools, because their complex geometry was distorted by the high temperature involved in the process.

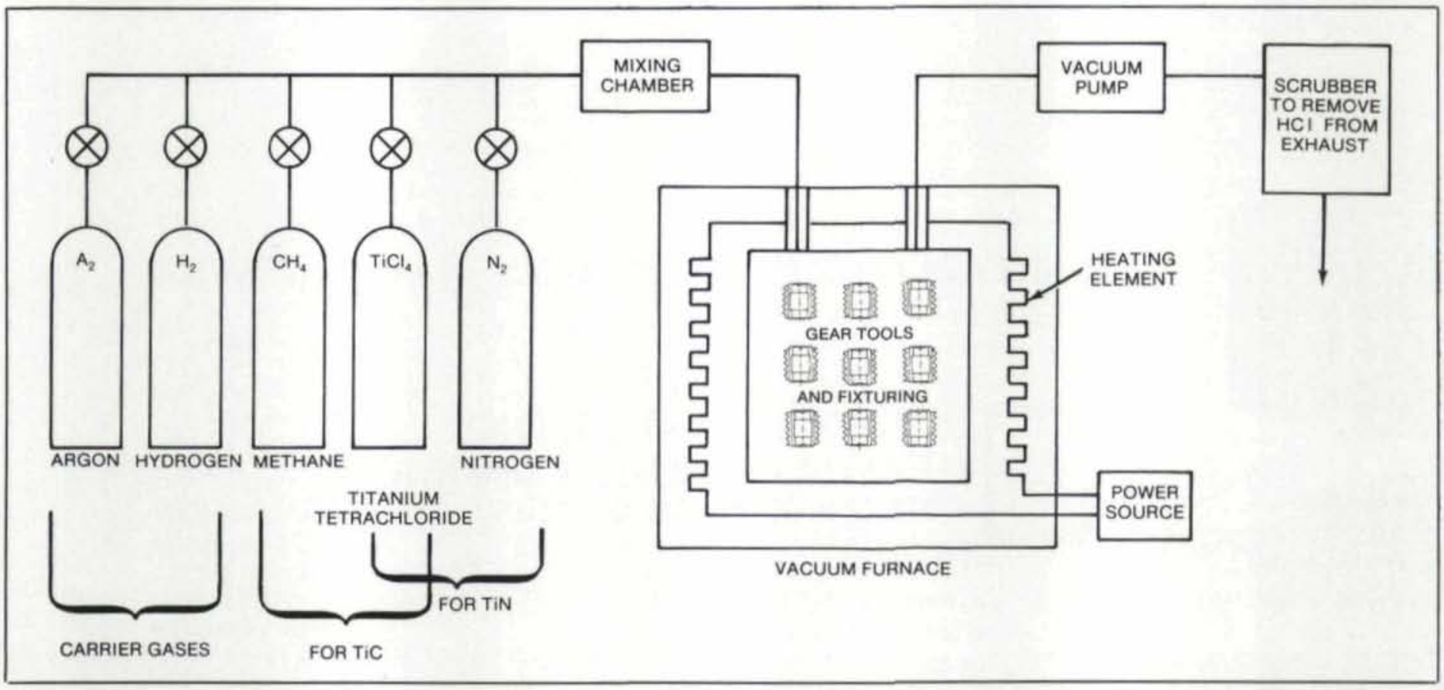

FIG. 1 — Schematic Diagram of the CVD process.

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In spite of the above, experimentation and development of titanium carbide (TiC) and titanium nitride (TiN) coatings of gear hobs and gear shaper cutters was being carried on in this country using the CVD process in late 1979 and early 1980. The physical vapor deposition (PVD) process, which is conducted at a low enough temperature such that no annealing or thermal distortion of hardened high speed steel occurs, was successfully applied to gear cutting tools early in 1980 in Japan. The very rapid growth and acceptance of the PVD process are illustrated by the following. There was only one coated gear hob displayed at the International Machine Tool Builders Show in September of 1980 in Chicago; but within the next year, there was a multitude of high speed steel cutting tool applications including many gear tools at the EMO Show held in Hanover, Germany in September of 1981.

The tool coatings mentioned above, titanium carbide and titanium nitride, produce very hard, thin, and wear resistant layers. These characteristics combine to make those coatings ideally suited to the critical and complex geometries involved in gear cutting tools. Since titanium carbide is the somewhat harder of the two, it is recommended when the type of service encountered is highly abrasive. On the other hand, titanium nitride, with its low coefficient of friction and anti-weld characteristics, is applicable in cases in which gauling or welding are encountered.

Chemical Vapor Deposition Process

Chemical vapor deposition (1) is carried out in a vacuum furnace at the relatively higher temperatures of 1750 to 1930°F. In the process, illustrated schematically in Fig. 1, the vapors of titanium and nitrogen (TiN) or the vapors of titanium and carbon (TiC) are chemically combined and deposited on the surface of the cutting tool.

The high temperature involved require that these coatings be applied to a tool in the soft condition or that subsequent rehardening would be necessary due to the fact that such high temperatures would anneal a hardened tool. In either case, the necessity to vacuum harden the coated tool, after the final machining operations on the cutting teeth, results in distortion, which is excessive for all but the lower quality classes of gear cutting tools.

CVD coatings range from 3000 to 3500 Knoop hardness for titanium carbide and 2500 to 3000 Knoop hardness for titanium nitride. These numbers compare to maximum extrapolated Rockwell C hardnesses of 90 and 85 respectively. When compared to hardened high speed steel ranging from 64 to 68 Rockwell C, it can be seen that very significant improvements in hardness are achievable. TiN and TiC CVD coatings are also relatively thick at .0003 inches. While this can be a detriment to the accuracy of high precision gear tools, it does provide the potential of substantial life improvment.

The CVD process also has the potential of producing more economical coatings. One of the reasons this is true is that the equipment used is less complex, in that lower vacuums are employed. This means that not only is the equipment itself more economical, but the energy costs involved are also lower. Additionally, since small amounts of relatively inexpensive materials are utilized, the overall material cost of the process is also modest. With the high temperature involved in the process, which inherently produces improved adherence of the coating, work preparation and cleanliness are not as critical as in other methods.

The major applications for CVD are to provide wear resistant coatings for carbide inserts and lower precision classes of high speed steel tools. Tool life improvement of as much as six times on higher speed steel cuttings tools has resulted in a high degree of customer satisfaction.

Physical Vapor Deposition Process

The highest precision grades of high speed steel tools have geometric tolerances which are less than the distortions which occur during even the most closely controlled hardening operations. Therefore, the critical dimensions of such tools must be finished subsequent to hardening, and no additional high temperature operations are permitted. In order to coat precision high speed steel tools successfully, the low temperature range of 530 to 890°F of the PVD process is necessary to prevent annealing of the high speed steel substrate. Because of the lower temperature levels, there is no appreciable distortion of the tools. Fig. 2 is a schematic diagram of the PVD Reactive Ion Plating process employed by Barber-Colman Company to produce TiN Gear Tool coatings.

PVD is an entirely different process in which ions of titanium react with ions of nitrogen or carbon at the substrate surface resulting in a compound (TiN or TiC) which is physically deposited on the tool surfaces. These coatings range in maximum hardness from 2000 to 2800 Knoop for TiN and TiC respectively which correspond to approximately 80 and 85 Rockwell C. Comparing these values to the normal range of hardened high speed steel, 64 to 68 Rockwell C, it is seen that a very significant improvement in tool life is possible. The coating is extremely thin, only .000120 inch which makes it ideally suited for use o the most precise grades of high speed steel gear tools.

The coating process is carried out in a high vacuum furnace, with pressures ranging from 10^{5} to 10^{6} torr. This very

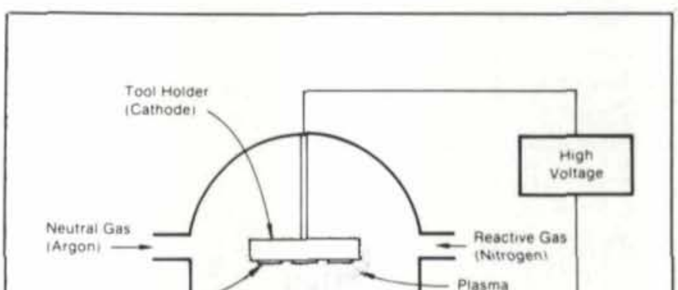

FIG. 2 — Schematic diagram of the PVD reactive ion plating process in which the tool is exposed to ion bombardment cleaning both before and during deposition.

high vacuum requires expensive equipment and substantial energy costs. The material costs, however, are quite nominal.

There are various physical vapor deposition processes in use.

The three main methods are:

Evaporation — Not applicable to high speed steel precision tools due to low film adhesion and problems in obtaining uniform coverage of complex geometries. An additional difficulty associated with TiN coating is the necessity to melt the compound titanium nitride which has a very high melting point of 5828°F.

Sputtering — This process is utilized by a number of domestic, as well as foreign companies. However, the process has low coating rates, uses much energy, and is somewhat difficult to control and quite susceptible to contamination.

A refinement of this method is called Reactive Sputtering in which the atoms of a gas introduced into the deposition chamber react with the pure metal atoms to form a metallic compound on the work.

Ion Plating — The basic methods applied are essentially off-shoots of work done by D. M. Mattox [2, 3] dating back to 1963. Ion Plating has an inherently high degree of controlability and is the basic process used by a number of foreign equipment builders.

The reactive gas refinement noted above under sputtering can similarly be applied providing Reactive Ion Plating to produce metallic compound coatings.

Although current PVD processes employ the latest techniques of plasma physics and thin film technology, the basic methods are not new. Applications in which PVD has been used for many years include depositing of refraction index improvement coatings on optical equipment, such as the lenses in eye glasses, telescopes, binoculars, microscopes and cameras. Decorative coatings have been applied to various metals and plastics for a wide range of industrial and consumer products. Watch cases and other items of jewelry have been enhanced with the beauty and durability of TiN. The electronics industry has utilized the PVD thin film technology for application of very critically controlled coatings to semi-conductors, vacuum tubes, cathode ray tubes and other components.

The characteristics of TiN which have the potential of providing wear and abrasion resistance are its high hardness, low coefficient of friction, and inertness which results in an anti-weld surface.

These characteristics also allow use of cutting tools at higher speeds and feeds. The high quality coatings, producing up to six times life improvement at no distortion or dimensional changes in the high speed steel, make the PVD Reactive Ion Plating process ideally suited to gear cutting tools.

Table 1. Equivalent Hardness Of Various Materials

Material	Knoop Hardness 1000g Load	Extrapolated Hardness Rc
Diamond	7000	--
Borazon	4500	--
Titanium Carbide	3500	90
Titanium Nitride	3000	85
Tungsten Carbide	1870	80
High Speed Steel	870	66

Application Engineering Of Coated Gear Tools

Advantages of TiN for HSS Tools

Titanium nitride possess a number of physical characteristics which are particularly effective in enhancing the life of high speed steel tools. Probably the most important of these characteristics is its extremely **high hardness**. It can be seen in Table 1 that the extrapolated equivalent hardness of titanium nitride at Rockwell C 85 is much higher than that of the high speed steel upon which it will be deposited. It should also be noted that the hardness of titanium nitride is considerably higher than that of tungsten carbide and is even approaching the hardness of Borazon (Cubic Boron Nitride).

The high hardness of titanium nitride provides excellent wear and abrasion resistance to heavy and prolonged cutting loads.

Titanium nitride rubbing against soft steel has a considerably **lower coefficient of friction** than hardened high speed steel would have. This reduces the tool loads and, therefore, the heat generated during cutting.

Actual tests have proven conclusively that due to the lower frictional characteristics of the TiN coatings that machine loads and the resultant power required have been reduced. Documented records are available indicating reductions of 25% to 30% in power requirements. There have been numerous instances in which the amount of oil coolant smoking due to high temperature in gear cutting operations has been reduced significantly by the use of coated tools.

The resultant lower temperature contributes to extended tool life and also improves the accuracy of the gear generating process. The major benefit of the lower heat generated as a result of reduced friction would be to allow the use of higher speeds and possibly feeds which of course would reduce the machining time and cost of the gear cutting operation.

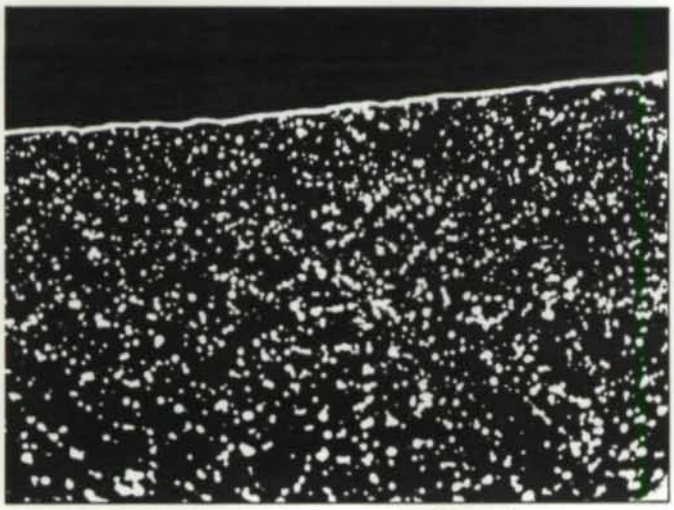

FIG. 3 — Photomicrograph of ASP23, 3-thread ground automotive hob: 400X, 5% nital etch with .000120 inch thick TiN Coating.

One of the reasons for wide spread use of titanium nitride as a protective coating on jewelry is that it is **extremely inert.** Because of this characteristic, coatings will produce no chemical reaction with the normally encountered gear materials these tools will cut, nor will they suffer any adverse effects in conjunction with gear cutting fluids.

Fig. 3 is a photomicrograph of a TiN coated powdered metal high speed steel gear hob tooth. Because of the very **thin** titanium nitride layer, .000120 inch, there is no appreciable dimensional change to the tool on which it was applied.

In addition, the maximum temperatures encountered in the PVD reactive Ion Plating Process are low enough to prevent annealing of hardended high speed steels. Since there is no significant dimensional build-up or thermal distortion the process is applicable to the highest precision grades of gear cutting tools.

Application Data

Because a wide range of accurate application engineering data for TiN coated gear cutting tools is not yet available, it is necessary to carefully consider each case individually. However, test results from a reasonable number of applications are available to allow realistic estimates and projections of potential advantages. The following information can be used, recognizing that it is based on a limited amount of overall experience.

Tool Wear & Performance Improvements

Fig. 4 illustrates the various types of wear often found on gear tools. Both chipping and gouging are types of wear which are due to deficiencies in the gear cutting operation which should be corrected. These types of wear produce damage deeply into the teeth and therefore will not be improved by the very thin layer of the Titanium Nitride coatings.

For the purposes of this discussion, each of the three (3) types of wear which occur on the relieved surfaces of the tooth directly in back of the cutting edge will be grouped together and referred to as "Flank Wear". These are periphery wear, corner wear, and lower flank wear, each occurring at a tooth location defined by its name. Flank wear is the type which is normally predominant in properly applied gear cutting tools. Since it occurs on the relieved tooth surfaces, those surfaces which are not removed by subsequent sharpening of the tool, TiN coating will be most effective in reducing flank wear and thus increasing tool life. In addition, the low frictional and anti-weld characteristics of tianium nitride can be utilized to allow higher speeds and feeds thus providing increased productivity.

Cratering is the eroding of material away from the cutting face of a hob or shaper cutter. The erosion of that surface is a result of the abrasive action of the chip curling over the face of the tooth, or a chemical reaction of the chip and coolant combination or welding in which the high pressures and heat encountered in the cutting action tend to weld the chip to the cutting face. As it is broken away a small particle of the face is removed with the chip. Since this cratering occurs on the cutting face of the tooth, only the first use of the tool before sharpening would be improved by the TiN coating. When cratering is a problem, it would generally be advisable to consider appropriate coolant changes or additives, or possibly the use of a higher alloy tool steel which would be resistant to the abrasive action which caused the cratering.

A series of in-house tests was conducted to determine life improvement ratios available through TiN coating of high speed steel gear hobs and shaper cutters. Since it is always necessary to at least maintain or hopefully improve existing standards of accuracy when applying new types of tools, the amount of acceptable wear before sharpening a preshave protuberance type hob was determined by the number of pinions cut before the amount of undercut produced or the true involute form (TIF) diameter violated established tolerances.

The results of these tests, conducted at fixed feed and speed rates, are shown in Fig. 5 which indicates that the coated flank wear was reduced to about 1/3 of the uncoated wear when the effective cutting edge dullness was held constant for both the uncoated and the coated tools. However,

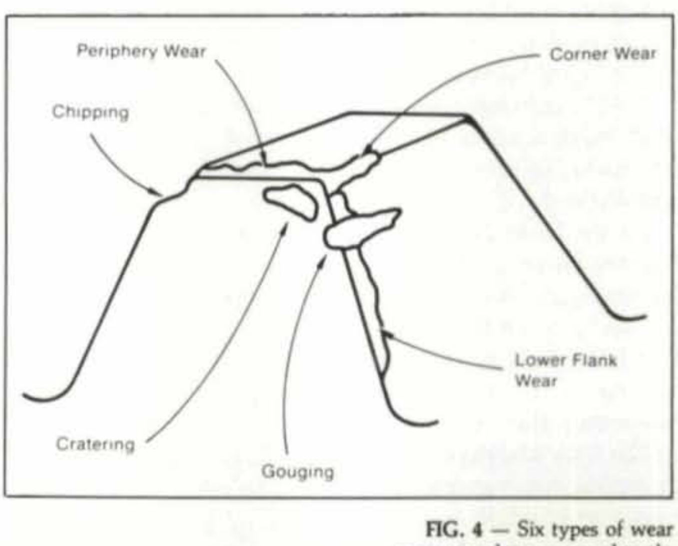

FIG. 4 — Six types of wear encountered on gear tool teeth.

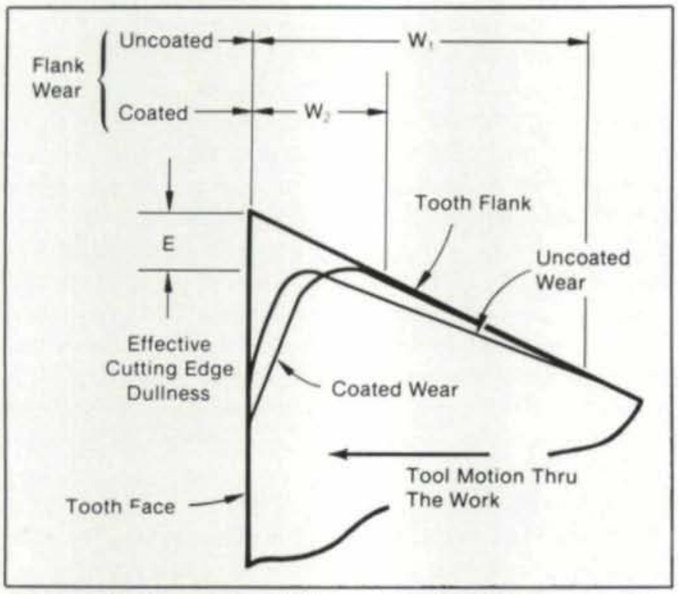

FIG. 5 — Flank wear when holding cutting edge dullness constant for coated vs. uncoated tools.

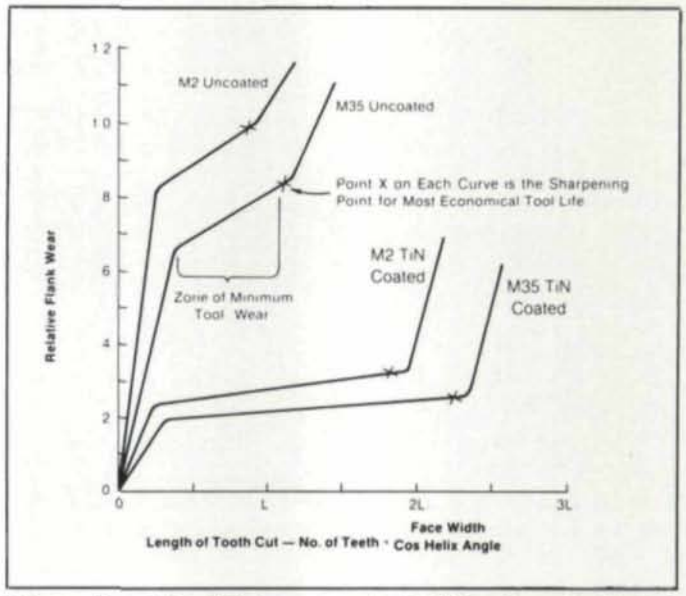

FIG. 6 — Potential tool life improvement with TiN coating under identical cutting conditions.

at the time at which the amount of undercut and the TIF diameter exceeded established tolerances, the number of pinions cut with the coated tool was twice the number cut with the uncoated tool. The increase in tool life was three (3) times in terms of flank wear and two (2) times in the number of parts cut. Therefore, the overall tool life was increased by a factor of six (6) times. Subsequent tests, both in-house and at various customer manufacturing operations, have shown that improvements up to 10 to even 15 times are possible.

Fig. 6 is a graph of the Relative Flank Wear vs. the Length of Tooth Cut for uncoated and coated tools of M-2 and M-35 tool steel. The curves show that, as normally expected in high speed steel tools, there is a high initial rate of wear after which a zone of minimum tool wear occurs. As the tool continues to dull during the zone of minimum wear, a point will eventually be reached at which time the cutting edge breaks down rapidly due to increased head and load. Subsequent failure of the tool is very rapid and catastrophic if the cutting action is not stopped at this time. In order to optimize the economy of the cutting tool application it would be necessary to sharpen the tool at the point marked "X" on each curve.

This point is at the end of the low wear rate portion of each curve just prior to the point at which rapid breakdown of the cutting edge is imminent. Currently these points must be established by test procedures in specific instances. However, after TiN coatings have been used for a sufficient length of time to accumulate accurate application data it will be possible to reasonably predict the economical life for low production runs.

It should be pointed out that because the amount of wear on coated tools will be much less that that encountered in previous practice, it will be important to assure that sharpening practices are revised. Obviously the amount of stock removed in sharpening must be reduced to approximately 1/3 that of prior practice. Also the amount of stock removed in sharpening in excess of the actual wear must be held to a minimum. For example, if prior practice was such that tools were sharpened after .025 of wear and .030 stock was removed, the amount of tool life removed in excess of actual wear would be 17% (5/30) of the total sharpening stock. However, if the wear encountered with a coated tool was only .008 and an additional .005 was removed in sharpening, the amount of the tool life removed, in excess of actual wear, would be approaching 40% (5/13) of the total sharpening stock or over two (2) times that amount in previous practice.

Another extremely important point to bear in mind is, that even though cratering had not been a problem when using an uncoated tool, if the same tool is TiN coated and more pieces per sharpening are being produced, then cratering is very likely to become a problem.

This is because cratering is a function of the amount of chips which have been curled over the cutting face and it is that face which does not have the benefit of TiN protection. A critical characteristic of cratering is that a point is eventually reached when the workpiece chip loads in the eroded craters cause sections of the tool cutting edges to break away. These broken sections usually exceed the amount of normal flank wear by a considerable amount. In fact, in severe cases when cratering is excessive, the whole top of a tooth can be broken away. Fig. 7 is an example of a hob which had been used to cut an excessively long linear length of work tooth resulting in catastrophic failure. The cratering shown in the close-up view of the tooth tips was the cause of the breaking out of entire hob teeth as seen in the overall view. Fig. 8 is a similar example of a severely cratered shaper cutter tooth. Good practice would forbid use of a tool to this extent due to the high risk of tooth breakage.

Optimized Productivity

In order to assure that the maximum potential of TiN coatings is obtained, it is necessary to consider both the tool itself and the machine in which it is being used. In most gear

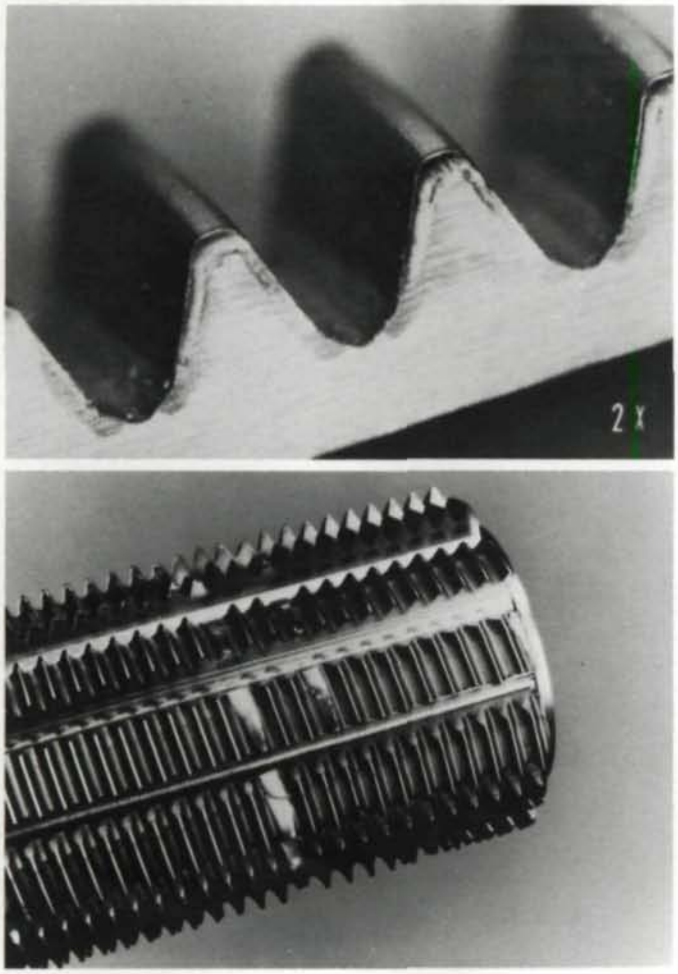

FIG. 7 — 15 DP hob illustrating castastrophic tooth failure due to excessive cratering caused by hobbing too many linear inches.

cutting production operations, the tool cost per piece cut is usually in the range of 5% to 25% of the total cost of the gear cutting operation. This means, that even if the entire tool cost could be eliminated, only 5% to 25% of the gear cutting cost could be saved. However, to save that much in the cost of machining time would require a change of speed or feed, or feed and speed in combination, of only about 30% at the most.

Actual tests of TiN coated drills and end mills have shown amazing results, In the case of drills an increase of feed actually increased the tool life, and in the case of end mills, an increase of speed significantly increased the tool life. At this time, most gear tool testing at increased speeds or feeds indicates that a range of 30% to 50% increase of speed and approximately 10% to 20% increase of feed is possible at no adverse loss of tool life.

Therefore, in order to obtain the optimum potential of TiN coating, it is important to increase the speed, and possibly the feed, to the maximum amount, depending upon a number of factors which would have to be evaluated for each specific application. Among these factors are consideration of the work piece material, its hardness and its machinability. It is also necessary to consider the material used in the cutting tool, the rigidity of the machine and the work holding fixtures, as well as, the condition of the machine itself in terms of wear, tightness adjustments, etc. Obviously, the machine must have sufficient power to operate at the increased metal removal rates, and must have sufficient speed range or feed range available. The rigidity of the structure of the workpiece itself must also be adequate to withstand the possible increased loads due to higher feeds or speeds.

The coolant also becomes more critical at elevated speeds. It may be necessary to change coolants to accommodate the more adverse conditions due to increased speed and load. Limited in-house and field tests have shown substantial tool life improvement when using TiN coated tools with borate additives, in some cases, and with chlorinated cutting oils, in others.

Because of the improved cutting efficiency it may be possible to increase the cutting depth of multiple cut operations. This could reduce the number of cuts or passes and yield significant productivity improvements.

In the overall, it would be expected that more pieces per sharpening and reduced tool wear will both be available thru the use of coated tools. It may be required that heavy duty machinery be applied to obtain the maximum benefits.

A side effect of TiN coated tools will be the improved accuracy, which results because of the lower cutting loads and the fact that sharper tools are used during a higher percentage of the overall production run. This will result in less scrap, reduced lead and involute errors, and improved surface finish.

Production Test Results

To illustrate many of the foregoing remarks and recommendations, consider the actual production test results

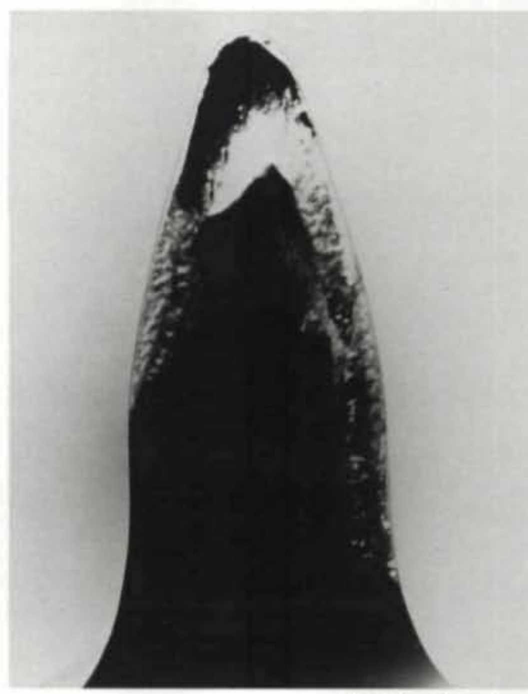

FIG. 8 — Excessive cratering on DP shaper before sharpening cutter tooth due to shaping too many parts.

shown in Tables 2 through 5 and summarized in Table 6. These tests were conducted on the production floor selected, high volume gear or pinion manufacturers.

The data at the top of Tables 2 through 5 includes the specifications of the tool, the workpart being cut, and the machine in which the gear cutting operation took place. The remaining information is a tabulation of the operating data, the gear cutting results and the gear cutting cost analysis for the conditions of: 1) The uncoated tool operating under previously established production conditions, 2) The TiN coated tool operating under the same conditions as had been established for the previously applied uncoated tool, and 3) Assumed increased speed or depth of cut, the resulting wear, and the number of pieces cut when applying the TiN coated tool in order to obtain increased productivity.

To gain the maximum potential available from TiN coated gear tools, it is necessary to increase the speed, and/or increase the feedrate, and/or reduce the number of cuts in a multiple cut operation. For the purpose of illustrating the large savings available by reducing the machining time, it was assumed that the tools tabulated in the tables could be operated at increased speed, and in one case at a reduced number of cuts. It was further assumed that they would produce only half the number of pieces when worn the same amount as the TiN coated tools at the originally established lower speed. These are conservative estimates based on results of other gear tool tests and on experimental work done with other types of high speed steel cutting tools.

Note that the costs tabulated in Tables 2 through 6 include only the cost of the gear cutting tool and the cost of the actual hobbing or shaping operation itself. The machining costs are based on the calculated cutting time at a conservative estimate of $25.00 per hour. In the simplified analysis presented, the tool sharpening cost and the cost of the gear cutting machine downtime for tool changing have not been included. When these costs are considered, the economic advantages of applying TiN coated tools are increased substantially because the amount of sharpening stock and the frequency of sharpening are greatly reduced.

The detailed information contained in the tables can be examined to the depth desired by the reader. A few comments will be provided here relative to significant improvements in the overall operation due to application of TiN coated tools.

Table 2 lists the condition of hobbing a 16 tooth automotive transmission pinion with a single thread, unground Class C, TiN coated hob. Comparing the results of the uncoated and the TiN coated hob under the same operating conditions, and the assumed results for the TiN coated hob at a 30% increase in hob surface speed, it can be seen that, under the same operating conditions, the coated hob produced the same number of pieces with only approximately half the hob wear of the uncoated tool. This provided an overall savings per part of 1.7%

However, when operating at the 30% increase of surface speed, the overall savings per part would increase over 10 times to 20.7%. This, of course, is due to the fact that for the original uncoated tool application the percentage of the hob cost per part, to the total cost per part, was only 5.2%. When cutting under the same conditions with a coated hob, that ratio fell to 3.5% and increased to 8.7% when operating at the increased surface speed. Also note that the tool cost at the higher productivity conditions increased over and above that of the uncoated tool, 8.7% vs. 5.2%, but that overall savings per piece, when including machining time, was 20.7%.

The hob test in Table 3 was for a coarser pitch, double thread, Class C accurate unground hob, in which the surface speed was increased by 30% in the assumptions made, for comparing economic advantages at higher productivity rates. Note that the number of pieces per sharpening and the number of pieces per life of the hob are approximately 2 times and 3 times, respectively, for the coated hob at increased productivity over the uncoated hob. This large increase in tool life, combined with the approximate 30% reduction in machining time, yields a very substantial 27.1% savings in overall hobbing costs per part.

The shaper cutter test data for the 51 tooth automative gear of Table 4 is for a shaping application which produced exceptional tool wear reduction. When the TiN coated cutter was initially used at previously established production rates, the number of gears produced prior to its first sharpening, that is with TiN coating on the shaper cutter tooth face, was an astonishing 906 pieces or 12 times the number of pieces produced with an uncoated cutter. At that time, the amount of flank wear on the cutter was only .015 compared to .025 for the uncoated cutter. After sharpening the cutter, thus removing the TiN coating from the tooth face, it was found that 225 pieces could be cut before cratering had progressed to the point that it was feared cutting additional parts would cause tooth breakage. At that time, the flank wear on the cutter was only .005.

Continuing to operate under those productivity conditions and running lots of 225 pieces per .005 of sharpening, the cutter produced 22,500 parts during its life which changed the percent of cutter cost per part to the total cost per part from 21.3% for the uncoated cutter to 2.9% for the TiN coated cutter. This resulted in an 18.9% total cost savings per part cut.

However, an even greater savings in total gear shaping cost would be available by increasing the stroke rate by 20% from 750 to 900 strokes per minute. At the assumed increased wear of .010 per 225 pieces cut, the cutter cost per part would increase to $0.06 which would still be $0.21 less than the cost per part of the uncoated cutter. As shown in Table 4, the resulting machining cost reduction to $0.81 would result in a total savings per part cut of 31.5%.

Another shaping test of an 8.5 NDP 20 tooth 22° right hand helical gear is listed in Table 5. In this test it was intended to utilize as nearly as possible the same speeds and feeds with the coated cutter as were being applied in the existing production line with an uncoated cutter. However, some slight changes in stroke rate and depth of cut were necessary, and their values were adjusted in order to approximate the same cycle time. As can be seen in Table 5, this resulted in an increase of almost 12 times in cutter life (17550/1488) and a total savings per part of 22.6%.

Table 2. TiN Coated Hob Test

Hob Data		
Tool No.		T-368530
ID No.		67041-80-01
OD x Length	(in. x in.)	2.75 x 4.00
NDP		15.58
NPA	(deg)	20
No. Threads		1
Class	(AGMA)	C
No. Gashes		12
Sharpenable Tooth Length	(in.)	.370
Material		M2
Coating		TiNite™

Part Data		
Part No.		8631142
Material		5140H
Hardness		98-100 R_B
No. Teeth		16
Face Width	(in.)	1.016
Linear Inches/Part	(in)	17.09

Machine Data		
Make		Cleveland
Model No.		1886
Cap'y: Dia x Lg	(in. x in.)	
Age	(Yr.)	

Operating Data		Uncoated Hob	TiN Coated Hob: Same Speed, Feed &/or Depth	TiN Coated Hob: Incr'd. Speed Feed &/or Depth
Hob Speed 1st Cut	(rpm/sfm)	200/144	200/144	260/187*
2nd Cut	(rpm/sfm)			
Feed 1st Cut	(in/rev.)	.120	.120	.120
2nd Cut	(in/rev.)			
Hob Shift	(in/pc.)	.006	.006	.012*
Conventional/Climb		Climb	Climb	Climb
Coolant		Oil	Oil	Oil
Parts Per Load		1	1	1
Hob Travel	(in.)	2.00	2.00	2.00
No. Cuts		1	1	1
Hobbing Time	(min/pc.)	1.33	1.33	1.02
Machining Time Hourly Rate	($/Hr.)	25.00	25.00	25.00
Hobbing Results				
Av. No. Pcs. Per Sharpening	(pcs/Shr'g)	315	315	157*
Av. Stock Per Sharpening	(in.)	.030	.014	.014*
No. Sharpenings/Hob		12	26	26
Total Pieces Per Life of Hob	(pcs/Hob)	4095	8505	4239
Gear Cutting Cost Analysis				
Hob Price	($)	120	120	120
Price of TiN Coating	($)		48	48
Total Hob Price	($)	120	168	168
Hob Cost Per Part	($)	.03	.02	.04
Hob Savings/Part	($)		.01	-.01
Machining Cost/Part	($)	.55	.55	.42
Machining Savings/Part	($)		0	.13
Total Cost/Part	($)	.58	.57	.46
Total Savings/Part	($)		.01	.12
Hob Cost/Part to Total Cost/Part	(%)	5.2	3.5	8.7
Savings/Part	(%)		1.7	20.7

*Assumed

Table 3. TiN Coated Hob Test

Hob Data		
Tool No.		AD-587326
ID No.		76258-81-01
OD x Length	(in. x in.)	3 x 4
NDP		10.5
NPA	(deg)	22°30′
No. Threads		2
Class	(AGMA)	C
No. Gashes		13
Sharpenable Tooth Length	(in.)	
Material		M2
Coating		TiNite™

Part Data		
Part No.1		6835566
Material		5130H
Hardness		140 BHN
No. Teeth		19
Face Width	(in.)	1.44
Linear Inches/Part	(in.)	27.4

Machine Data		
Make		Lees-Bradner
Model No.		
Cap'y Dia x Lg	(in. x in.)	
Age	(Yr.)	

Operating Data		Uncoated Hob	TiN Coated Hob	
			Same Speed, Feed &/or Depth	Incr'd. Speed Feed &/or Depth
Hob Speed 1st Cut	(rpm/sfm)	290/228	290/228	377/296*
2nd Cut	(rpm/sfm)			
Feed 1st Cut	(in/rev.)	.060	.060	.060
2nd Cut	(in/rev.)			
Hob Shift	(in/pc.)	.010	.0025	.005*
Conventional/Climb				
Coolant		OIL	OIL	OIL
Parts Per Load		1	1	1
Hob Travel	(in.)	2.27	2.27	2.27
No. Cuts		1	1	1
Hobbing Time	(min/pc.)	1.24	1.24	.95
Machining Time Hourly Rate	($/Hr.)	25.00	25.00	25.00
Hobbing Results				
Av. No. Pcs. Per Sharpening	(pcs/Shr'g)	250	959	480*
Av. Stock Per Sharpening	(in.)	.018	.012	.012*
No. Sharpenings/Hob		8	12	12
Total Pieces Per Life of Hob	(pcs/Hob)	2000	11511	5760
Gear Cutting Cost Analysis				
Hob Price	($)	138.50	138.50	138.50
Price of TiN Coating	($)		55.00	55.00
Total Hob Price	($)	138.50	193.50	193.50
Hob Cost Per Part	($)	.07	.02	.03
Hob Savings/Part	($)		.05	.04
Machining Cost/Part	($)	.52	.52	.40
Machining Savings/Part	($)		0	.12
Total Cost/Part	($)	.59	.54	.43
Total Savings/Part	($)		.05	.16
Hob Cost/Part to Total Cost/Part	(%)	11.9	3.7	7.0
Savings/Part	(%)		8.5	27.1

*Assumed

Table 4. TiN Coated Shaper Cutter Test

Shaper Cutter Data		
Tool No.		
ID No.		65356-80-01
PD x Length	(in. x in.)	4.0886 x .975
NDP		18.7773
NPA	(deg)	20
No. Teeth		66
Class	(B-C)	3
Helix Angle/Hand	(deg)	33/RH
Sharpenable Tooth Length	(in.)	.500
Material		M2
Coating		TiNite™

Part Data		
Part No.		
Internal/External		External
Material		
Hardness		
No. Teeth		51
Face Width	(in.)	
Helix Angle	(deg)	33
Linear Inches/Part	(in.)	

Machine Data		
Make		
Model No.		
Cap'y: Dia x LG	(in. x in.)	
Age	(Yr.)	

Operating Data			Uncoated Cutter	TiN Coated Cutter: Same Speed, Feed &/or Depth	TiN Coated Cutter: Incr'd. Speed Feed &/or Depth
Total Depth Of Cut		(in.)	.160	.160	.160
Infeed/Stroke		(in./Stk.)	.001	.001	.001
Work Pitch Diameter		(in.)	3.238	3.238	3.238
Infeed Time		(min.)	.347	.347	.289
1st Cut	Depth	(in.)	.090	.090	.090
	Rotary Feed	(in./Stk.)	.025	.025	.025
	Stroke Rate	(Stk./min.)	750	750	900*
	Cutting Time	(min.)	.542	.542	.452
2nd Cut	Depth	(in.)	.055	.055	.055
	Rotary Feed	(in./Stk.)	.025	.025	.025
	Stroke Rate	(Stk./min.)	750	750	900*
	Cutting Time	(min.)	.542	.542	.452
3rd Cut	Depth	(in.)	.015	.015	.015
	Rotary Feed	(in./Stk.)	.015	.015	.015
	Stroke Rate	(Stk./min.)	750	750	900*
	Cutting Time	(min.)	.978	.978	.753
Machining Time		(min.)	2.41	2.41	1.95
Parts Per Load			1	1	1
Machining Time Hourly Rate		($/Hr.)	25.00	25.00	25.00
Coolant			Sol Oil	Sol Oil	Sol Oil
Shaping Results					
Av. No. Pcs. Per Sharpening		(pcs/Shpg.)	75	225	225*
Av. Stock Per Sharpening		(in.)	.025	.005	.010*
No. Sharpenings/Cutter		(Shpg./Ctr.)	20	100	50
Total Pieces/Life of Ctr.		(pcs./Ctr.)	1500	22500	11250
Gear Cutting Cost Analysis					
Shaper Cutter Price		($)	399.00	399.00	399.00
Price of TiN Coating		($)		239.00	239.00
Total Shaper Cutter Price		($)	399.00	638.00	638.00
Cutter Cost Per Part		($)	.27	.03	.06
Cutter Savings/Part		($)		.24	.21
Machining Cost/Part		($)	1.00	1.00	.81
Machining Savings/Part		($)		0	.19
Total Cost/Part		($)	1.27	1.03	.87
Total Savings/Part		($)		.24	.40
Cutter Cost/Part-to Total Cost/Part		(%)	21.3	2.9	6.9
Savings/Part		(%)		18.9	31.5

*Assumed

Table 5. TiN Coated Shaper Cutter Test

Shaper Cutter Data		
Tool No.		FGS-4749
ID No.		80238-82-00
PD x Length	(in. x in.)	4.40 x 1.25
NDP		8.5
NPA	(deg)	22°30′
No. Teeth		36
Class	(B-C)	3
Helix Angle/Hand	(deg)	22/LH
Sharpenable Tooth Length	(in.)	.625
Material		M2
Coating		TiNite™

Part Data		
Part No.		10-22-080-002
Internal/External		External
Material		4027H
Hardness		
No. Teeth		20
Face Width	(in.)	1.18
Helix Angle	(deg)	22/RH
Linear Inches/Part	(in.)	25.4

Machine Data		
Make		B-C
Model No.		HD 150
Cap'y Dia x Lg	(in. x in.)	6 x 1.57
Age	(Yr.)	1

Operating Data			Uncoated Cutter	TiN Coated Same Speed, Feed &/or Depth	Cutter Incr'd. Speed Feed &/or Depth
Total Depth Of Cut		(in.)	.333	.333	.333
Infeed/Stroke		(in./Stk.)	.00136	.00136	.00136
Work Pitch Diameter		(in.)	2.5377	2.5377	2.5377
Infeed Time		(min.)	.790	.706	.706
1st Cut	Depth	(in.)	.166	.166	.261*
	Rotary Feed	(in./Stk.)	.0326	.0326	.0326
	Stroke Rate	(Stk./min.)	400	448	448
	Cutting Time	(min.)	.611	.546	.546
2nd Cut	Depth	(in.)	.095	.095	.072*
	Rotary Feed	(in./Stk.)	.0326	.0326	.012
	Stroke Rate	(Stk./min.)	400	448	672
	Cutting Time	(min.)	.611	.546	.988
3rd Cut	Depth	(in.)	.072	.072	—*
	Rotary Feed	(in./Stk.)	.0115	.009	—*
	Stroke Rate	(Stk./min.)	600	672	—*
	Cutting Time	(min.)	1.155	1.318	—*
Machining Time		(min.)	3.167	3.116	2.240
Parts Per Load			1	1	1
Machining TimeHourly Rate		($/Hr.)	25.00	25.00	25.00
Coolant			Oil	Oil	Oil
Shaping Results					
Av. No. Pcs. PerSharpening		(pcs/Shpg.)	48	225	112*
Av. Stock Per Sharpening		(in.)	.020	.008	.008*
No. Sharpenings/Cutter		(Shrg./Ctr.)	31	78	78
Total Pieces/Life of Ctr.		(pcs./Ctr.)	1488	17550	8775
Gear Cutting Cost Analysis					
Shaper Cutter Price		($)	676.48	676.48	676.48
Price of TiN Coating		($)		136.00	136.00
Total Shaper Cutter Price		($)	676.48	812.48	812.48
Cutter Cost Per Part		($)	.45	.05	.09
Cutter Savings/Part		($)		.40	.36
Machining Cost/Part		($)	1.32	1.32	.93
Machining Savings/Part		($)		0	.39
Total Cost/Part		($)	1.77	1.37	1.02
Total Savings/Part		($)		.40	.75
Cutter Cost/Part To Total Cost/Part		(%)	25.4	3.6	8.8
Savings/Part		(%)		22.6	42.4

Table 6. Tool Cost Vs. Machining Cost per piece of Uncoated and TiN Coated Tools

From Table	Tool / Work Material	Costs/Savings		Uncoated	TiN Coated: Same Speed, Feed & Depth	TiN Coated: Increased Speed, Feed &/or Depth
2	2.75 x 4 15.58 NDP UNG HOB M2 5140H 100 R_B	Tool Cost/PC Machining Cost/PC Tool Cost of Total Savings/PC	\$ \$ % %	.03 .55 5.2 —	.02 .55 3.5 1.7	.04* .42 8.7 20.7
3	3 x 4 10.5 NDP UNG HOB M2 5130H 140 BHN	Tool Cost/PC Machining Cost/PC Tool Cost of Total Savings/PC	\$ \$ % %	.07 .52 11.9 —	.02 .52 3.7 8.5	.03* .40 7.0 27.1
4	4.0886x.975 18.7773 NDP Shaper Cutter M2	Tool Cost/PC Machining Cost/PC Tool Cost of Total Savings/PC	\$ \$ % %	.27 1.00 21.3 —	.03 1.00 2.9 18.9	.06* .81 6.9 31.5
5	4.40x1.25 8.5 NDP Shaper Cutter M2 4027H	Tool Cost/PC Machining Cost/PC Tool Cost of Total Savings/PC	\$ \$ % %	.45 1.32 25.4 —	.05 1.32 3.6 22.6	.09* .93 8.8 42.4

*Assumed

The above summary combined with similar tests from a number of other applications indicates the following values are realistic.

Tool Condition	Production Rates	$\frac{\text{Tool Cost}}{\text{Total Cost}}$ %	Total Savings %
Uncoated	Existing	5 to 25	—
TiN Coated	Existing	2 to 5	2 to 20
TiN Coated	Increased	5 to 10	20 to 40

During the course of testing, the TiN coated cutter it was suggested that it would be appropriate to reduce the number of cuts from two to three in order to increase overall productivity.

Therefore, the assumptions in establishing the calculations for Table 5 were that combining the depth for the original first and second cut and holding the average sharpening stock to .008 would result in being able to cut 112 gears per sharpening. This increase in productivity would reduce the machining cost per part by \$0.39 and provide a total savings per part 42.4%.

The economic results of Tables 2 through 5 are summarized in Table 6 for easy reference where it can be seen that for 8 to 20 DP high production gear tools the maximum savings potential is available in utilizing TiN coated tools at increased production rates. It is possible to save 20 to 40% of the gear cutting costs.

New Coating Developments

As noted earlier, the application of titanium nitride coatings to gear cutting tools is relatively new. The major coatings which have proven advantageous to-date are titanium carbide and titanium nitride. Currently, titanium carbide is being applied primarily by the CVD process. Work is being done to enable titanium carbide coating by the PVD process. Titanium carbide has the advantage in that its hardness is approximately Rockwell C 90 which is somehwat harder than the titanium nitride coating at Rockwell C 85. However, titanium carbide is more brittle and must be utilized with more care. It also has a higher coefficient of friction which would generate more heat and higher tool loads. At present, the CVD process often is

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ADVANTAGES OF TITANIUM NITRIDE . . .
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utilized to apply titanium nitride over an initially applied titanium carbide surface in order to provide improved frictional characteristics.

Among the currently anticipated gear tool coating improvements, the following appear to be the most promising:

1. Certain developments are being pursued in titanium nitride coatings with the PVD process to provide reduced processing costs.

2. Titanium Carbo-nitride (TiCN) is most likely the next high speed steel coating which will be developed to provide higher hardness and improved abrasion resistance. The major disadvantage of Titanium Carbo-nitride is its brittleness.

3. Titanium Carbon Oxynitride (TiCON) is generating interest in certain quarters, but its total characteristics and advantages are not well known at this time.

4. Hafnium Nitride (HfN) and Zirconium Nitride (ZN) are candidates for future test work. Some basic testing has been done to date indicating that Hafnium Nitride is not as hard as Titanium Nitride, but has higher thermal stability.

5. Titanium Boride (TiB) has a serious disadvantage due to the extreme toxicity of gaseous boron which is used during the coating process. Therefore, not much work has been done with this possible coating.

6. Silicon Carbide (SiC), Silicon Nitride (SiN) and Tungsten Carbide (WC) are additional possibilities for future coatings applicable to high speed steel, but currently not much work is being done.

7. There are also possibilities of obtaining enhanced characteristics from combinations of the above coatings through the use of multi-layer coatings. This technique is used extensively in coating lenses in the optical industry. However, the boundaries between layers offer potential adhesion problems which would have to be solved before the process would be completely applicable to HSS cutting tools.

Until any of the above possibilities of improved coatings are proven realities, the most advantageous tool cost and gear cutting productivity improvements available will be through application of TiN coated tools.

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