Know Important from Urgent

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ABSTRACT

No doubt dry and high speed machining are the two most important tendencies in tooling today. But only the combination of these trends gives us the chance to be competitive in the times of globalization. This paper gives an overview of important outlooks for its realization: materials to be cut, EPD-gradient cutting materials, multi- / nanolayer coatings, glide coatings, minimum jet lubrication, self-adjusting intelligent tools in agile machining centers, tool management, tooling service via Internet, and distribution systems.

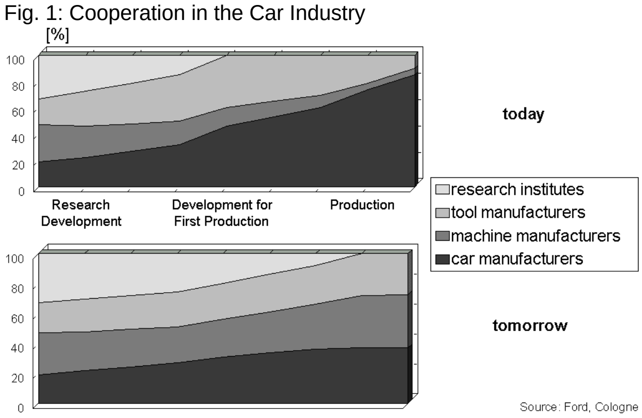
INTRODUCTION

The point in knowledge management is to keep development focused on substantial topics, not letting *urgent* affairs divert one's attention from the *important* [1]. Especially in today's boom times, the situation is very dangerous: Most customers are only interested in new innovations purely out of technical curiosity, just wanting to be supplied with the older but well-known tools. However, the boom years of the second half of the nineties seem to be coming to an end around the year 2000. The question "who can supply me with tools at all?" will again disappear and the questions "Who can offer me newly developed, innovative tools that save me money?" and "Who can act and who only react?" will again become very important. Therefore, this article tries to show some of the new and current topics in the industry, of course without claiming to be complete. They appear to become very significant around the turn of the millennium:

1. What materials do users want to machine?
2. Hard - dry - fast: 10 Commandments of Dry High Speed Machining
3. EPD-gradient carbides instead of HSS and brazed PCD
4. Will multi- and nanolayer coatings do away with good old TiN?
5. Soft glide coatings and minimum jet lubrication instead of high pressure coolant
6. Self-adjusting intelligent tools in agile machining centers
7. One-way tools in our throw-away society
8. Offering cutting capacity with tool management, not just tools
9. The Internet changes catalogues, distribution systems and even jobs
10. Patented one-way street or spiraling distribution?

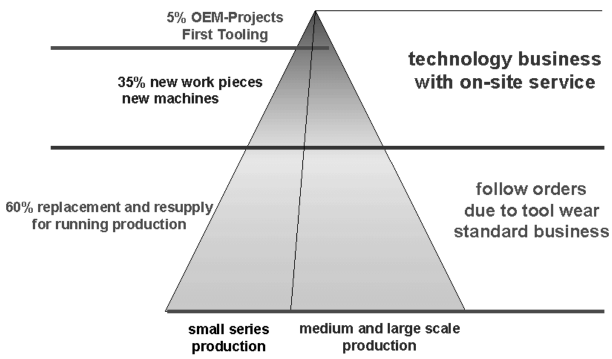
The "expert" specialists in the sales, production and development departments of the tool industry have only indirectly decided about new products for a long time now [2]. The customers also do not determine (order) directly about which tools should be produced. Through simultaneous engineering and outsourcing, they let the machining processes of their products be co-developed by the tool and machine makers (fig. 1). Consequently, the requirements for today's tools are set by mutual projects.

Fig. 1: Cooperation in the Car Industry



In the process of these projects - which are always urgent - tools are developed that are really up-to-date. They try to use the current technological possibilities with regard to reliable production. For the day-to-day business of the tool companies, these projects are decisive, but they are only the tip of the iceberg (fig. 2). For the future of tool makers, that research and development work has to be important which will make it possible to use even more productive tools in the projects after 2000.

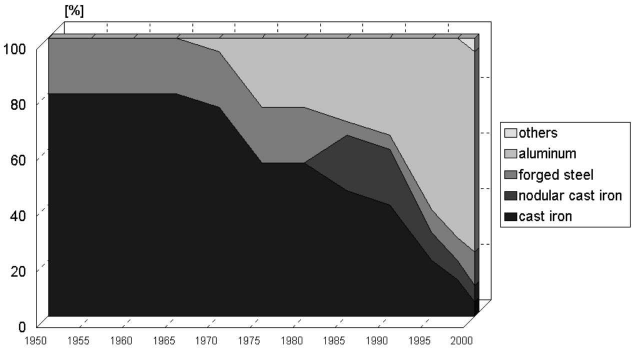
Fig. 2: Tool Market Shares by Field of Application



1. WHAT MATERIALS DO USERS WANT TO MACHINE?

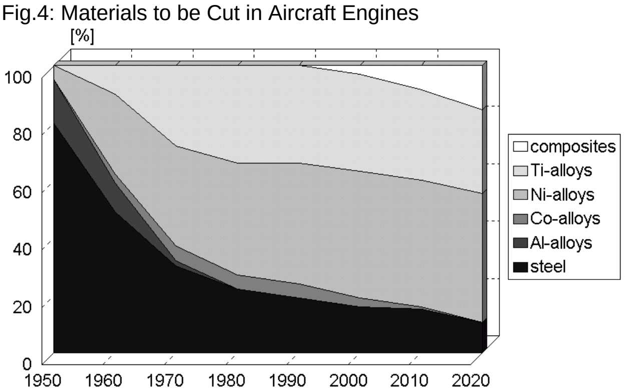
The foremost question is: What work piece materials will new tools for future projects have to machine? In both of the key industries to the tool makers, the answer is quite clear. Aluminum alloys play a dominant role in the automobile industry (fig. 3). With airplane bodies, it is the same; in their jet engines, nickel and titanium alloys are also important (fig. 4, [3]-[5]). This straightforward picture can change if composite cast iron and magnesium (fig. 5) play a more important role than expected in the future. Here, the achievable machining productivity and tool life will be decisive.

Fig. 3: Materials to be Cut in the Car Industry



Source: Volvo, Skövde

Fig.4: Materials to be Cut in Aircraft Engines



Source: Volvo, Trollhättan

Fig. 5: Comparison of Material Features to be Cut

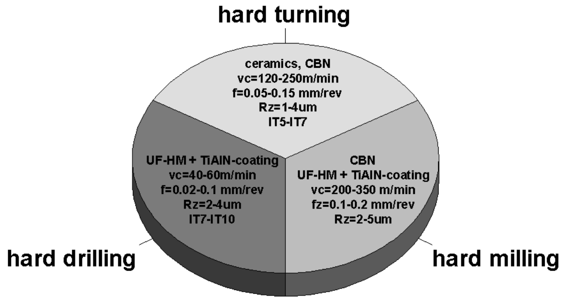
Material	*cast iron*	*composite cast iron low perlite 70%*	*composite cast iron high perlite 95%*	*AlSi9 Cu3*	*magn-esium AZ91HP*
tensile strength [MPa]	230	440	480	255	225
elastic modulus [GPa]	130	145	145	74	45
hardness [HBN]	190	200	250	100	72
cylinder head before machining [kg]	40,4	30	30	27,5	21,5
cylinder head after machining [kg]	35,2	24,5	24,5	22	17

All values are averages

2. HARD - DRY - FAST: 10 COMMANDMENTS OF DRY HIGH SPEED MACHINING

Hard machining, especially of case-hardened steels, is now state-of-the-art (fig. 6).

Fig. 6: Typical Parameters for Hard Cutting Procedures

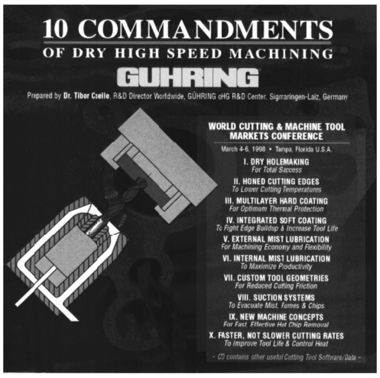


Source: ISW, Hannover

The most important trend in manufacturing today is clearly dry machining (fig. 7 [6]-[11]). Let's just have a look at the 10 most important requirements which make it economically possible to make use of this technology:

1. Dry machining only makes sense if all cutting processes can be performed with little or no coolant
2. Only special tool geometries make dry machining possible and effective
3. Cutting materials with sharp edges to reduce temperature
4. Hard multilayer TiAlN coatings to isolate heat
5. Soft glide coatings for lubrication and for chip transportation of the hole
6. External minimal lubrication is simple and effective for machining operations with few tool changes
7. Internal minimal lubrication for machining centers
8. Chip and steam suction are necessary because hot chips and vapors must leave machine quickly
9. New machine concepts
10. Faster, not slower cutting so chips take away the heat

Fig. 7: 10 Commandments of Dry High Speed Machining CD



Some of the points will also mentioned later in this article. The most important "commandment" is the 10th: against all passion and love for the advantages of dry machining, it only has a realistic chance to be widely used if it, at least, doesn't reduce productivity. Fortunately, experience shows an even more positive direction: the cutting parameters have to be increased so that the chips take away the heat instead of letting it into the tool and the work piece. That allows us to do even more than originally anticipated: increased, not reduced productivity. However, experts still don't agree about just how fast this technology will grow (fig. 8+9).

Fig. 8: Forecast for Growth of Dry Machining in the German Manufacturing Industry

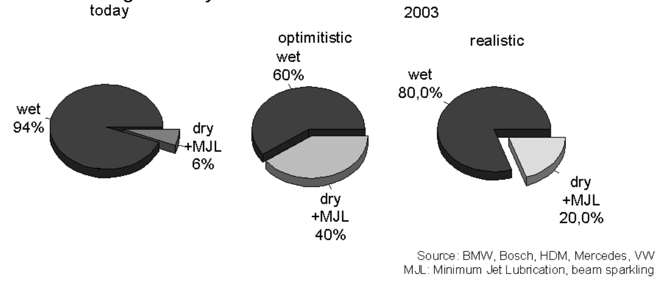
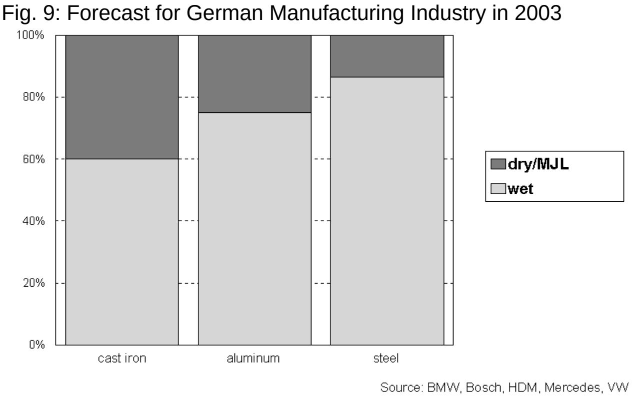


Fig. 9: Forecast for German Manufacturing Industry in 2003



The expansion of dry machining can be greatly accelerated. A good example is this priority list of new investment guidelines already in use today by two large car manufacturers:

- If dry machining can be applied to a process, the dry cutting machines should be bought.
- Next, the applicability of minimal jet lubrication for a process should be checked.
- If flood coolant cannot be avoided, emulsion should be preferred.
- Because of deflagration and fire hazards, oil coolant should only be used if the process cannot be realized in any other way.

3. EPD-GRADIENT CARBIDES INSTEAD OF HSS AND BRAZED PCD

The market is presently dominated by carbide as cutting material [12][13]. The old dogma that P-grades were for steel and K-grades were for cast iron and aluminum has finally disappeared. The only reason for the existence of P-grades are the small advantages at machining steel after regrinding without recoating. But this is made up several times by the additional power of coated ultra fine grain carbides (fig. 10, [14]). Striving for higher toughness, these carbides contain more and more cobalt. The resulting loss in hardness is then made up by using finer grains (fig. 11). The extremely high toughness of these carbides offers the chance to replace HSS tools even in unstable and critical environments.

Fig. 10: Tool Life Comparison K40UF <-> P40

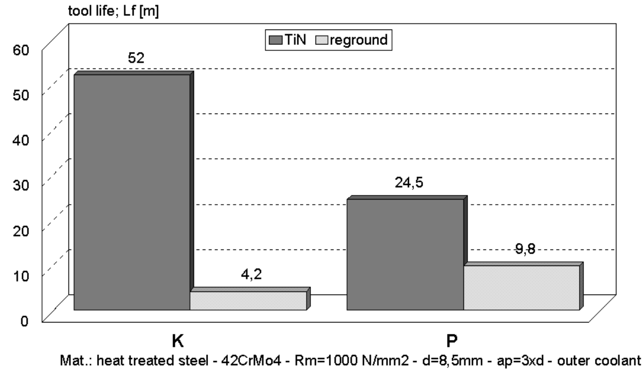
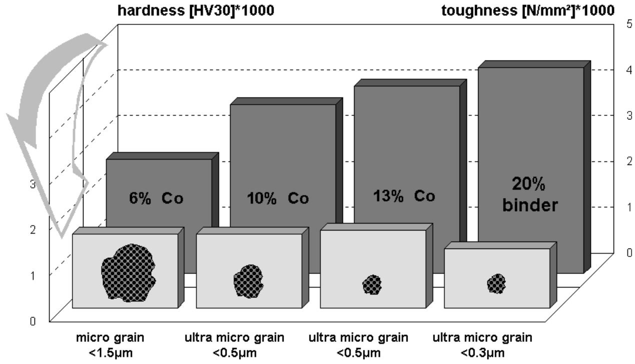
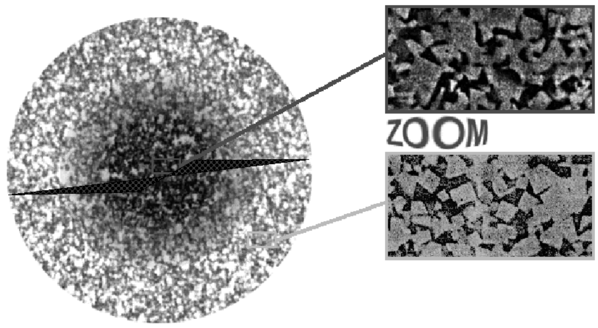


Fig. 11: Hardness and Toughness of K-grade Carbides



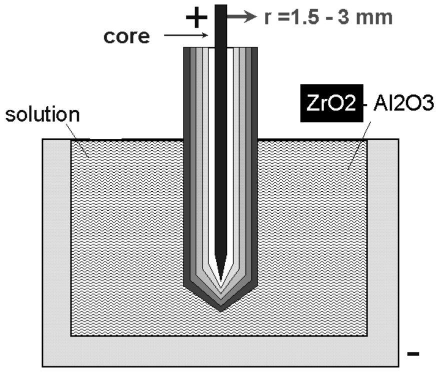
Highest toughness and hardness at the same time can be achieved today by using nanograin carbides. Because they are still exorbitantly expensive, carbides with a tough core and the hard surface using gradient structures are being developed (fig. 13).

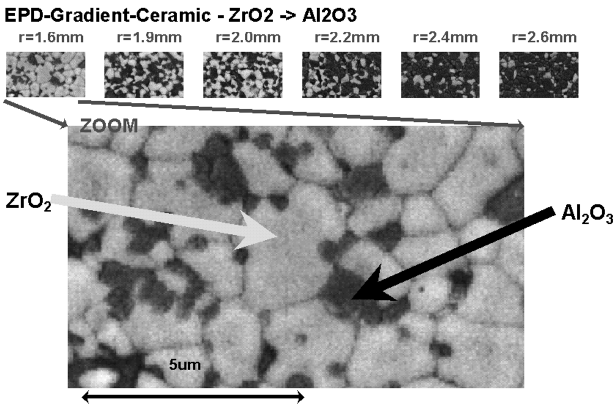
Fig. 13: Functional Gradient Carbide: K60UF → K40UF

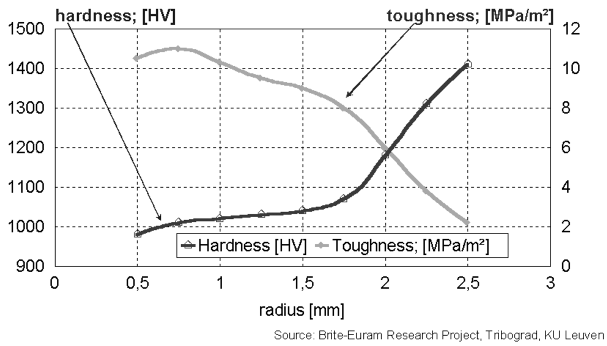


Surely, this is an excellent solution for tools with edges on a constant radius, like reamers and end mills; But with tools that have radial edges, like drills and conical end mills, hardness and cutting behavior would change too much, and chisel edge wear would be very fast. Here, electrophoretic deposition could be the required breakthrough (fig. 14). This procedure allows varying the ratio of toughness and hardness in very fine steps. Each of the gradients can be applied on any kind of original shape. If diamond is deposited as the last surface layer, the un-ecological, cost-intensive and quality-critical brazing of PCD tools with complicated shapes can be avoided.

Fig. 13: ElectroPhoretic Deposition







4. WILL MULTI- AND NANOLAYER COATINGS DO AWAY WITH GOOD OLD TIN?

Layer systems also dominate coatings. Multilayer coatings are deposited with the help of the previously condemned ARC technology. The power of this technique was never in question. But the droplets that are always caused by ARC are still a problem. If this problem is solved, multilayer coatings (fig. 18, [15], [16]) can bring about an enormous gain in productivity (fig. 19), especially when compared with the ordinary, evaporated TiN.
This gain in productivity is by far more important than any kind of tool life increase. The production of nanolayers can further increase the hardness and, consequently, the wear resistance of tools.

Fig. 14: TiAlN-TiN - Multilayer Coating Structure

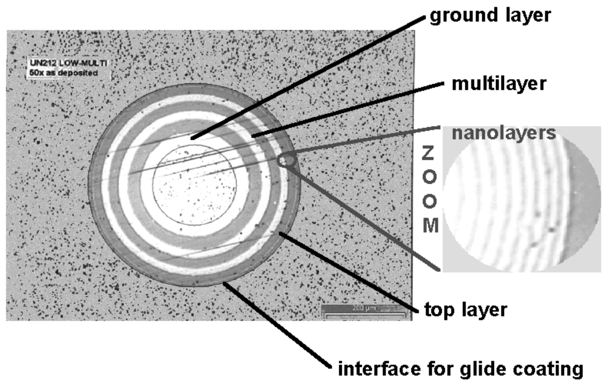
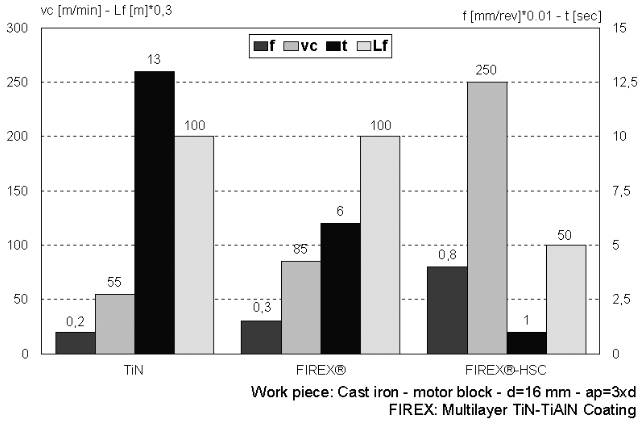


Fig. 15: Increasing Productivity when Dry Drilling



Nanolayers (fig. 16, 17, [17], [18]) can already be disposed today, if the electronic ignition control and the mechanical rotation of the tools to be coated can be exactly synchronized. In the real world, this can only be done with a large number of tools with the same geometry. At a coating sub-contractor company, which has to fill it's machines with various objects, this is impossible to do. Here, it is much more important to be able to decoat - "strip" - multilayer coatings. Since multilayer coatings can hardly be recoated, this stripping know-how will really decide about the capabilities of any kind of coating service. Since many neither have the stripping capacity nor the ability to minimize droplet formation, the good old, evaporated, smooth and easy-to-recoat TiN will not go anywhere for a long time.

Fig. 16: Superlattice Nanolayer

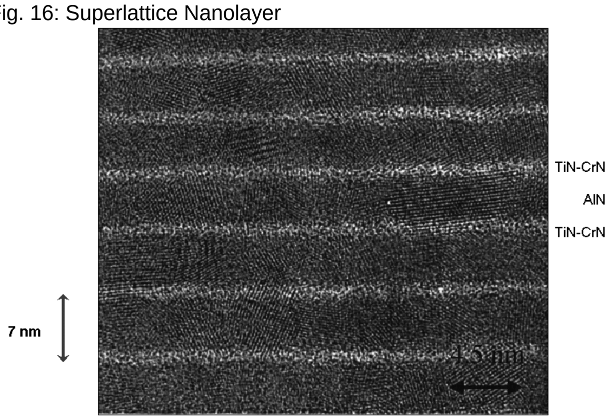
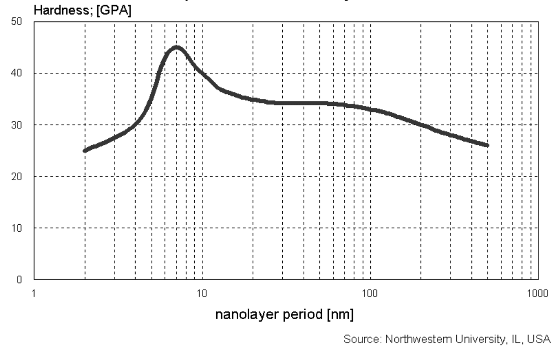


Fig. 17: Hardness of Superlattice Nanolayers



Another very promising new coating technology is plasma ion implantation. However (PII, [19]), it is still far away from practical applicability. The idea of fastening the lattice structure by "shooting in" metal ions makes it possible to increase the hardness without changing the dimensions of a tool. This can become very important for fine cutting tools. Even a hybrid coating could be achieved by only partially applying PII technology: Ion implantation first rows "roots" for conventional coatings into the substrate, achieving optimal adhesion.

Forecasts predict an enormous growth in the coating industry. Accordingly, big coating centers are being established everywhere. But they won't be able to live from coating tools alone. Therefore, they will enter the business of coating constructional elements, which demand far lower prices creating a lower profitability. In contrast, the field for small coating machines to be used at regrinding facilities is still uncovered.

5. SOFT GLIDE COATINGS AND MINIMUM JET LUBRICATION INSTEAD OF HIGH PRESSURE COOLANT

Glide coatings and minimum jet lubrication both have the same goal: to reduce friction between the tool and the work piece as well as to avoid built-up edges. Therefore, although they are competitors, their developments were boosted by the connecting trend, dry machining.

As with soft coatings, which show their full potential in combination with hard coatings, three major directions of development can be seen:

- The rough surface, the intolerable coat thickness and, most importantly, the maximum cobalt content (~6%) have obstructed the success of diamond coatings. New ARC technology makes it possible to dispose amorphous DLC coatings at very low temperatures. In this way, any kind of carbides, steels and even construction components made of aluminum can be coated [11]. Apart from high hardness, these coatings maintain very low friction coefficients for a long time, which could, for example, make the dream of a gear box without oil possible [20].
- The very soft coatings are available primarily based on MoS_2 (fig. 23). In the first place, they improve the entry behavior of tools (fig 25, [21], [22]).
- Glide coatings of medium hardness, e.g. on WC/C basis [23] have higher friction levels on entry (fig. 24), but they have a higher abrasion resistance than the MoS_2 coatings. This can be important if the low friction values are not effective due to self-polishing effects at later points of tool life [22].

Fig. 18: Double Coating; Hard + Soft

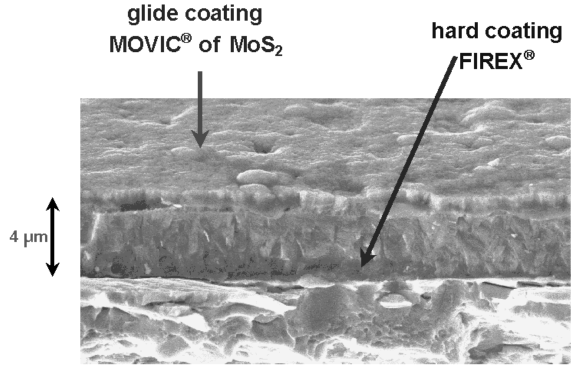
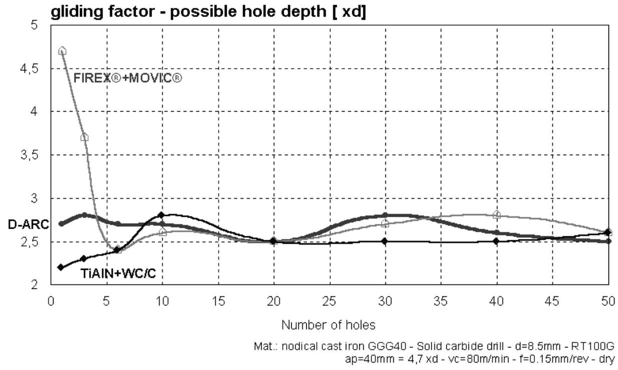


Fig. 19: Comparison: Gliding Factors of Coatings

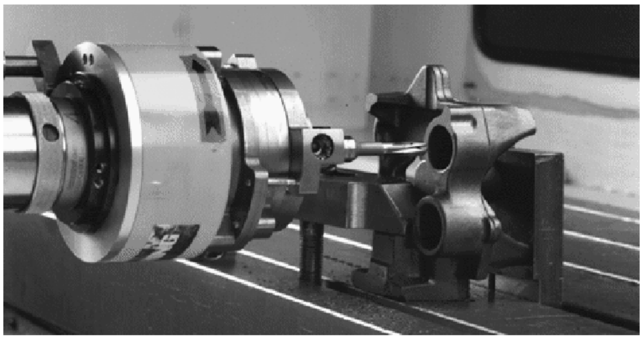


The integration of lubrication into cutting and forming tools as well as in construction components such as bearings, pumps, motors, and gears promises a great future for glide coatings [24].

Fig. 20: External Minimum Jet Lubrication at End Milling

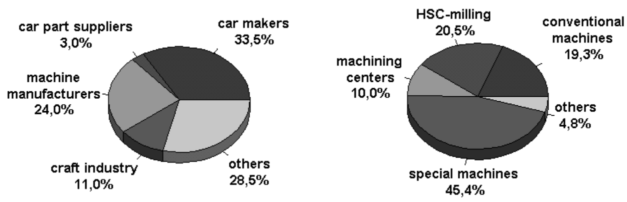
Minimum jet lubrication (fig. 20, 21) is the real smash hit in today's manufacturing environments. It is available for a very low investment of around $1,200-12,000. Adding it (even internal minimal lubrication) to existing machines is relatively simple, since the requirements (fig. 29) [11], [24] are very easy to fulfill. The market in Europe currently absorbs around 15,000 minimum lubrication machines a year, and this number is expected to increase during the coming years (fig. 22). Minimal lubrication has substantial advantages over flood coolant: better lubrication effects, avoidance of thermoshock, around 60,000 times less oil, dry chips and work pieces, and - in combination with chip and steam suction - it fully protects the environment and health.

Fig. 21: Internal Minimum Jet Lubrication with ECO-Chuck®



With all these advantages of minimal jet lubrication, are soft glide coatings still necessary? The answer is yes. Especially in "emergency situations", when the minimal lubrication can not, for whatever reason, reach the important parts of the tool. The author would like to dare to make the prediction that by 2005, the combination of minimal jet lubrication and soft glide coating will have replaced full coolant in up to 10% of all new German machining centers.

Fig. 22: Who uses Minimum Jet Lubrication?

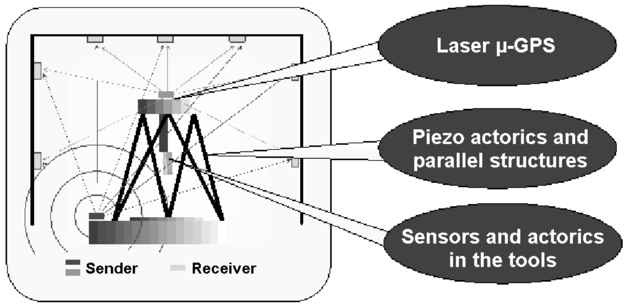


6. SELF-ADJUSTING INTELLIGENT TOOLS IN AGILE MACHINING CENTERS

There are lots of new terms in this subtitle! Measuring and self-adjusting tool holders (actorics) and the adaptive and self-learning, self-regulating (agile) machining centers are, in theory, not new. What is new is the measuring, computing and drive technology now available. The following are entirely new technologies for tooling [26]:

- GPS (Global Positioning System) allows to precisely determine one's position on the earth's surface with the help of satellites. The µGPS measuring system uses this principle in the work room of machining centers (fig. 23). This was necessary because the increasing popularity of hexapod machines, where measuring through the axes (rods) is extremely difficult.

Fig. 23: Accuracy Controlled Machine with Intelligent Tools



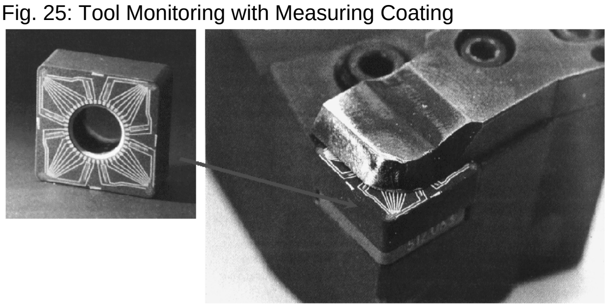
Source: wbk, University Karlsruhe

- Actorics in tools and machines (fig. 24). They use wireless connections for transmitting commands to compensate for size deviations and to be able to automatically detect the end of tool life.

Fig. 24: Installation of Rotating Euro-Palet into Machining Center for Measurement of Cutting Forces with Telemetric Signal Transmission

- Measuring coatings, which, when being deformed, worn, or exposed to high temperatures, can change their electric resistance and transform this into electronic signals (fig. 25).

Fig. 25: Tool Monitoring with Measuring Coating



Source: Dimigen, Braunschweig

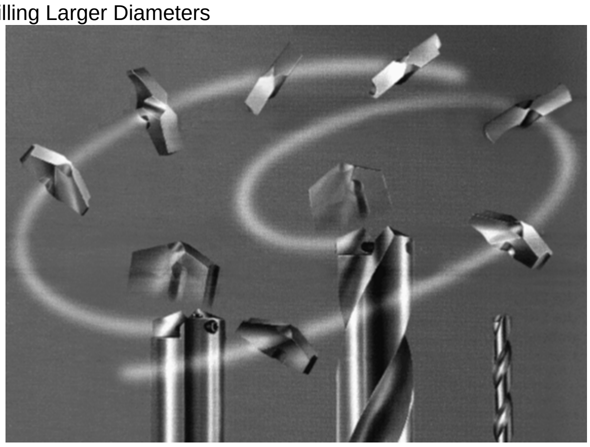
- Adaptive balancers using gels and piezo crystals which cancel out unbalances and help reducing chatter vibration.

The biggest difference is the number of participants: During the eighties, there were a few attempts in different laboratories to build prototypes [27][28]. Now, a large group of German mechanical engineering experts work together to find applicable solutions [26].

7. ONE-WAY TOOLS IN OUR THROW-AWAY SOCIETY

No one would seriously consider regrinding the extremely inexpensive sintered indexable inserts of milling cutters and turning tools. This trend seems to follow through to larger drilling tools (fig. 34).

Fig. 26: Interchangeable Inserts of Carbide and PM-HSS-E for Drilling Larger Diameters



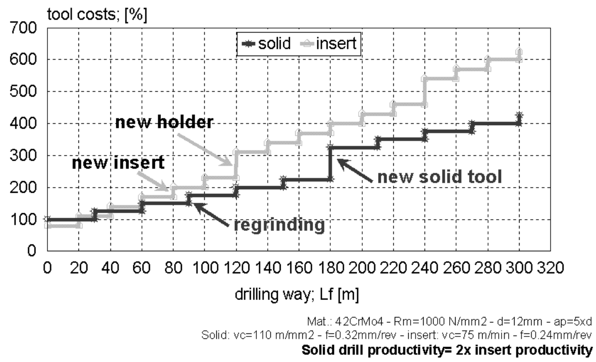
The reasons for this are, once again, not only of technical, but also of economical nature:

- On the one hand, the required precision for these larger dimensions (Ø > 16 mm) can be achieved easier by making use of near-net-shape technology (e.g. precision injection moulding).
- On the other hand, the rising substrate costs do not give solid carbide tools of larger diameters a chance.

In contrast, throw-away inserts in the lower diameter range currently cannot compete with solid drills. The reasons:

- The desired qualities of the critical insert surfaces can only be accomplished through grinding.
- The carbide price is not significant at these sizes.
- The higher performance and precision of well-reground and well-recoated solid tools does not give the throw-away tool an economical chance (fig. 35).

Fig. 27: Solid Carbide <-> Interchangeable Insert for Drilling



The requirement for this is a well-organized regrinding and recoating service. This secures quality and logistics, e.g. by outsourcing of the internal tool management.

8. OFFERING CUTTING CAPACITY WITH TOOL MANAGEMENT, NOT JUST TOOLS

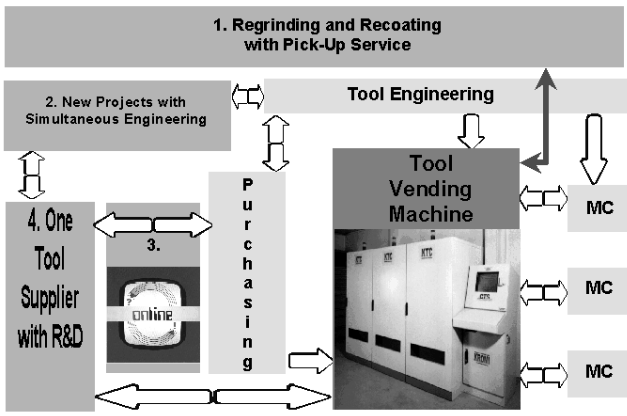
The continuous development of outsourcing more and more tasks that were, until now, done in-house, seems inevitable, especially considering the extreme examples in the automobile industry in fig. 28 [29]. Fortunately, numerous manufacturers have recognized the dangers of outsourcing. They at least want to keep key know-how in their production, thereby avoiding total dependency from suppliers.

Fig. 28: The Changing Role of Car Manufacturers

	1980	1997	2005/2010
	car manufacturer	car assembler	car architect - integrator
outsourced production	30-50%	to 70%	80-90%
features	R &D; manufacturing of components; assembly	car conception; chassis; logistics; assembly; manufacturing of core: components, motor, gear box	architect project manager assembly of subsystems; marketing; distribution; finances; service
examples	GM bought 30% of the components	Chrysler bought 70% of the components	Smart (MCC) Fiat (Brasil) VW (Brasil)
remarks		R&D by simultaneous engineering with key suppliers	several car manufacturer s refuse giving up core production

Where is the 'healthy' borderline between outsourced and in-house production tooling? A reasonable interface is the semiautomatic tool vending machine (fig. 29). The tool manager takes care both technically and logistically of always having the required tools stored in the machine and so offers "cutting ability", i.e. cutting capacity with guaranteed total tool life, not just tools. The maximum logistical effectiveness and productivity are achievable in tool management if the tool manager can concentrate on supplying separate, well-divided production sections [30].

Fig. 29: Tool Management with Commodity Supplying System

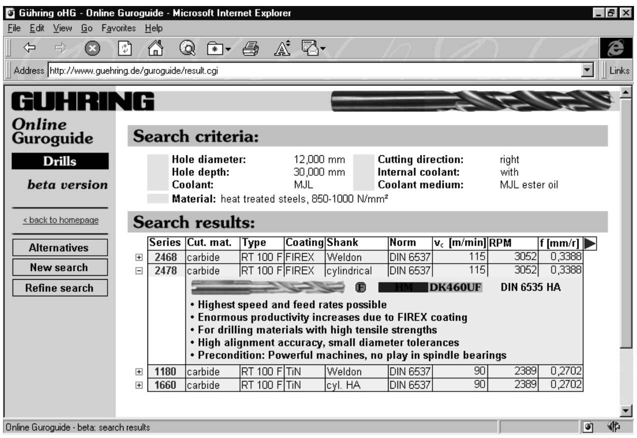


Tool management can be very successful especially when it resulted from simultaneous engineering, in a project with competent partners. These partners for planning of tool and technology issues are and can only be tool manufacturers, not trading companies. If a tool manufacturer is to be chosen as tool manager, users tend to select the manufacturer of the finishing tools. The principle is: "They should guarantee the critical work piece dimensions with their own tools and they will surely take care of buying the right tools for preworking."
This is why manufacturers of precision tools will still play a key role in these projects. Another important requirement is the complexity of the manufacturer's tool palette which the tool manager can choose from. If the tool manufacturer is competent at only a small part of the tools necessary, the tool manager could just as well be a trading company...

9. THE INTERNET CHANGES CATALOGUES, DISTRIBUTION SYSTEMS AND EVEN JOBS

The power of the Internet has been demonstrated quite impressively to the entire world's population by recent half-political publications. The tool industry primarily uses the Internet for self-presentation and for fast advertising of own products. Few online catalogues (fig. 30, [31]) are available and the sale of tools over the Internet has still not really started.

Fig. 30: Online Catalogue and Data Base on Internet



Contrary to today's situation, large customers demand online catalogues to be available as fast as possible, because CD-ROM catalogues were never quite able to replace the old, printed ones. Why?
CD-ROM catalogues are rarely completely up-to-date, and often, they are not put onto the computer networks of large companies due to security concerns. Also, they often include lots of information unimportant for individuals. An online catalogue is different. It really reflects the information a company possesses (this, of course, requires that the company keeps updating it's website regularly). The catalogue can be used when it is needed and requires practically no storage space on a client computer. Most importantly, it makes the direct contact to the company itself possible.

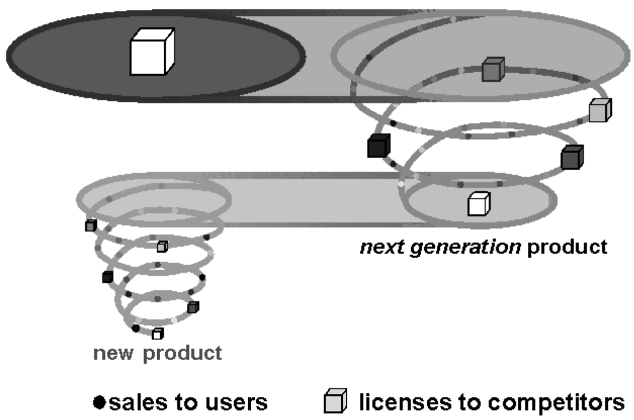
Contrary to the online catalogue, e-commerce, the direct sale of tools over the Internet, does not affect large customers, but primarily tool distributors. A protection of distribution regions is hardly imaginable on the Internet and the location of the storage of the tools is also unimportant in this time of fast direct delivery. What is left for the dealers? Proximity to the customer and improvement of service, like for example tool management [30].
But the Internet will not stop at the desk of the purchasing manager or the tool planner. Soon, machine operators will be able to download cutting data off the Internet from their machine controls, just like they will be able to perform simple trouble shooting without customer support with the help of expert systems. 80 % of all problems can be localized easily with preprogrammed algorithms. The computer industry already offers extensive trouble shooting programs that work around the clock, around the globe. This kind of help is free, contrary to the high costs of a software or hardware specialist. Consequently, specialists won't be called in for simple, unimportant tasks. Perhaps this method could help solving the problem of the lack of qualified advisors that many tool manufacturers and users have.
If with tool management, cutting ability is sold instead of tools, machine manufacturers could offer coating ability or coating capacity through the Internet instead of selling the small coating devices themselves. The recoater only pays a small or symbolic amount of money for the machine. Then, the coating machine manufacturer receives money for each coating process through the Internet.
Computer scientists are euphoric: by hooking up workers and machines to the Internet, a company's hierarchy can be made transparent and simpler by applying the principle of distributed intelligence. In reality, it is likely that the biggest profit for software companies will come from security software that manages and restricts information access both internally and externally [32].

10. PATENTED ONE-WAY STREET OR SPIRALING DISTRIBUTION?

The last question is about how these (surely patented) new tools and technologies will be marketed. Without going into much detail in the middle, two extreme examples can be shown.
Marketing on one's own is extremely difficult, since generally no purchasing manager will like buying from a monopolist. The way of marketing this patent alone only has a chance if one offers the extremely good product with short delivery times and an extremely good technical on-site service. Otherwise, the tool will be copied (or nearly copied) in spite of the patents and the market slowly disappears. Legal action is only effective after a long time, after and during which a product is already obsolete.
The second way is longer and a lot less straightforward (fig. 31). It is the continued marketing spiral of Bill Gates [33]. At first, the product starts out from a shaky base. It is offered to customers, and,

shortly after, to competitors in exchange for license fees. So, the group of users gets larger, the spiral becomes wider. When the excluded competition tries to enter the market with a copy or an allegedly better product, it is time to bring out the next, further developed version of the product. With help of an already recognized name, a new, wide base for a further widening of the spiral is created. But any product should only be allowed to become a de-facto-standard, because no money can be earned from official standards.

Fig. 31: Distribution Spiral



The expert reader can surely add his or her own examples to these marketing possibilities. Each company's management will have to decide about which compromise of these two ways is the right one, depending on the company size, the product and numerous other demands. In these times of globalization, the author has the opinion, that only very few companies will be able to successfully choose the first way. The second way is that of the distributed intelligence. Since both the customers and licensees are partners and view and take care of the product as if it was their own, it can be further improved. The best thing is that this neural network of distributed intelligence logistically organizes itself nearly autonomously.

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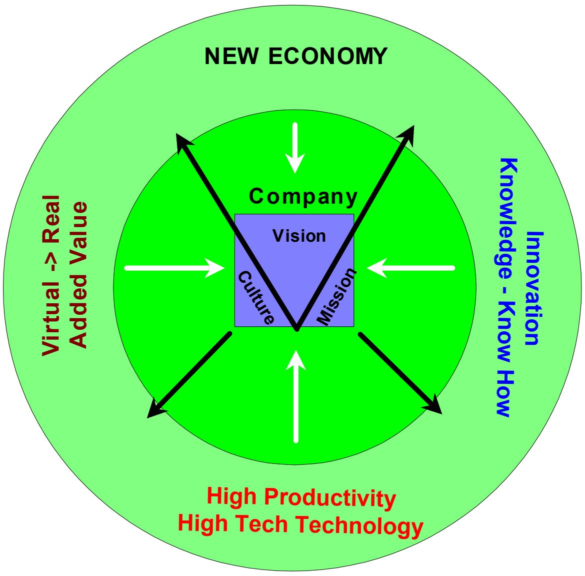


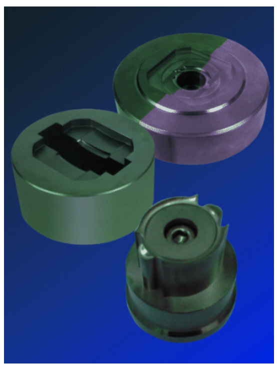
Keynote Lecture
Gorham Conference, Cutting Tools and Machining Systems
May 21-23, 2001, Atlanta, GA, USA

T. Cselle Platit AG, Grenchen, Switzerland

Invited 2 Days Workshop, March 1-2, 2002, Hong Kong

MOLDMAKING expo 2002
ENGINEER, BUILD, REPAIR

Hong Kong Productivity Council
香港生產力促進局



Advanced Coating Technology and Applications for Molds, Dies and Cutting Tools

Contents

1. The Manufacturing Companies in the New Economy
2. New Machine Concepts for Dry High Performance Machining
3. Intelligent Tooling
4. Flexible Coating

1. Manufacturing Companies in the New Economy

What is the New Economy?

A. The New Economy is part of the development process
   - from an industrial society
   - to a knowledge society.

B. The important means of production are
   - knowledge, know-how, and innovation

   They determine the value of the company much more than
   - real estate, working capacity and capital.

C. Due to states´ deregulation, privatization and globalization the national states lose, the national cultures and the companies win on importance.

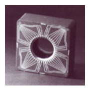
D. Not only IT (Information, Internet Technology) companies can achieve fast growth rates and profits in the New Economy.
   Innovative manufacturing industries (MI) can use the advantages as well, if they realize the New Economy's principles.

Main Points to Determine the Company´s Value:

Old Economy ↔ **New Economy**

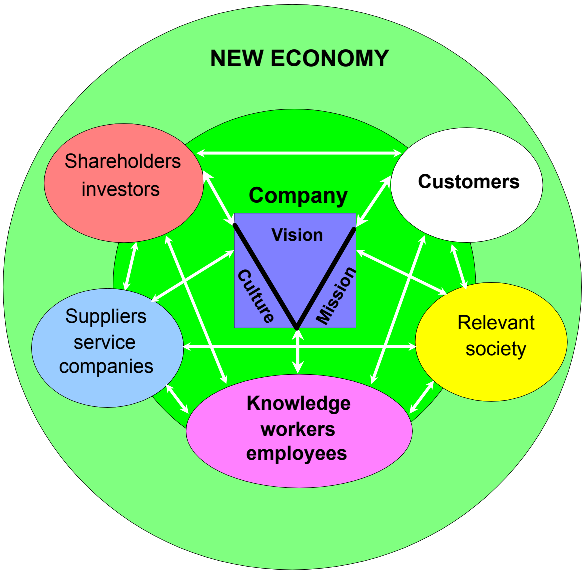
- real estate
- working capacity
- capital

- High-Tech innovation
- Know-How of the knowledge workers
- Vision, mission, culture, image
-> Increasing company value
-> Innovative High-Tech investment
-> Increasing added value
-> Increasing profit

IT New Economy		**MI New Economy**
		
Almost only IT; Internet companies	↔	Innovative manufacturing companies
Short term increase because of exaggerated stock euphoria	↔	Long term business through real industrial demand
New products for virtual possible markets	↔	New innovative products for existing markets
Only shareholder value important	↔	**Stakeholder value has priority**

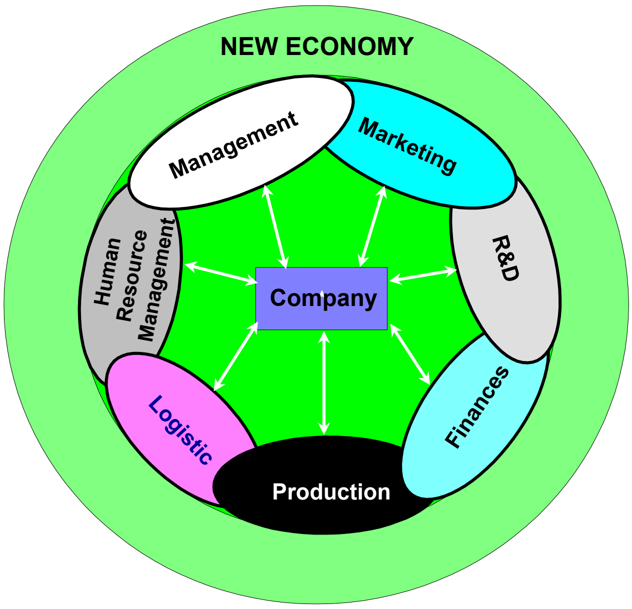
Company Target in the New Economy: Increasing Stakeholder Value

The Stakeholders in the New Economy



1. The main value of a company is the knowledge of the "knowledge workers".
2. The cooperation of the stakeholders is focused according to bottlenecks.
3. The suppliers and customers are very strongly integrated in development and production processes.
4. The interest of the stakeholders must be balanced by the management according the vision and mission of the company.

Flexible Flat Company Organization in the New Economy



1. The exchange of information and knowledge (not keeping it in one head) makes innovation possible.
2. The customer is well informed and more powerful. Marketing becomes not only mediation between production and customer but integration of customer processes.
3. Solving tasks should be done in projects not in departments.
4. The special projects of the knowledge workers can be leaded by specialized experts (Michael Jordan's).
5. Personal ego problems should be solved by rotation and changing project leaders and participants.

Company Identity in the New Economy

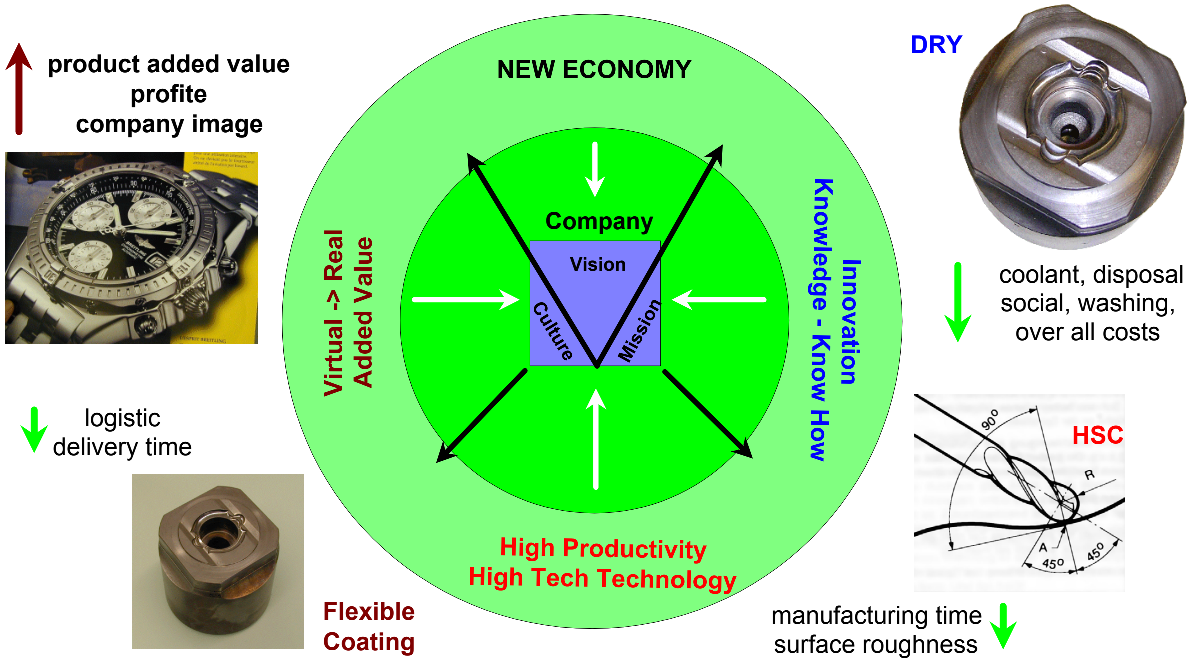
Vision, mission and culture are not phrases
they strongly influence the (virtual) value of the company

1. Added value will be generated
   - not only by goods and materials (input and costs), but
   - branded products and hopes (virtual profit) for better life, society and environment.
2. The virtual added value accumulates capital,
   - increases capital liquidity and investments without inflation.
3. Typical manufacturing example to generate customer and virtual added values:
   - dry -> healthy working condition, environmental protection
   - high performance machining -> effective machining with high productivity, more free time
   - with integrated flexible coating -> total tool production in own hand, fast reaction to customer demand
4. Invest in High-Tech
   -> Generation (virtual) added value of the company
   -> Generation real and customer values by High-Tech production
   -> Increasing profit and real value of the company

Dry High Speed Machining with Flexible Coating

Excellent Chance for Innovative Manufacturing Companies to Go into the New Economy

Dry Machining		Innovative health & environment protection
High Speed Machining		High productivity
Integrated Flexible Coating	→	**Increasing added product value**



2. New Machine Concepts for Dry High Performance Machining

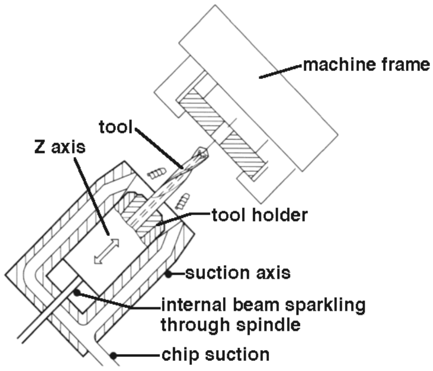
Why Dry Machining?

- Human health
  53% of all machine operators had or has skin problems because of coolant medium in Germany
  -> 1,000,000 work shifts are lost every year
- Environment protection
- Image
- Innovation
  -> Competitive advantage
- Costs

Source: Stockhausen, Krefeld, D

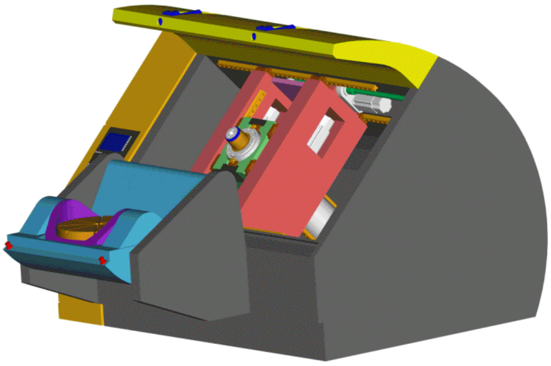
10 Commandments of Dry High Speed Machining

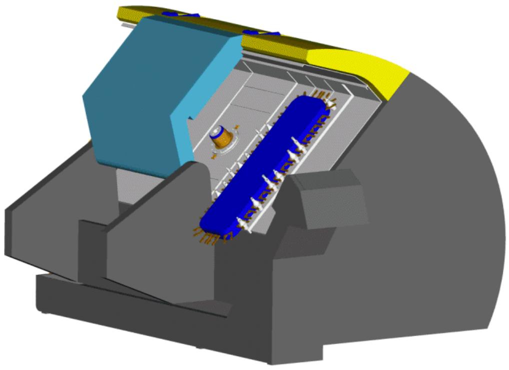
1. All operation dry in one machining cell
2. Cutting materials with high heat resistance
3. Hard coatings for heat insulation
4. Soft coatings for lubrication
5. External minimum lubrication for easy start
6. Internal minimum lubrication for high reliability
7. Intelligent tools adapted for dry cutting
8. Chip and steam suction
9. New machine concepts
10. Faster, not slower

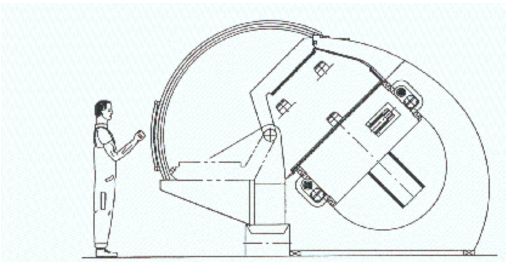


A. Using Gravity for Chip Removal

Machining Center with Inclined Axis

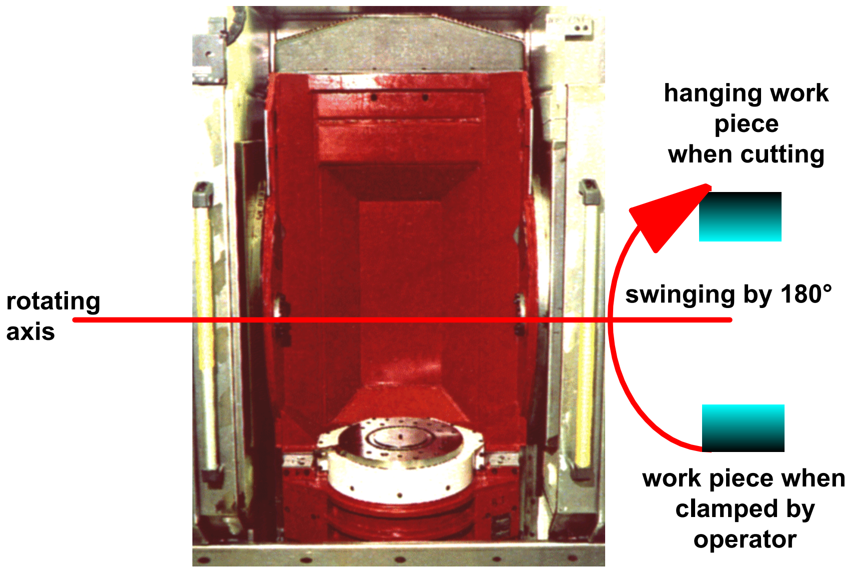






Source: Alzmetall, Altenmarkt, D

Loading Normal, Machining in Hanging Position in Dry Machining Center



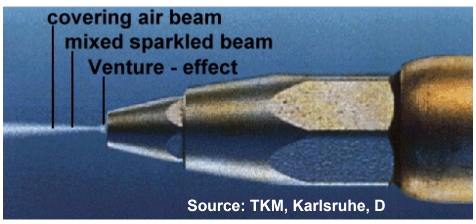
Source: Hüller - Hille, Ludwigsburg

B. Integration of Minimum Jet Lubrication (MJL) into Machine Tools

Over 80% of the European and Japanese machine center manufacturers offer Minimum Jet Lubrication solutions instead or in addition to the standard coolant systems.

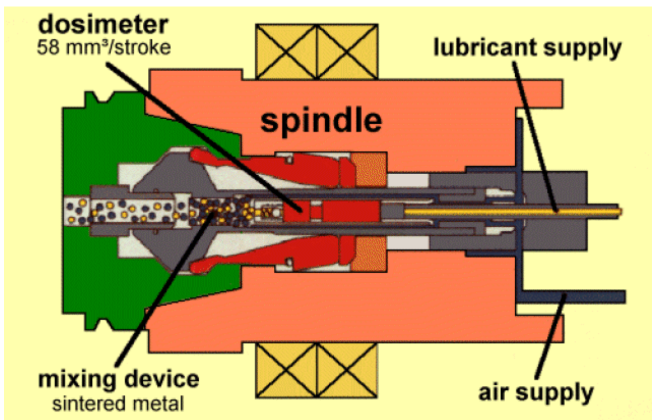
Integration Minimum Jet Lubrication into Machine Tools

External MJL



- Low air pressure (2-6 bar)
- Oil is vaporized
  - from double nozzle externally
  - from metal sponge internally
- Air beam carries oil to tool's edges
- Minimum oil quantities: 10-30 ml/hr
- Environment and health protection
- Dry workpieces after machining
  - no washing necessary
- Enormous cost saving

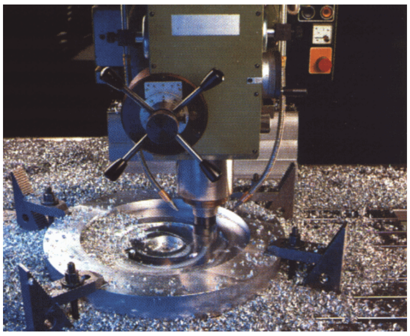
Internal MJL

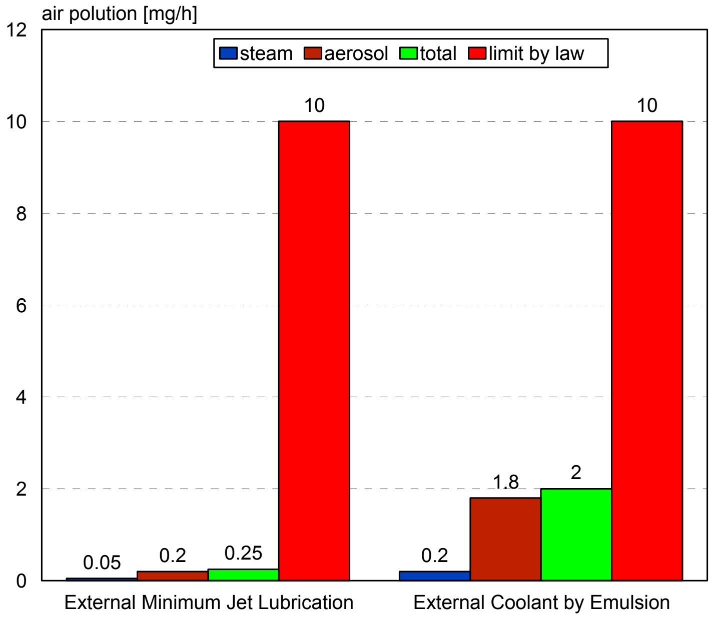


Source: Hüller-Hille, Ludwigsburg, D

Minimum Lubrication Systems burden environment and people much less with damaging pollution than wet coolant:

Air Polution when Machine Door Open - Steel Roughing at Milling



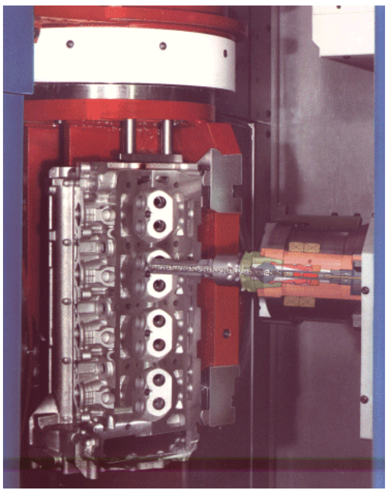


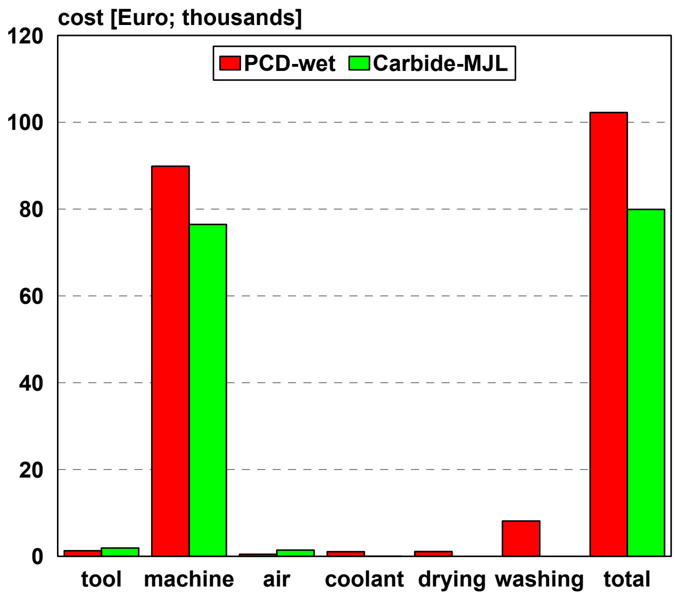
Source: Fraunhofer Institute, Pfinztal, D

Enormous cost saving with the help of Minimum Jet Lubrication:

Cost Comparison for Machining Cylinder Head

Wet Machining by PCD <-> Dry Machining with Coated Carbide and Minimum Jet Lubrication

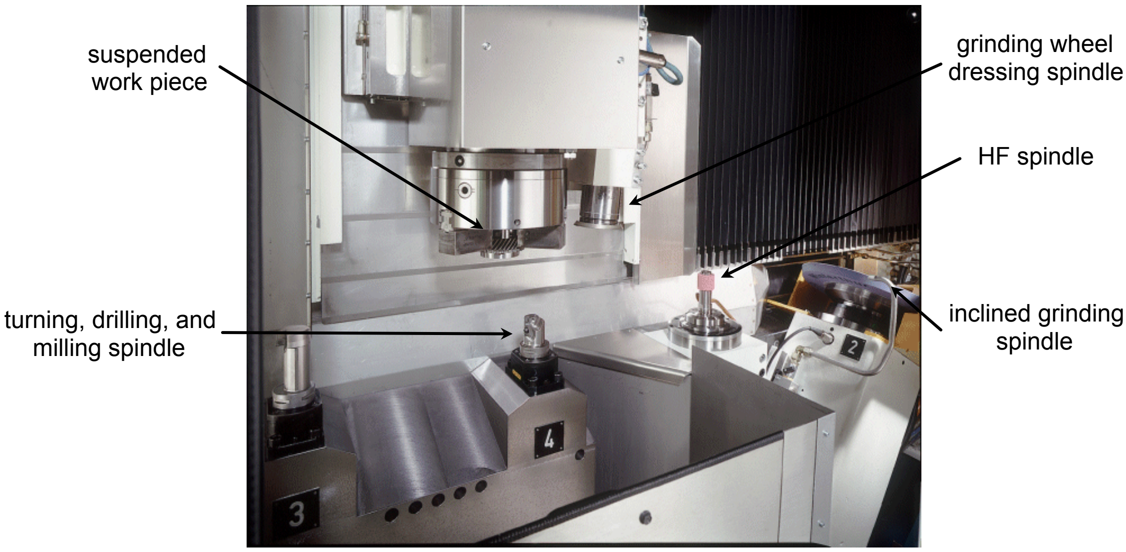




Source: Eucotooling - EU-Brite-Euram R&D Project

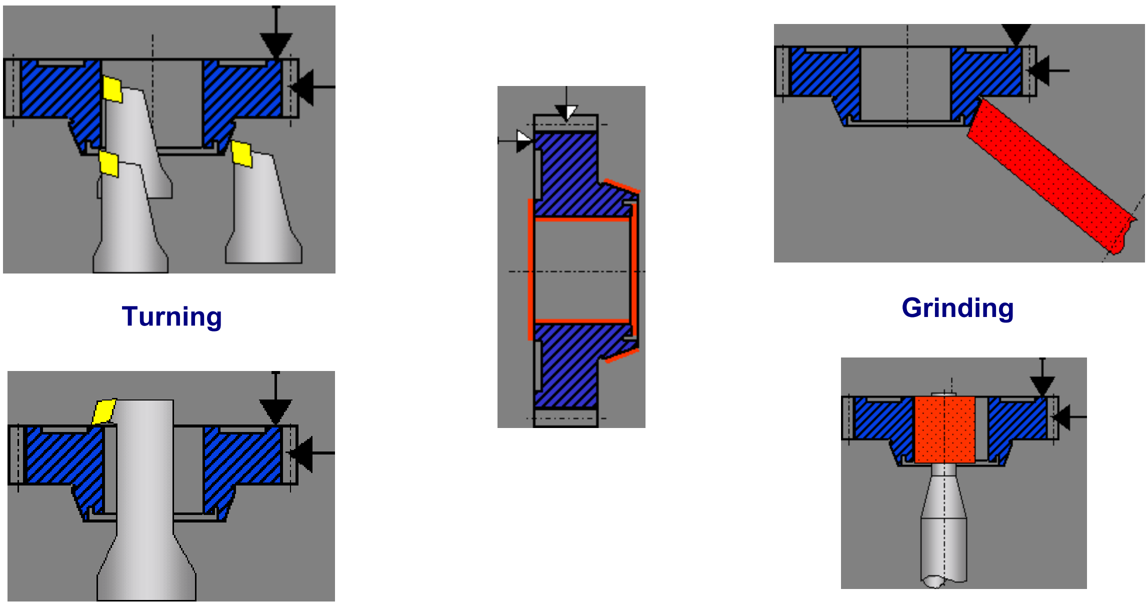
C. Integration of Different Cutting Technologies into One Machining Center

Machining Center Integrates Different Cutting Technologies with Optimum Chip Removal



Source: Schaudt, Stuttgart, D

Complete Machining with Different Cutting Technologies of Hardened Steel in One Clamping

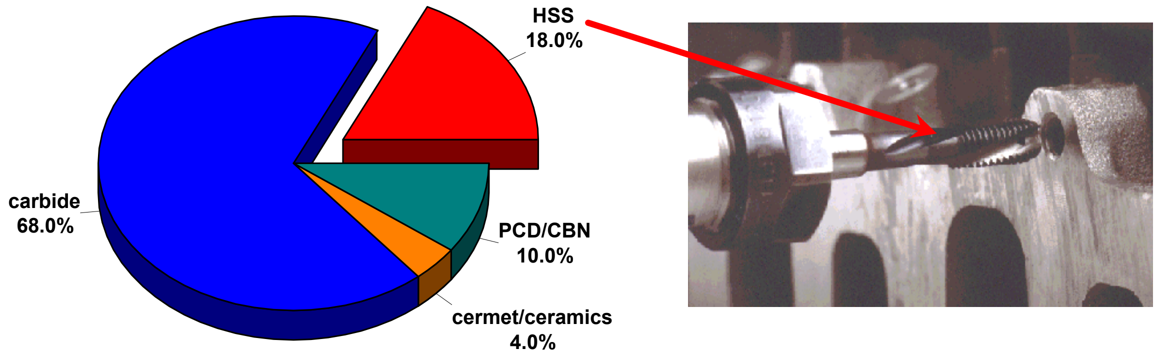


Source: Schaudt, Stuttgart, D

D. Increased Spindle Acceleration for High Speed Tapping

Cutting Materials in the High Performance Tooling

Over 80% of the HSS-tools are taps

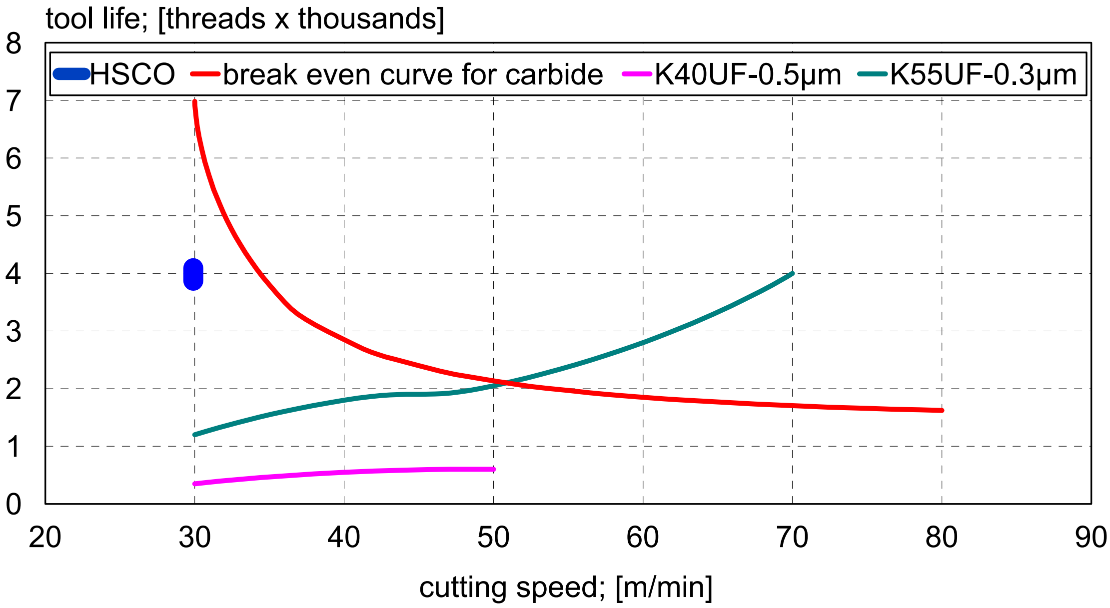


Source: VDMA, Frankfurt, 20000

Even high performance taps for steel machining are produced from HSS not from carbide, because

- of the low toughness of carbide and because
- even the newest ultra fine carbide taps would need high cutting speed.

Tapping in Steel with Carbide

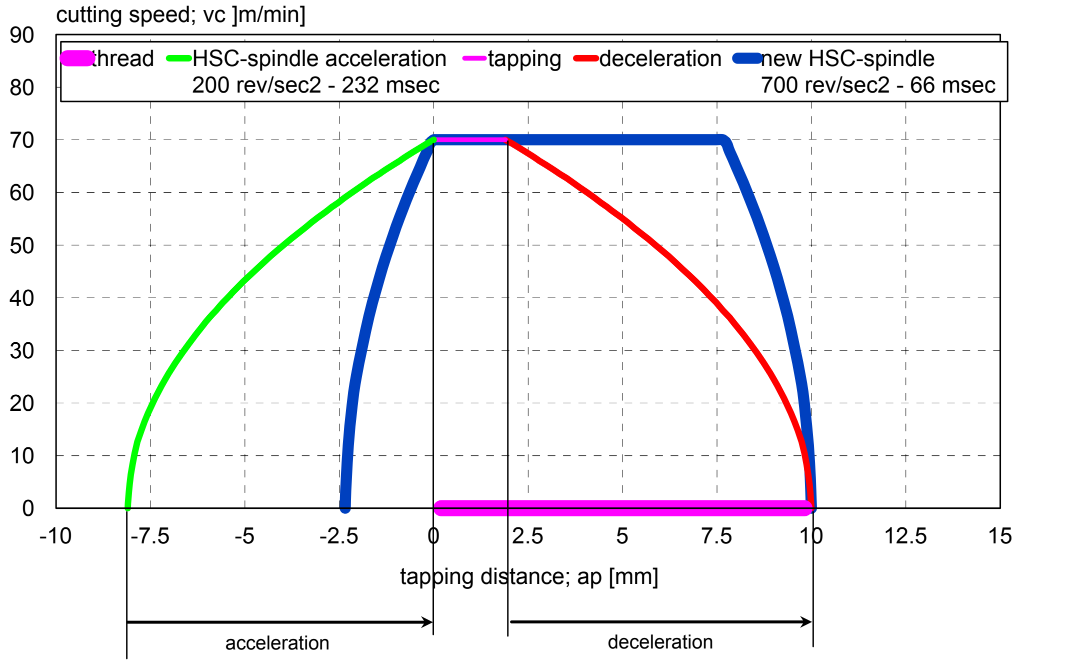


Mat.: C45 - connecting rod - Tool: M8 - ap=2xd - TiN- coolant: emulsion

To achieve the high cutting speed for tapping, high spindle acceleration is necessary.

Real Cutting Speed for Rigid Tapping

Rotating Spindle Acceleration Determines Real Cutting Speed

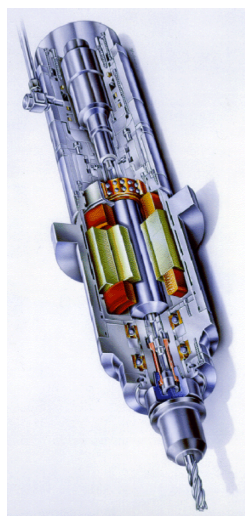


Thread: M8 - ap= 10mm blind hole

High Speed Spindle for Rigid Tapping

HSM700
The High Speed Milling Machine

- RPM-range: 0-42.000
- Accerelation time: <1 sec
- accerelation: 700 U/sec2
- HSK40E
- hybrid ceramic bearings



Source: Mikron, Nidau, Switzerland - Kessler, Bad Buchau, D

E. EDM or High Speed Cutting

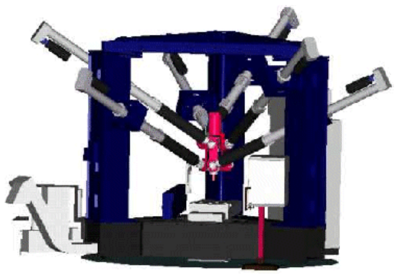
Comparison of EDM to High Speed Cutting

Criteria	EDM	HSC-milling
material	all conductive materials	all cuttable materials, steels up to 62 HRC
geometry	nearly free	limitations in depth, radius
sharp corners	possible	limits for walls > 1 mm limit on bottom > 0.3 mm
deep slots	depending on electrode	aspect ratio < 10-12
accuracy	good	very good
smooth surface	benchmark necessary	less benchmark
finishing	good	very good
surface structure	good	edging necessary
metallographic structure	micro-craks	surface tension
contour accuracy	good	very good
material removal rate	+ for long cavities areal removal	+ small cavities cutting on point or line
pre-machining	several electrodes for rough EDM	by simple tool changing
tools	electrode, most complex and expensive	standard

Source: Mikron AG, Nidau, CH

F. From Hexapod to 3-axis Parallel Kinematics

Hexapods Limitations



- Poor Workspace Size / Footprint ratio
- Reliable joints missing
- 6 motors for 5 axis (in machining)
- Heavy moving bodies
  - ball screws, motors, sensors, cables
- Thermal energy is produced in moving bodies
- Non direct position measurement at reasonable cost
- Ball screw not rigidly fixed
- Telescopic legs
- Not compatible with linear drives

Reference: LIRMM, Montpellier, F

Dreams and Reality of Hexapod Machines

- 1994: IMTS, Chicago
- "THE" solution for the future

!!!

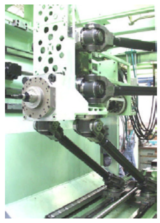
- 1997: EMO, Hanover
- Hexapods everywhere!
- To do what?

?

- 2000: IMTS, Chicago
- So,... is it really working?
- But: Urane!

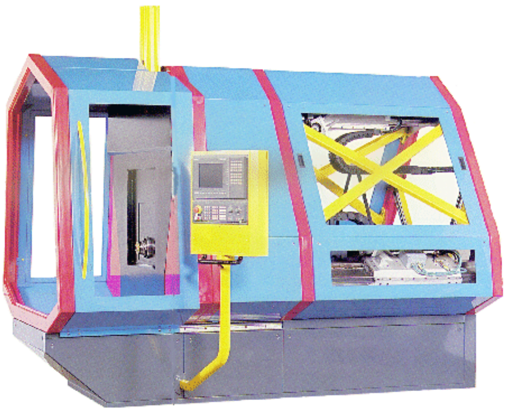
????

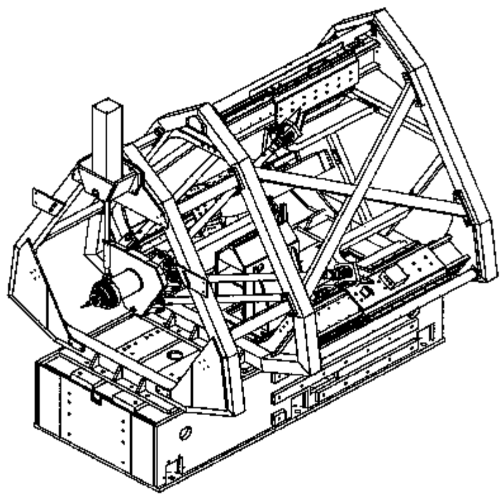
- **2001: EMO, Hanover?**
- **3 axis PKM -> breaktrough!**

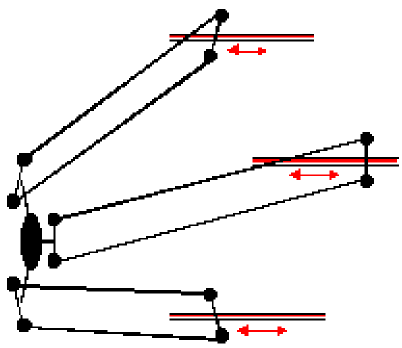


- Renault
- Heckert
- Toyoda
- Krause
-....

3-axis Hexapod with Linear Drive in Z: Urane







x/y/z: 500/500/200 mm
- vf= 120 m/min
- a=3.5 g
- n= 40.000 RPM

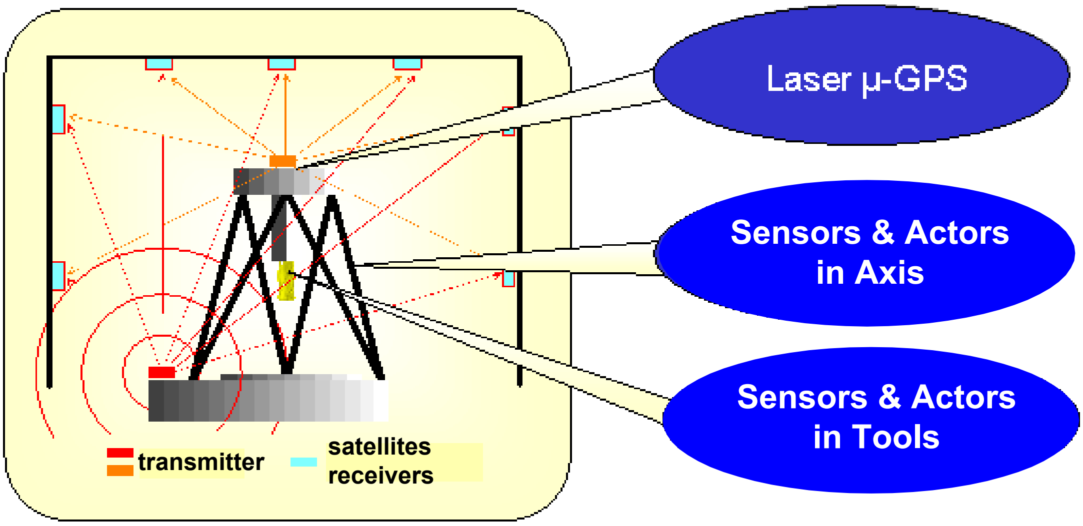
Source: Renault-Comau, Torino, I
LIRMM, Montpellier, F

G. New Measurement Concepts for Machine Tools

Measuring movement of the axis on the spindle with µGPS (Micro Global Positioning System):

- machine parts deformation -> no measurement error
- optimum measurement in hexapod structures (where conventional measurement of xyz movement is extremelly difficult)

Accuracy-Controlled Machine with Intelligent Tools



Source: ACCOMAT Project, wbk, Karlsruhe, D

Sensors inside machine tools for process control and optimization

Piezo Table for Measuring Cutting Forces

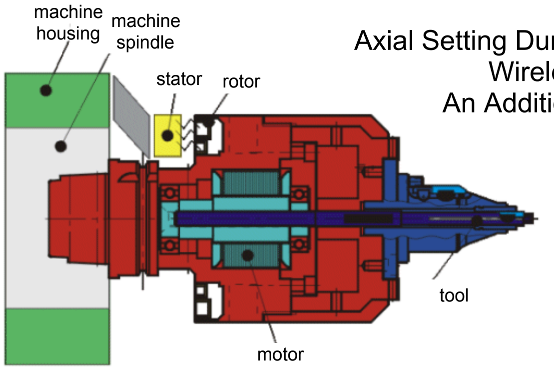
In Standard Palette Size for Machining Center

Source: Kistler, Winterthur, CH - Guhring, Sigmaringen, D

3. Intelligent Tooling

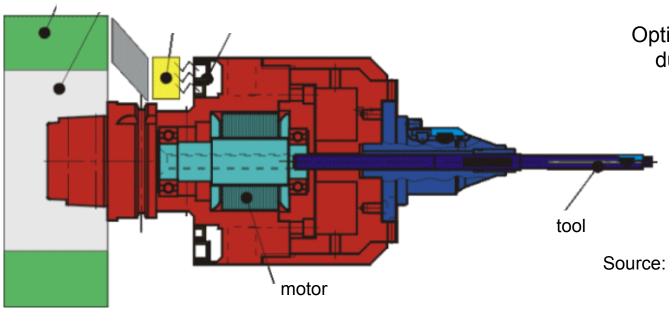
A. Tool setting during cutting

Intelligent Tool for High Precision Boring



Axial Setting During Machining with Integrated Motor
Wireless Energy Transmission
An Additional NC-axis for the Machine

starting tool position
before machining



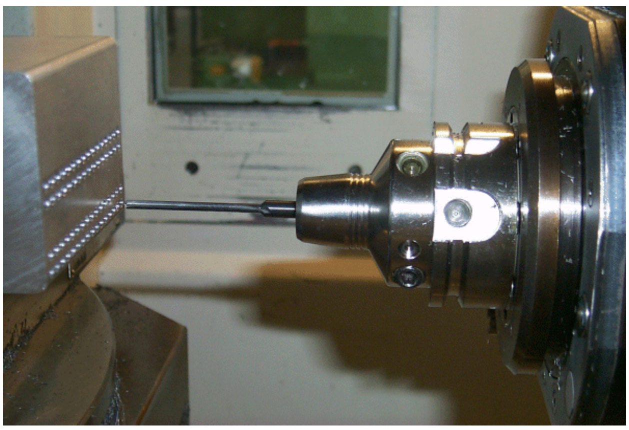
Optimum guidance (with short overhang)
during whole drilling process

final tool position
after machining

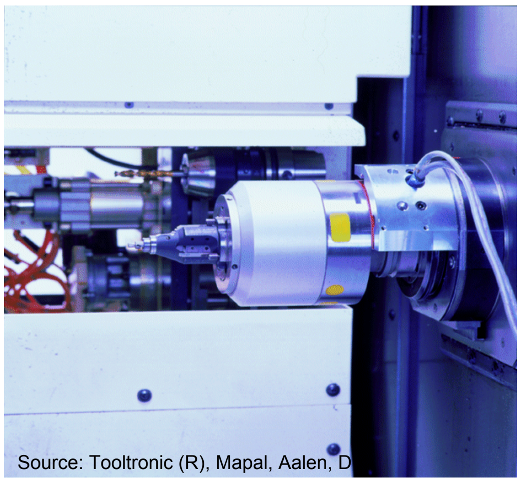
Source: Tooltronic (R), Mapal, Aalen, D

Tools for High Precision Hole Making with High l/d Ratio

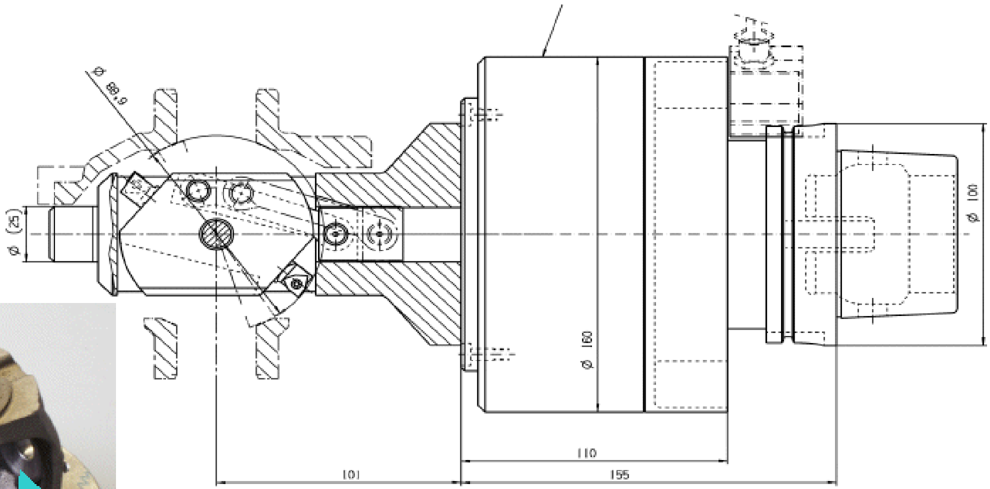
Solid carbide drill:
- cheaper tool
. no setting necessary and possible
- high deflection because high l/d ratio
- high position accuracy with bushing/guide only
  or tool has to make its own pilot hole
- lower feed rate at starting
- high risk for breakage
- special carbide grade necessary



Intelligent tool with own z axis
- optimum guiding (with short overhang)
  during whole drilling process
-> maximum position and form accuracy
- high feed rate for the total depth
- reliable production
- inserts are applicable



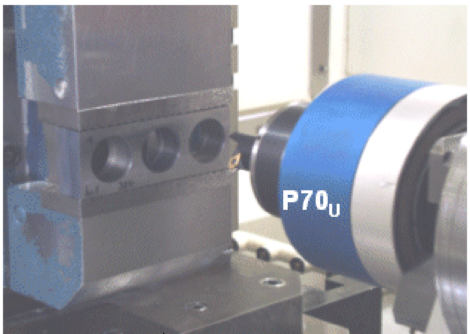
Machining Internal Ball Contour with the Help of the Programmable Axial Axis of the Intelligent Tool



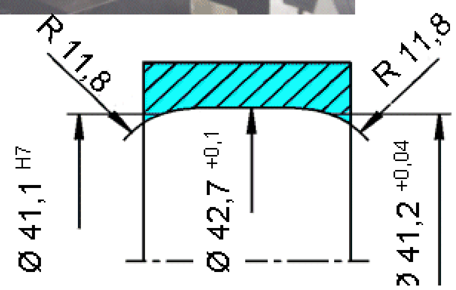
Intelligent Tool P70-PTP can be set and moved programmable in the z axis during cutting!

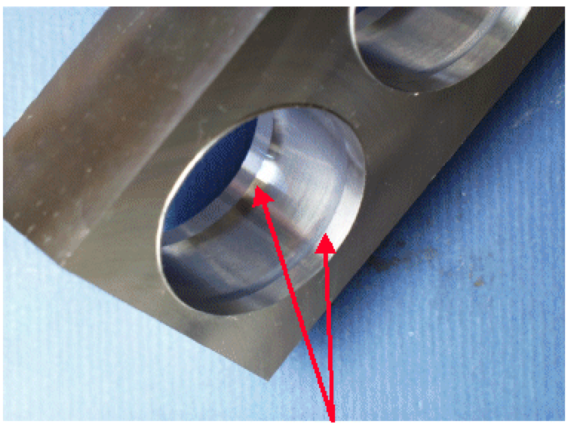
Source: Komet, Besigheim, D

Machining Internal Contour with the Help of the Programmable Axial and Radial Axis of the Intelligent Tool



Intelligent Tool P70-U can be set and moved on a programmable contour, in z and y axis during cutting!

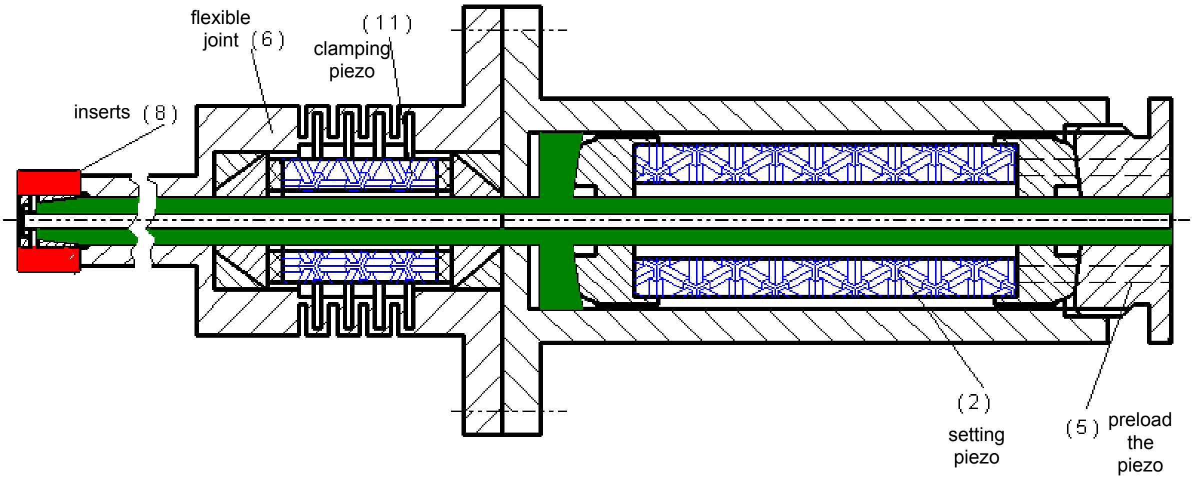




Source: Komet, Besigheim, D

High Precision Adjustment before Cutting without Mechanical Setting

Fine Boring Tool Adjusted By Piezo Actuator



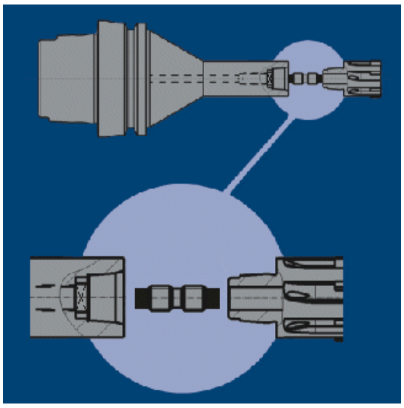
Source: Patent 19945455.8, European Patent Office, Munich
Patent owner: Gühring oHG, Albstadt, D

B. Direct Tooling with Short Hollow Cone for High Performance and Precision

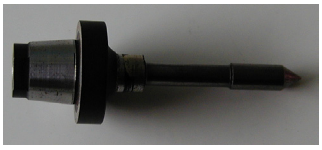
Direct Tooling

Tool is produced directly with short hollow cone shank

The tool will be clamped with the help of the
- deformation of the short hollow cone and
- plane face



Final grinding takes place at clamping on the short cone



Advantages of direct tooling:
- **highest stiffness**
- **highest accuracy: run out error < 2 um**
- **highest reproducibility**

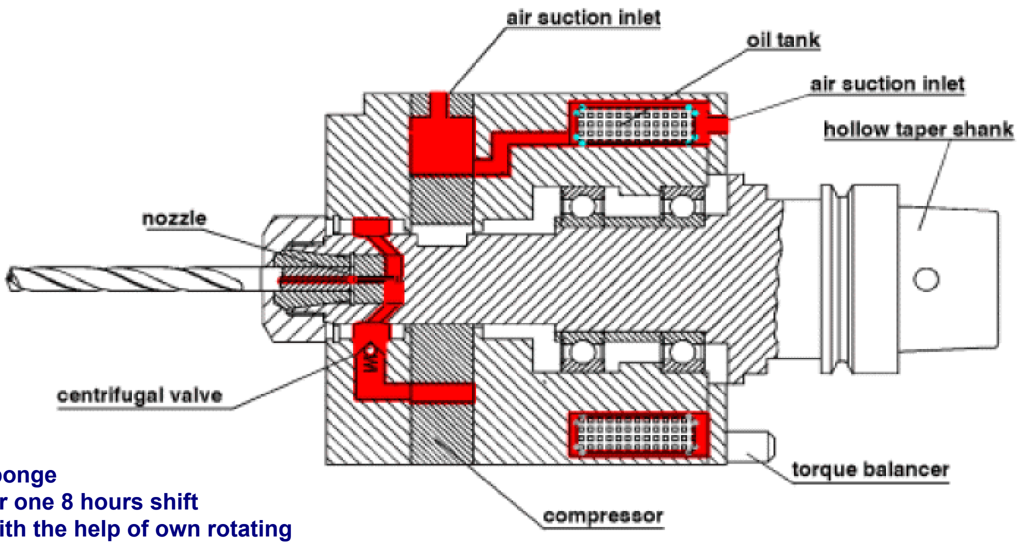
Source: Mapal, Aalen, D

C. Integration Minimum Jet Lubrication and Chip Suction into Tool Holders

The integration of minimum lubrication into machine spindle is not always possible:

- e.g. for spindles without straight center hole,
- only few sensitive operations need internal lubrication

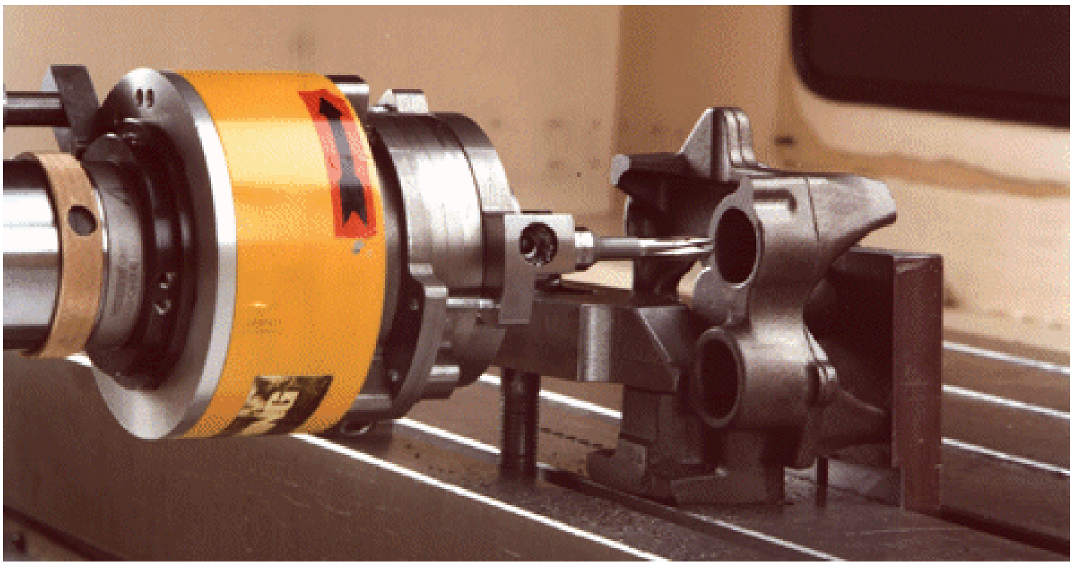
Eco-Chuck®



- oil stored in sponge
- oil reservoir for one 8 hours shift
- pump works with the help of own rotating
- centrifugal valve controls minimum working RPM
- internal minimum jet lubrication without rebuild machine spindle

Source: Patent 19618540.8, European Patent Office, Munich
Patent owner: Gühring oHG, Albstadt, D

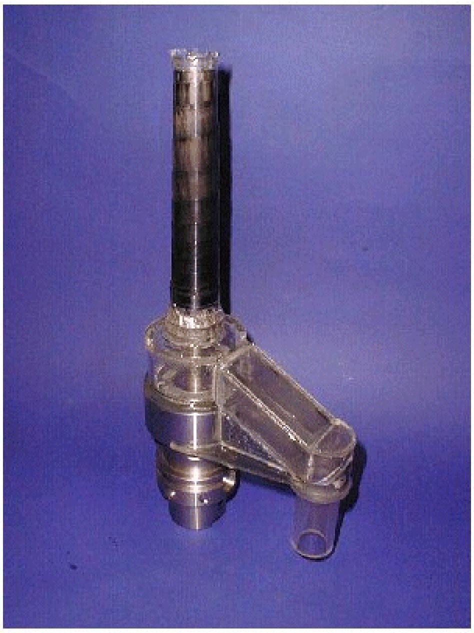
Eco-Chuck®

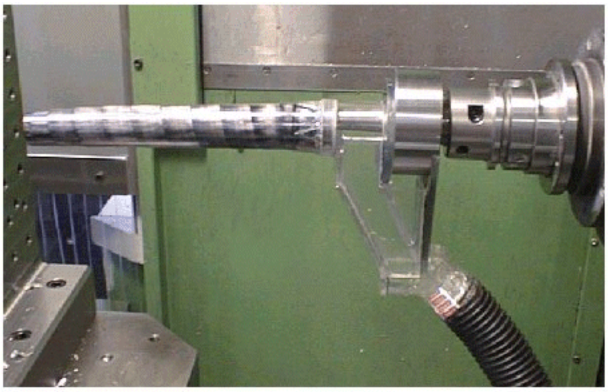


Source: Gühring, Albstadt, D

Vacuum-Chuck for Direct Chip Removal

with the Help of a Connected Suction Unit



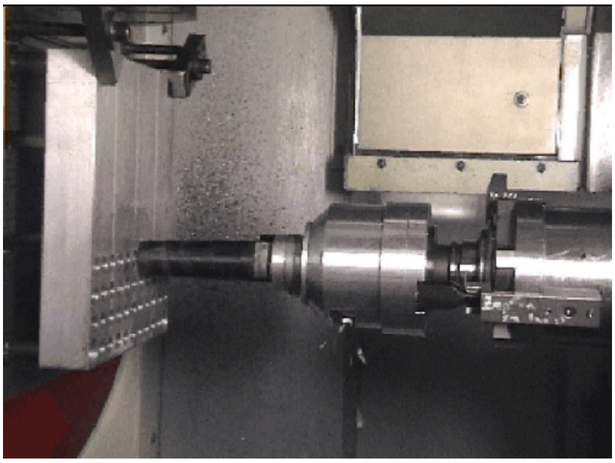


- Spirale telescope spring around the tool
- Suction by external vacuum pump
- Chips are moved out from the machine
- Development of standard connection to machine in progress
  -> chuck will be changed in as a standard tool holder

Source: IWS, Stuttgart, BMW Munich, D

Vacuum-Chuck for Chip Removal from the Workpiece

with the Help of Own Rotating



- Spirale telescope spring around the tool
- Suction with internal vacuum by rotation
- Chips are moved away from the workpiece
- But chips stay in machine
- Standard connection to machine
- Chuck can be changed in as a standard tool holder

Source: Mapal, Aalen, D

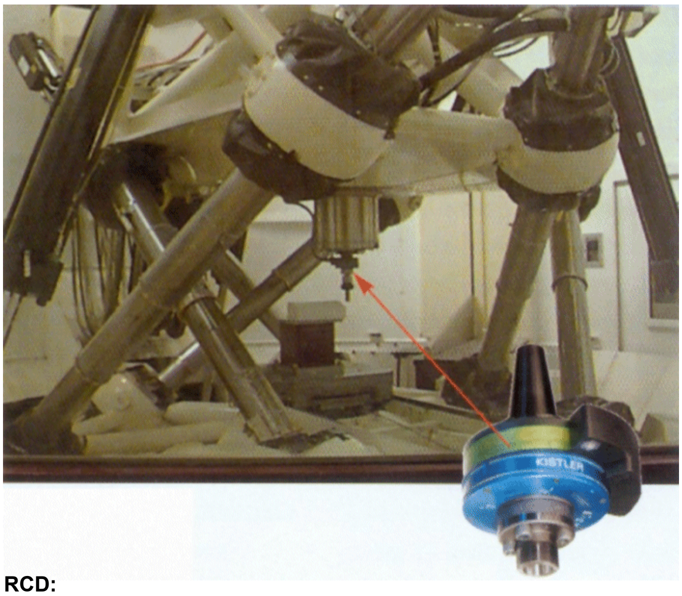
D. Measuring Cutting Forces with Piezo-Sensors at High RPM

Measuring Rotating Cutting Forces Directly on the Edge

With Wireless Signal Transmission

HSC-RCD:
Fz= -3000N, Mz: -50Nm,
RPM: -25.000, fs= - 4kHz

Source: Kistler, Winterthur, CH

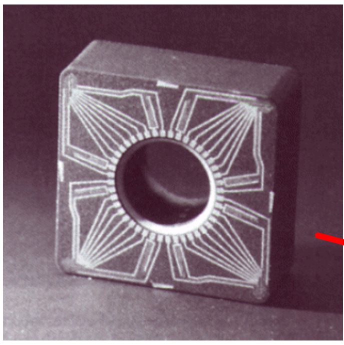


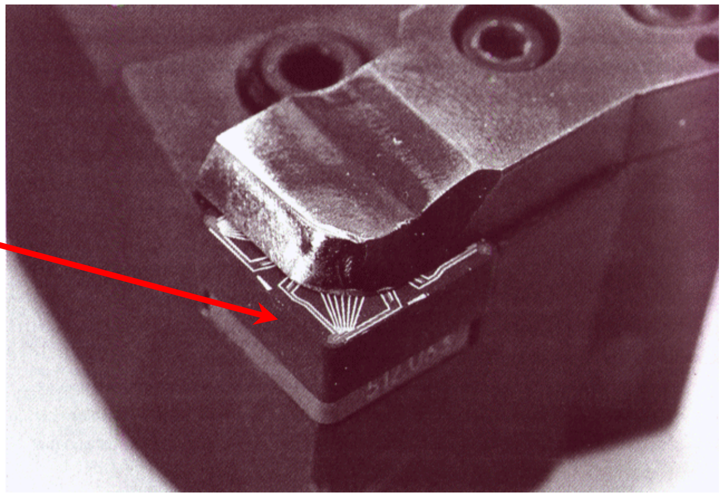
RCD:
Rotating Cutting-Force Dynamometer in hexapod machine
- Source: University of Nottingham, UK
Fx,y= - 5kN, Fz= - 20 kN, Mz= - 200Nm, RPM= -10000, fs= - 2kHz

E. Measuring Tool Coating

Measuring cutting forces with masked coatings on carbide inserts.

Tool Monitoring by Measuring Coating



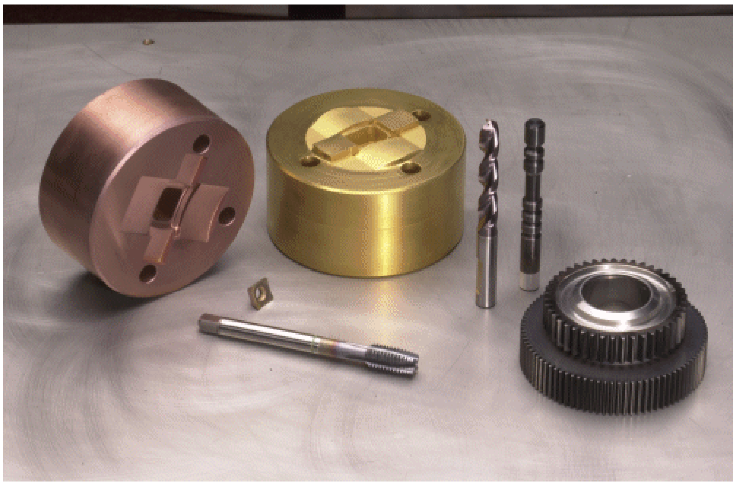


Source: ISF, Braunschweig, D

Go into the New Economy,
With High Performance Machining and Flexible Coating,

T. Cselle – Platit AG, Grenchen, Switzerland – Platit Inc., Hauppauge, NY

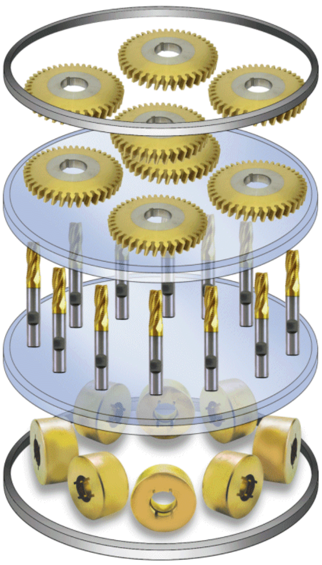
Flexible Coating

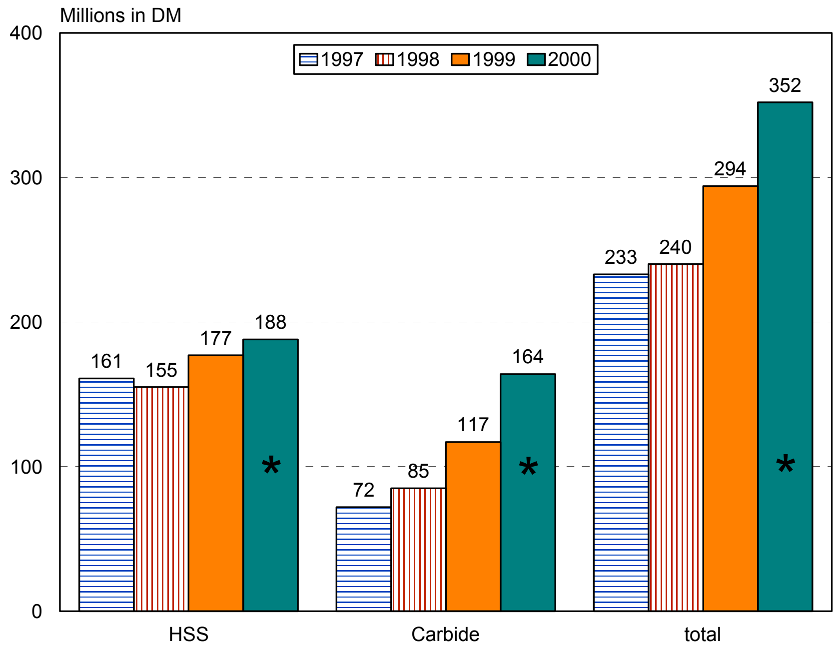


Coating for:
- cutting tools
- machine parts
- molds and dies

In recent years, sales of coated cutting tools increased dramatically:

Sales of New Coated Tools



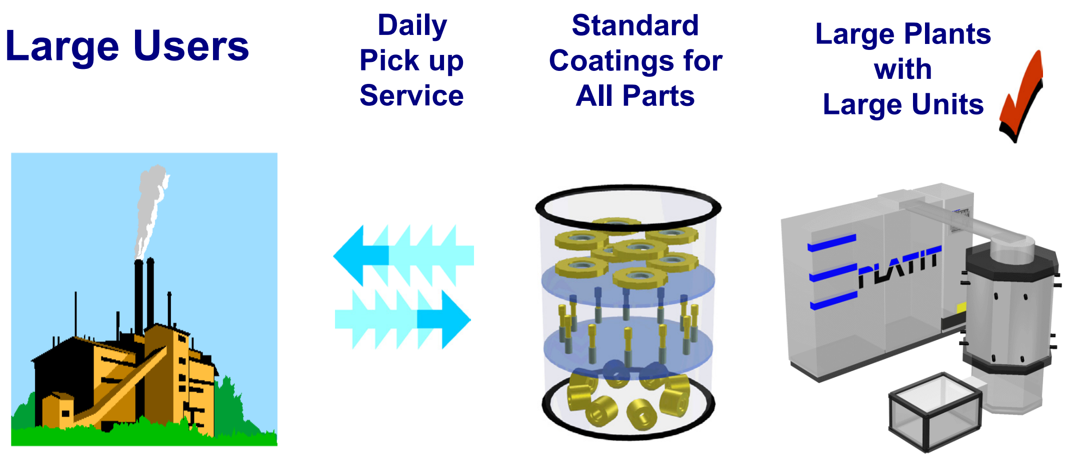


Statistics for the German market - Source: VDMA, Frankfurt, 2000 - *: not final values

A. Integration of Coating into the Manufacturing Process

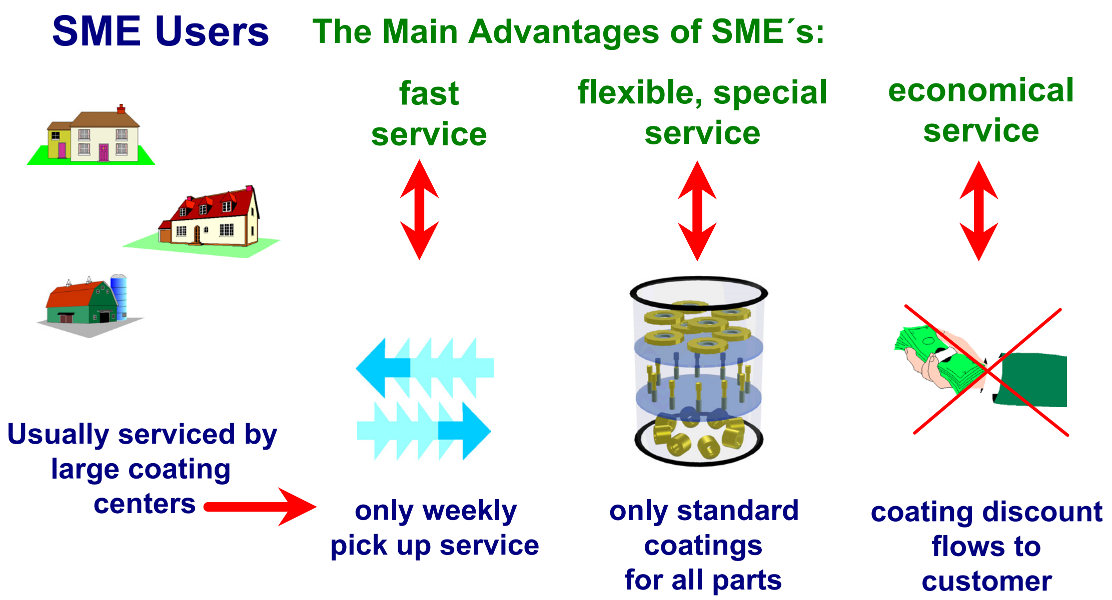
The growth of coated tools can be traced back to large coating centers:
They serve large users very effectively and economically if standard coatings for all parts satisfy them.

Excellent Service for Large Users by Large Coating Centers



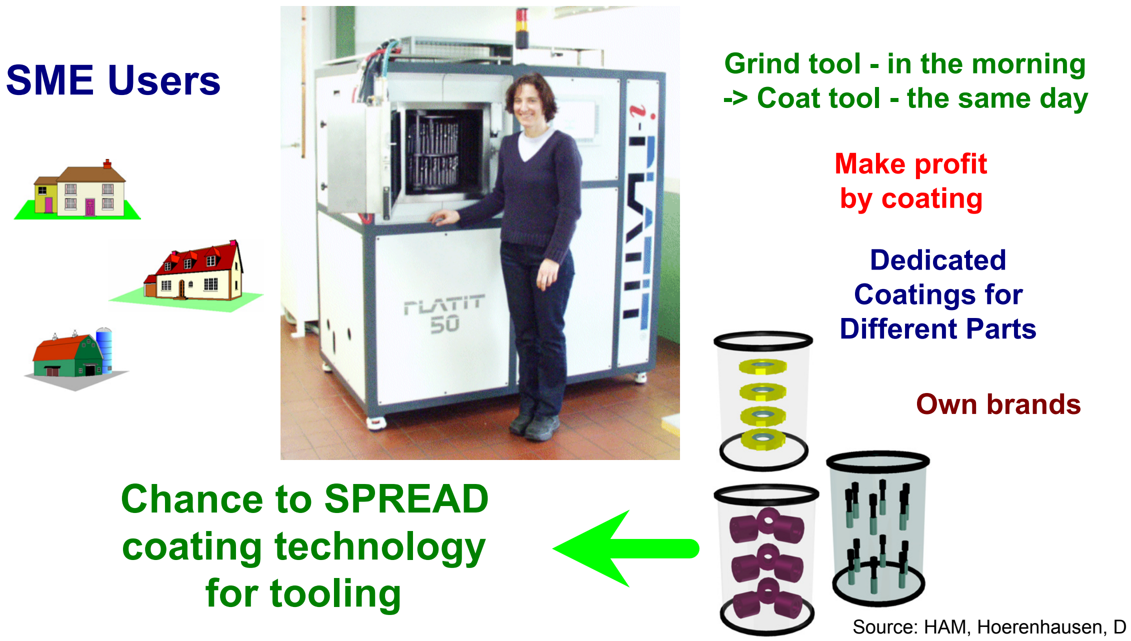
But the main advantage of the SME users is lost if they coat in the large centers.

Small and Medium Size Companies Lose Their Main Advantages when Served by Large Coating Centers

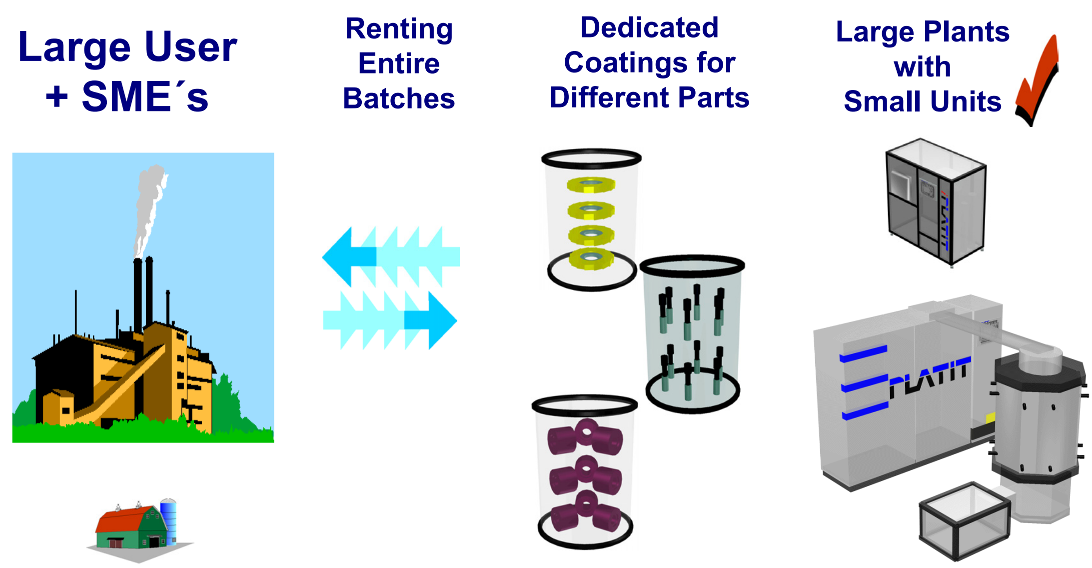


To spread coating technology to SME´s new ways and solutions are necessary.

Conclusion for SME´s: In-House Coating with Small Unit



Solution for Large Users and SME`s: Renting Whole Batches in Flexible Coating Centers with Small and Large Units

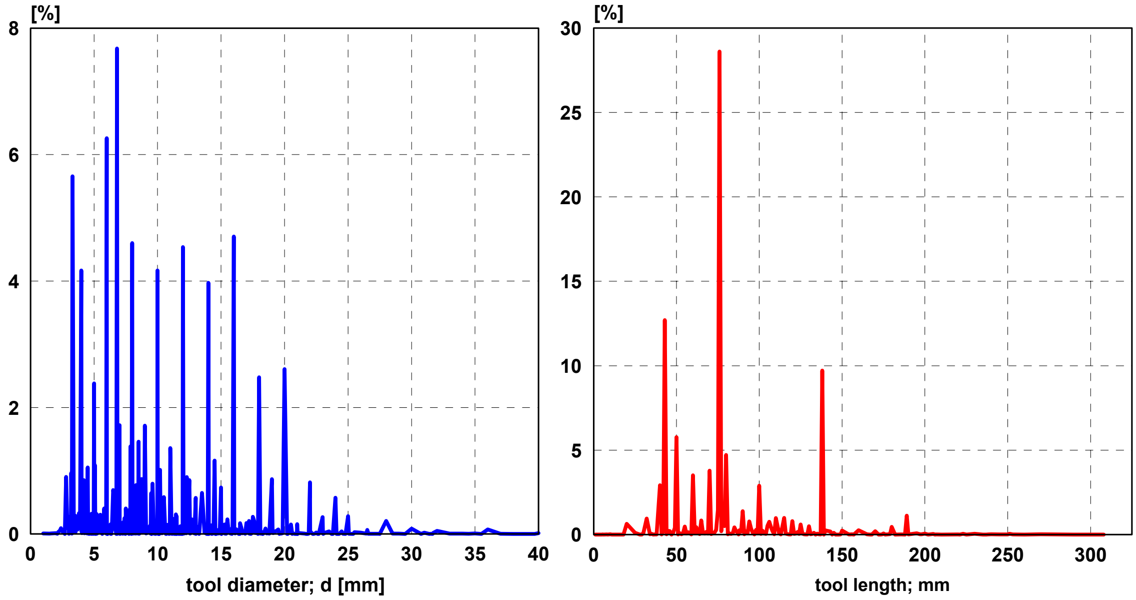


The small flexible coating units are the key for spreading coating technology.

B. Requirements for small flexible coating units

1. Chamber size: 90% of the tools to be coated should be coatable in the unit.

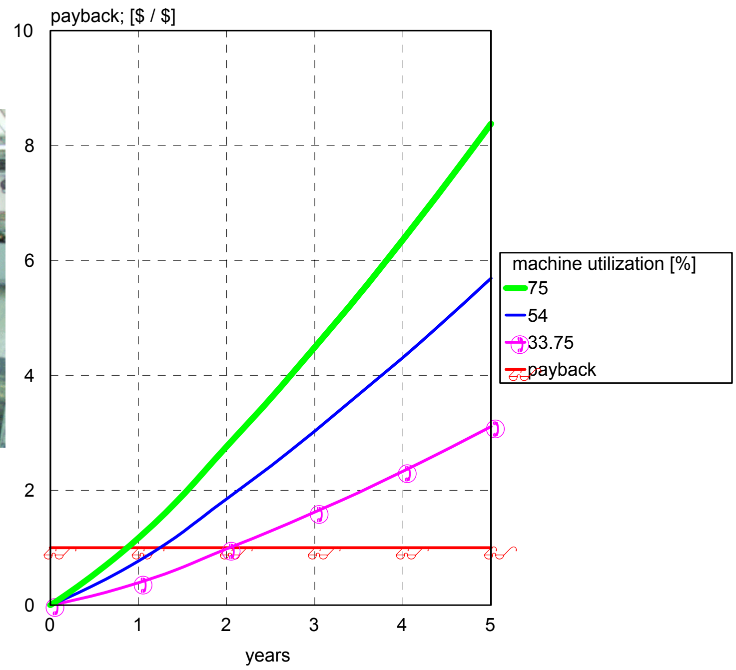
Statistical Distribution of Tool Diameters and Lengths to be Reground in a SME Regrinding Center



Number of tools to be reground every day: 825

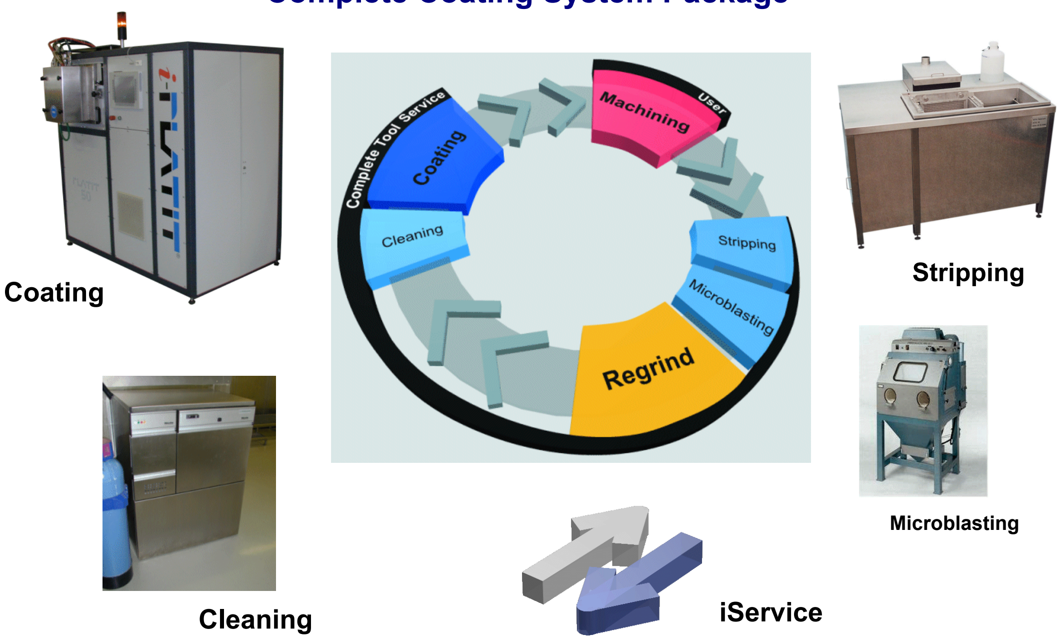
2. Amortization in 1 to 3 years.

Payback of Small Coating Unit in Tool Production



3. Top coating quality.
4. Full variety of coatings.
5. Short coating cycles.
6. Turnkey systems must be available with stripping, microblasting, cleaning and coating.

Complete Coating System Package



Flexible Coating Center in Milwaukee

Flexible coating can be economical even for small batches

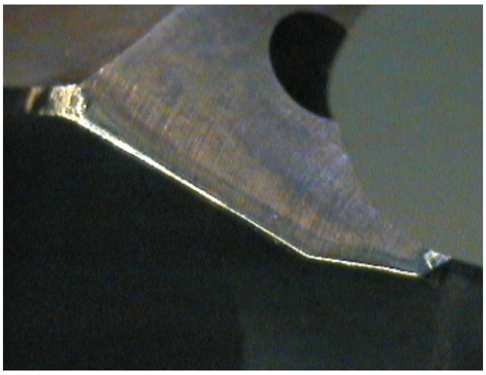
Source: Swiss-Tek, New Berlin, WI

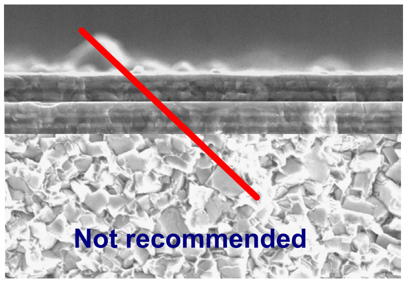
C. Stripping PVD Coatings of Carbide Substrates

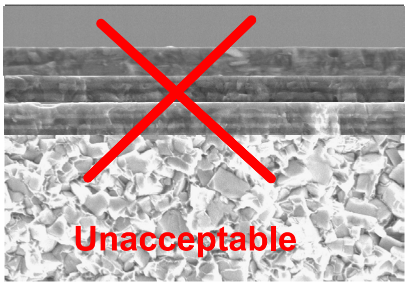
Stripping is especially necessary to avoid flaking off of the new coating after
- recoating multilayers (because of the high internal stress) and
- 3-times recoating of monolayers (because of weak adhesion of the individual layers.

No Recoating without Stripping because of High Internal Stress

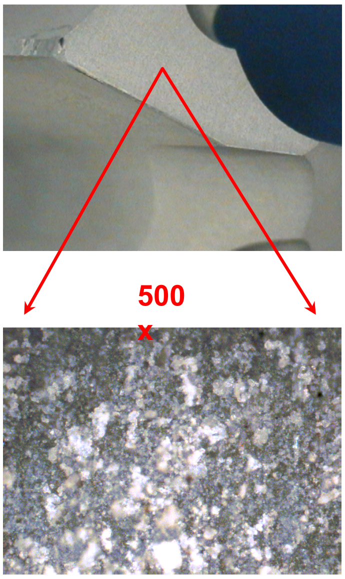
worn TiAlN coated tool



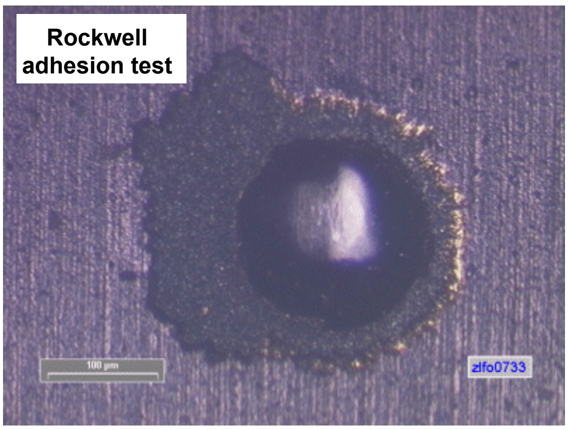




Coating after Conventional Stripping -> Adhesion Problems Due to Cobalt Leaching

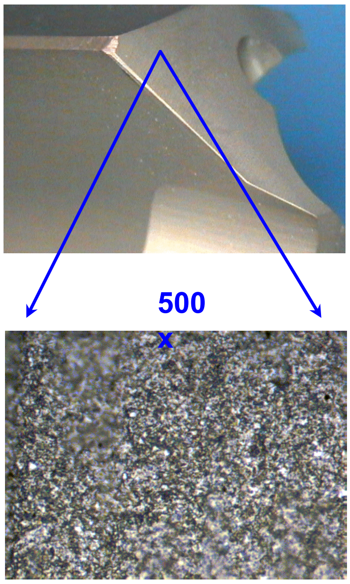


Cobalt leaching
after conventional
chemical or electrolytic stripping



Coating on cobalt leached surface
-> coating on carbide with less binder (cobalt)
-> very bad adhesion

Conventional Stripping of Carbide Tools Requires Microblasting



Surface after microblasting
is excellent for coating

- Microblasting removes the cobalt leached layer

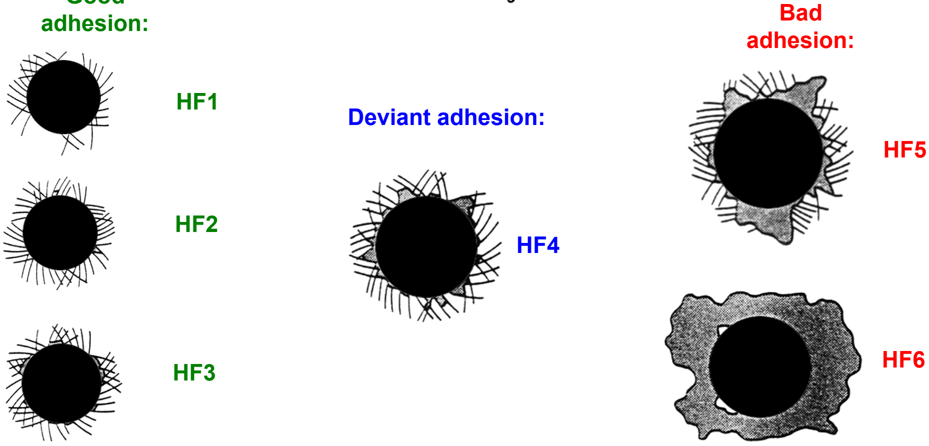
But microblasting:
- is a sensitive manual operation
    -> high expense
- rounds cutting edges
- not acceptable
    -> for reamers, taps, end mills etc.
- reduces tool diameter

For Stripping Development without Microblasting
1st question -> How much cobalt leaching can be accepted?

Evaluation with the
Rockwell test from
Mercedes Benz:
Characterization the
goodness of coating
adhesion
by HF classes

TEST PARAMETERS

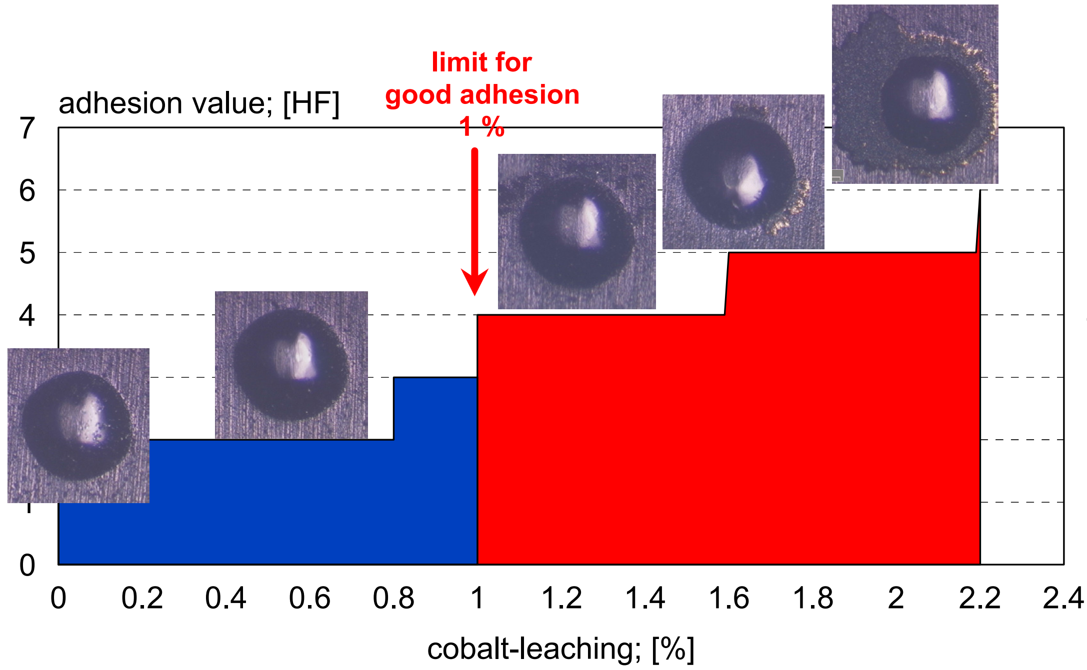
Substrate Hardness:	54 HRc minimum
Coating Thickness:	5 µm maximum
Indentation:	Rockwell C
Visual Magnification:	100x



The cobalt leaching was measured by X-ray Fisherscope on the tool margin

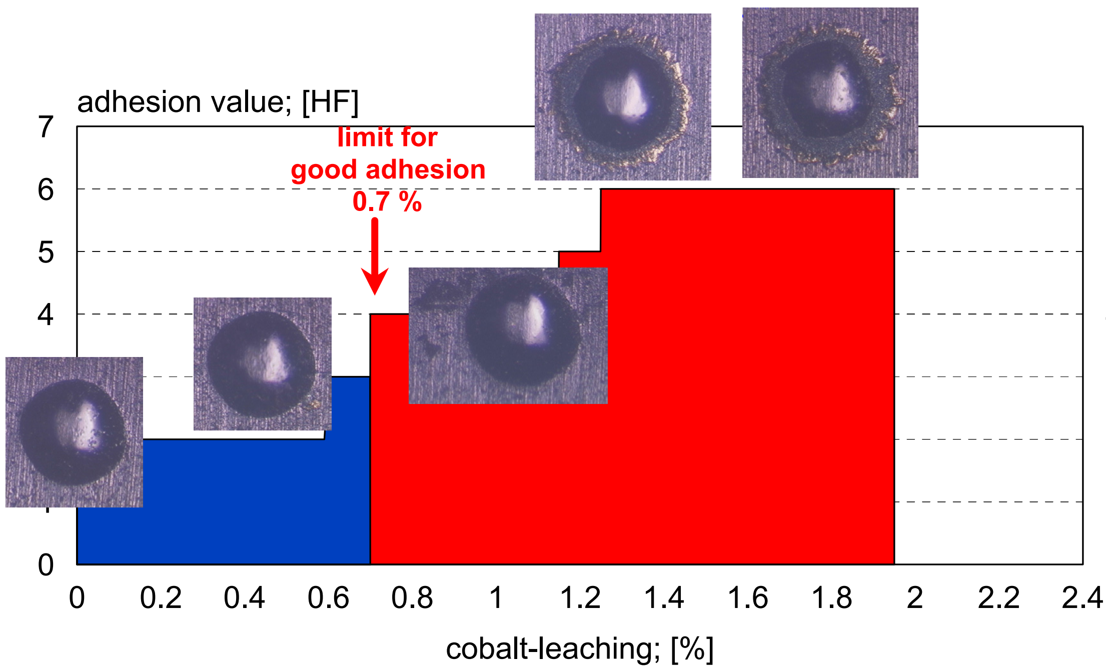
How much cobalt leaching can be accepted?

For good coating adhesion on K30/40 carbide with 10% cobalt



How much cobalt leaching can be accepted?

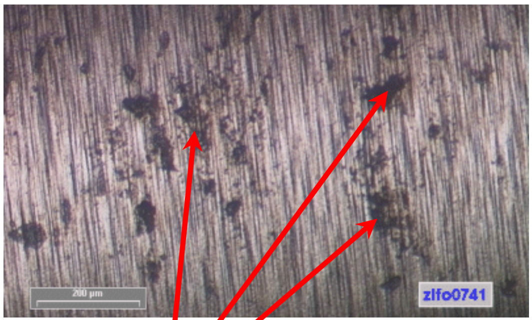
For good coating adhesion on K10 carbide with 6% cobalt



How to Check Cobalt-Leaching in a Simply Way?

Rubbing Test on Carbide

Check the carbide surface under 100x magnification

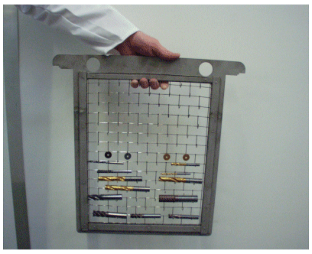


Cobalt-Leaching

Samples for Checking Cobalt-Leaching on Carbide in a Simply Way?

Cobalt-Leaching shown after rubbering
on K40 carbide with 10% Cobalt

Stripping Unit DETEC/Platit



- bath with coolant and optional heating
- sizes: W400xD300xL500
  - ca. 500 - 1000 inserts
  - ca. 100 end mills and drills (d<=12 mm)
  - up to 4 hobs with 80 x 200 mm
- long stripping times
- shiny surfaces
- **no cobalt leaching**

One Chamber Cleaning Units

Compact Cleaning Unit: Miele

- prebath for ultrasonic treatment
- spraying, heating, rinsing
- hand blow off before drying

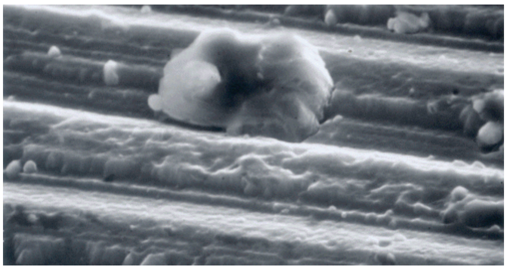
Fully Automatic Cleaning Plant: Eurocold/Platit

- integrated ultrasonic treatment under vacuum
- spraying, heating, rinsing
- air-knife blow-off before vacuum drying
- very short cycle time (<30 min)

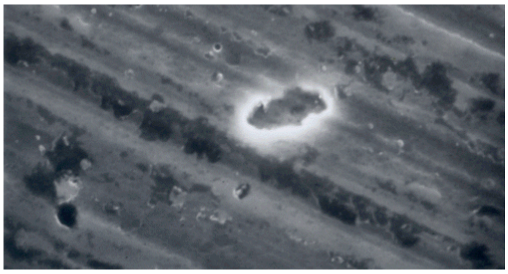
D. ARC technology and droplets

- Because of the required short cycle times, ARC technology is preferred.
- The macro particles (droplets) are harmless for most operations.
- Filtering the macro particles is too expensive and lengthen cycle time enormously.
- For small batches, the droplets can be removed by hand, or by extrude honing.

Droplet Removal by Hand or by Extrude Honing



before treatment

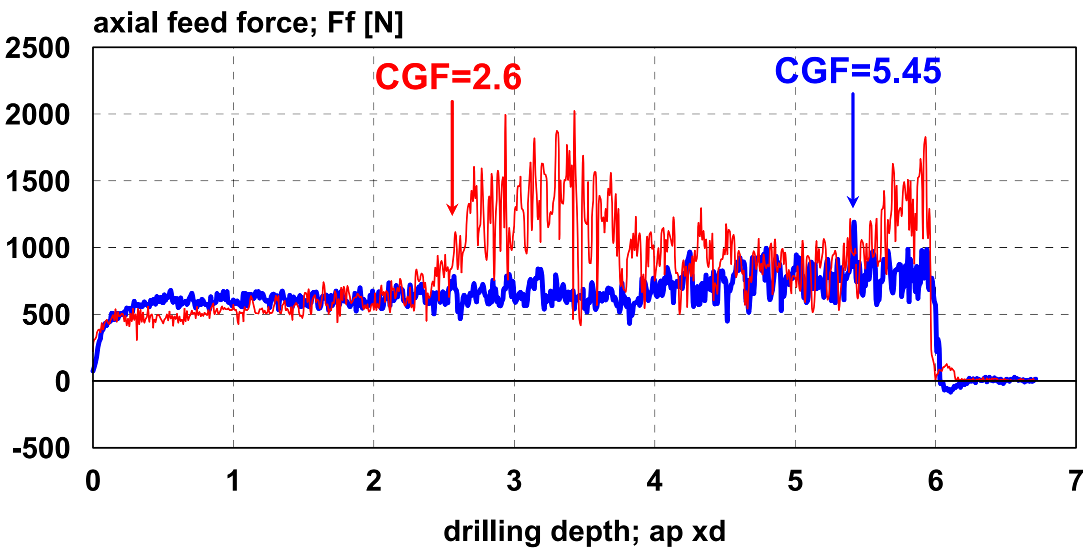


after treatment

- The influence of the droplets and the quality of the coating (fewer droplets) can be characterized by the Coating Glide Factor.
- The Coating Glide Factor gives the information how deep a hole can be drilled without chip evacuation problems.
- Algorithms for the Coating Glide Factor can be found in [35].

Comparison of Coating Glide Factors (CGF) for Characterization of Droplet Influence

ARC-TiAlN <- > ARC-TiAlN after droplet removal

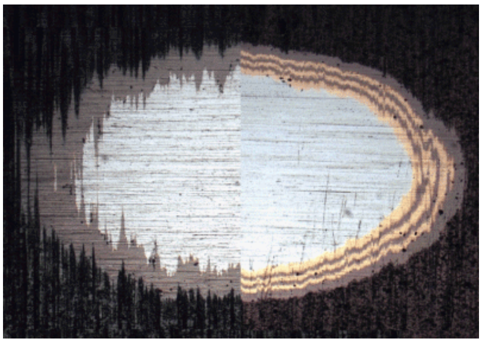


Mat.: GGG40 - Tool.: HSS-DIN 338 - d=6mm - ap=6xd - vc=30m/min - f=0.18mm/rev - dry

E, Monolayers, multilayers, nanolayers and nanocomposites

- 90% of the industrial coatings today are monolayer coatings.
- In spite of this the flexible small units should be able to coat multilayers because of the special advantages.

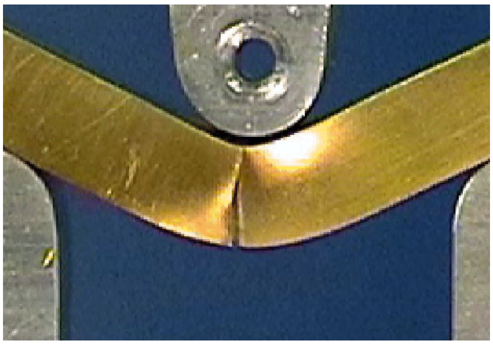
Basic Comparison of Mono- and Multilayers Coatings

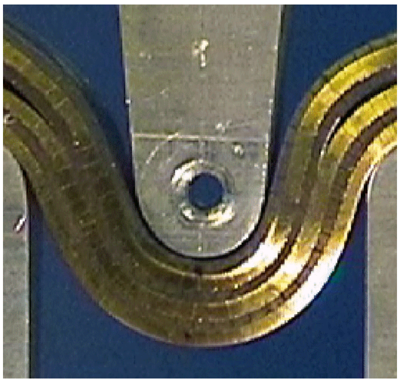


	monolayers	multilayers
coating time	100%	~ 140 %
crack absorbion	no	yes
tool life	100%	~50- ~250%
recoatebility	~3x without stripping	only after stripping

- Multilayers will be an absolute necessity if the theory of shearing is proven.

Simulation of Bending Mono- and Multilayers



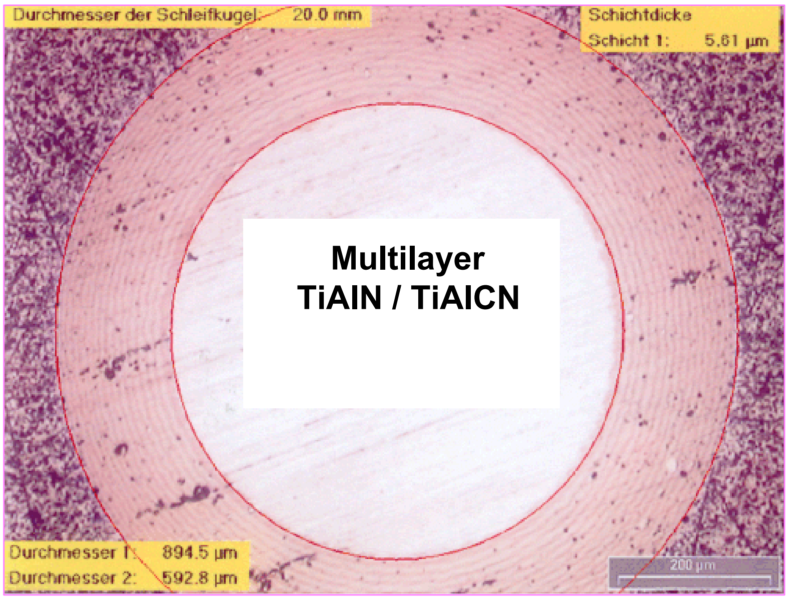


Source: A. Matthews, University of Hull, UK

- According to this theory the monolayer should easily brake by a bending load.
- In multilayers the hard layers can shear the softer layers.
- Therefore the hard layers can glide on the sheared soft layers, and the coating does not crack.
- With the help of these multilayers the total coating thickness can be increased, and the higher tool life will be possible for many applications.

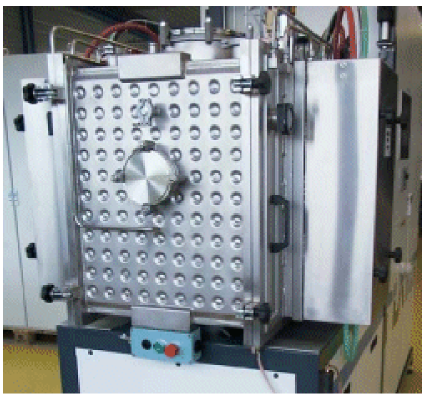
- Multilayer coatings can also be produced with one cathode.

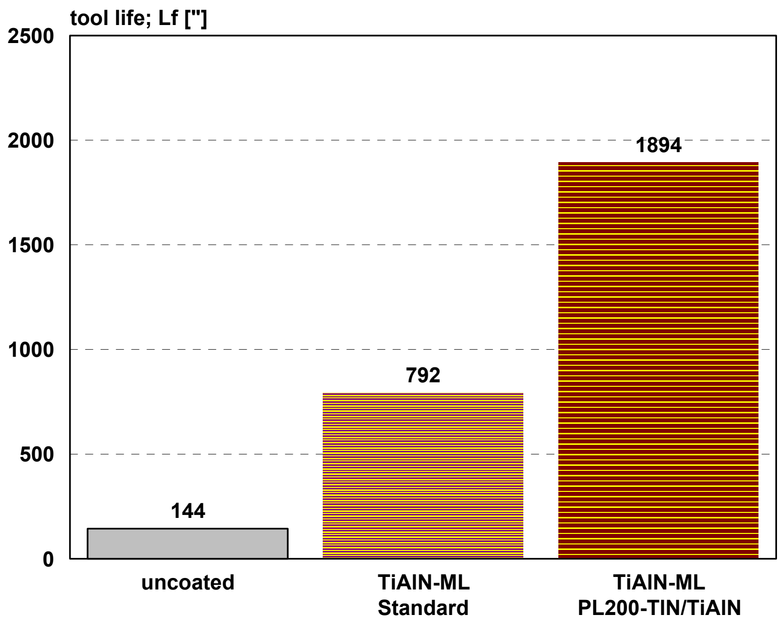
Multilayer for Interupted Milling Deposited by 1 Target



The multilayer structure achieves extremely good results even when compared to multilayers deposited in large coatings units.

Comparison of Coating for Interrupted End Milling





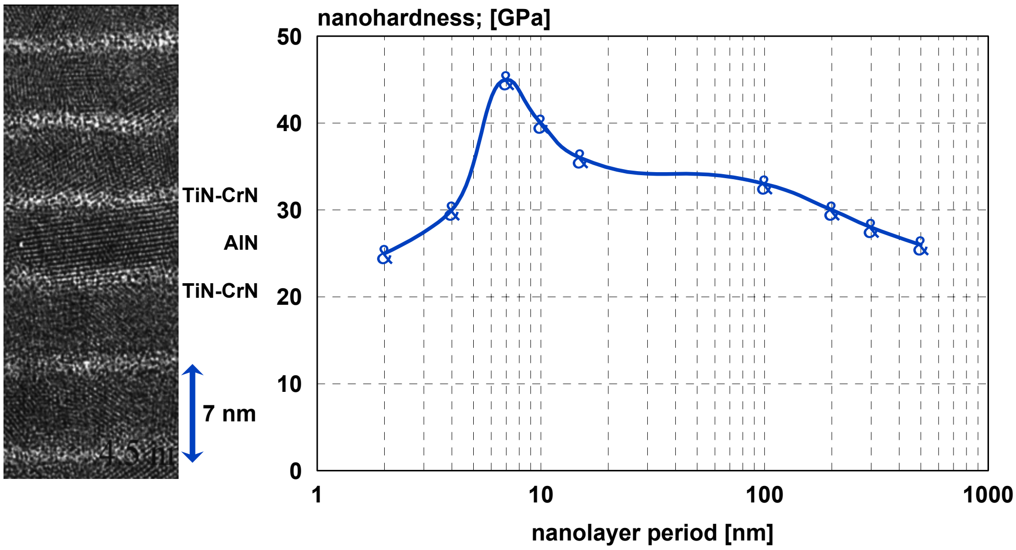
Mat.: steel; 4140 - 30 HRC - Tool: solid carbide
z=4 - d=0.375" ap=0.375" - ae=0.1875"
SFM=301 - fz=0.002"/tooth - Source: Carbide Tools, USA

Nanolayers:

. The refinement of multilayers, the decreasing of the thickness of the layers leads to nanolayers.

- The hardness of nanolayers depends on their periods.

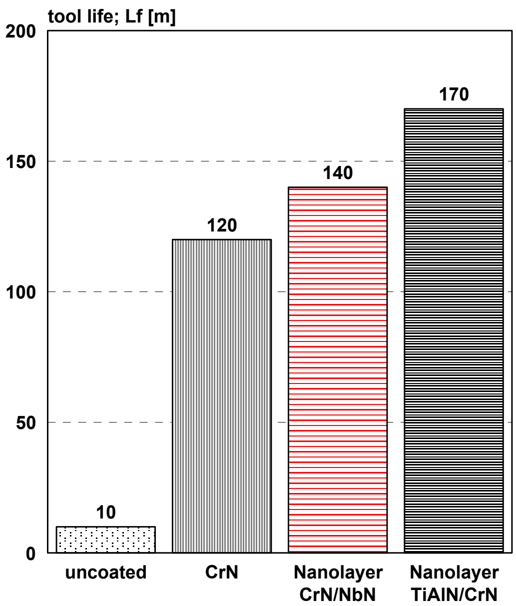
Superlattice Nanolayer



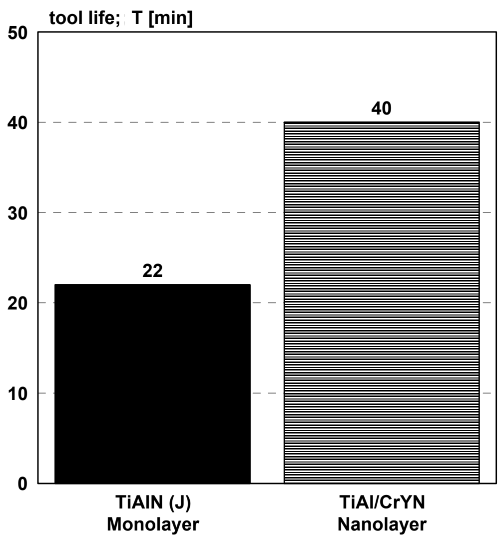
Source: Nortwestern University, IL, USA

- This makes the improvement of coating performance possible.

Tool Life Comparison for Nanolayers



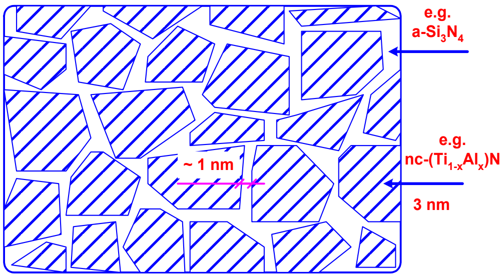
Coated tools: paper knifes



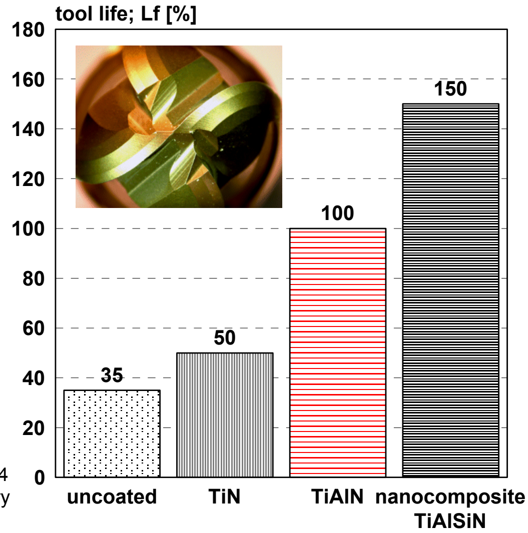
Tool life comparison at mold milling
Mat.: 100Cr6 HRC 58
Tool: solid carbide - z=2 - d=8 mm - n=21000 RPM
vf=1.5 m/min - ae, ap variated - dry
Source: Marwin , UK

- To deposit nanolayers, the power on target and the rotating tools must be synchronized. But the period can only be held constantly for the same substrates. To collect the same substrates for every batch is only possible for high scale tool production.
- Nanolayers can change their periods with changes in the working temperature. This can happen easily during cutting.
- Due to these two reasons, **nanocomposite coatings** seem to have a more promising future.

Tool Life Comparison for Nanocomposite Coatings



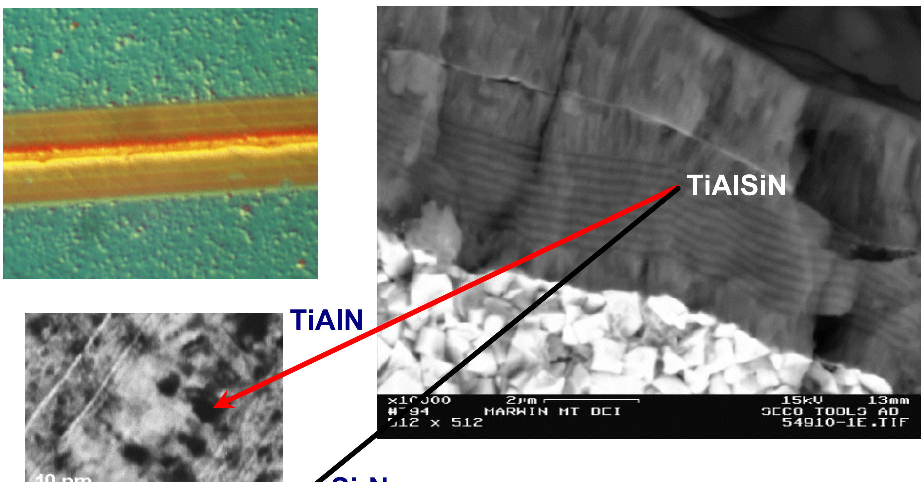
nanocomposite structure



Surface milling with solid carbide end mills - Mat.: 42CrMo4
Source: SHM, Sumperk, CZ + EU-Project Nacodry

- In the nanocomposite coatings two different materials are deposited, they cannot be mixed. For example nanocrystalline TiAlN and amorphous Si_3N_4.
- The combination of multilayer and nanocomposite coatings decreases the internal stress and the sizes of macro particles.
- The Si_3N_4 fills the empty places between the TiAlN grains and increases hardness.

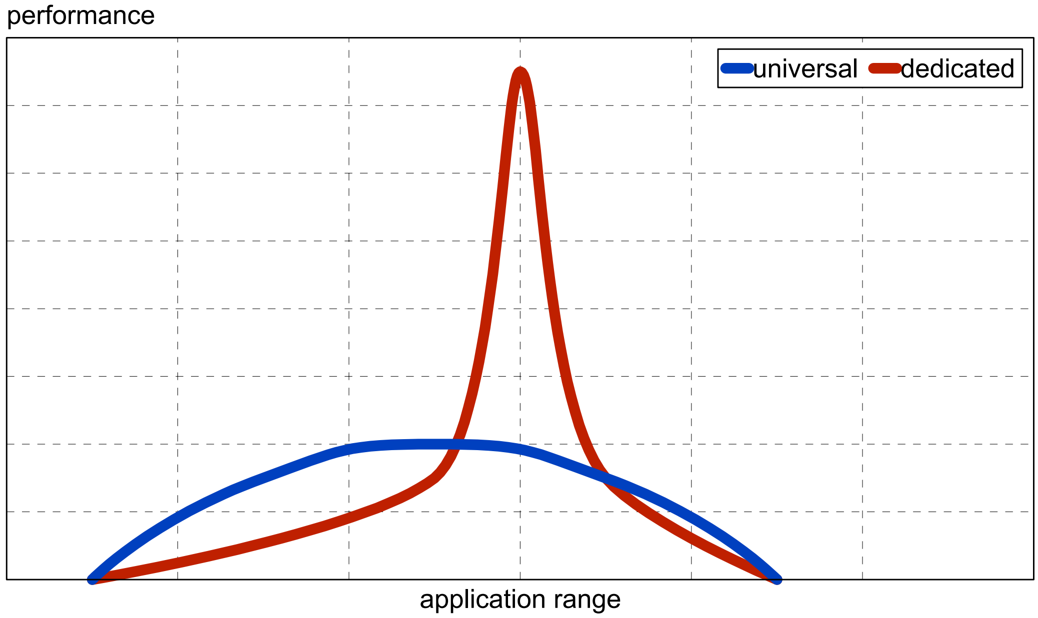
Multilayers Decrease Internal Stress of Nanocomposite Coatings



Source: SHM, Sumperk, CZ + EU-Growth Project NACODRY
Measured by TEM at EPFL, Lausenne, CTI-Project TOPNANC

Standard or Dedicated Coatings

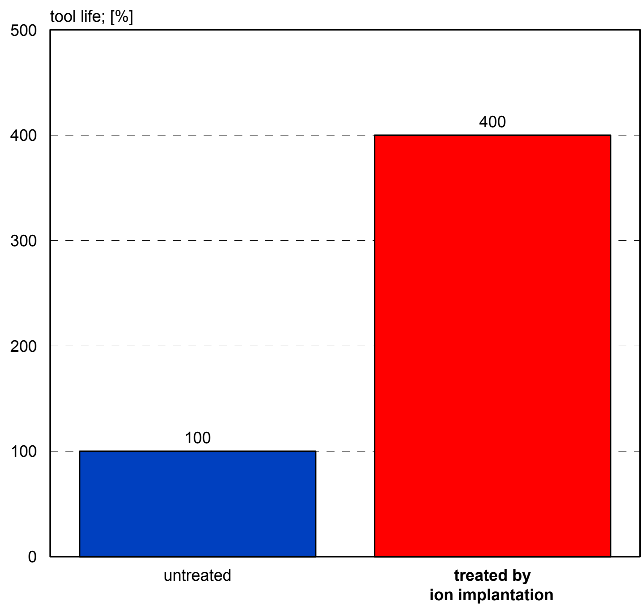
Application Field and Performance of Universal and Dedicated Coatings



Source: Zimmermann, H., Balzers, Lichtenstein

Typical dedicated treatment is the **ion implantation.**

Tool Life Comparision for TiAl6V4 Broaching with Ion Implanted Tools

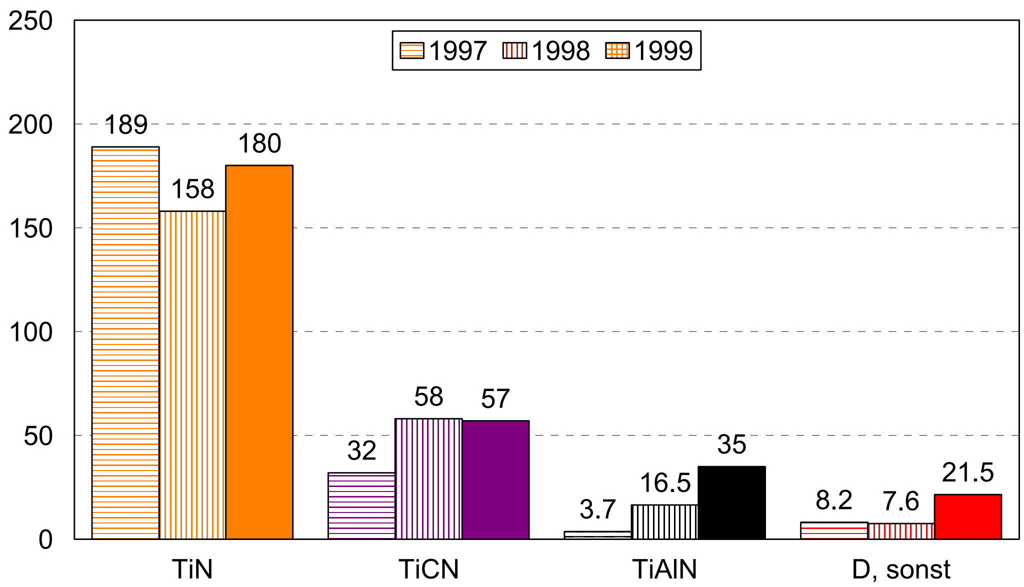


Source: Triion, Jyllinge, DK

F. Which Coating for Which Application?

TiN is continuously losing its exclusive position, but still covers over 50% of the market.

Sales of New Coated Cutting Tools with Different Coatings

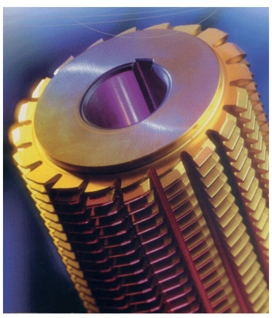


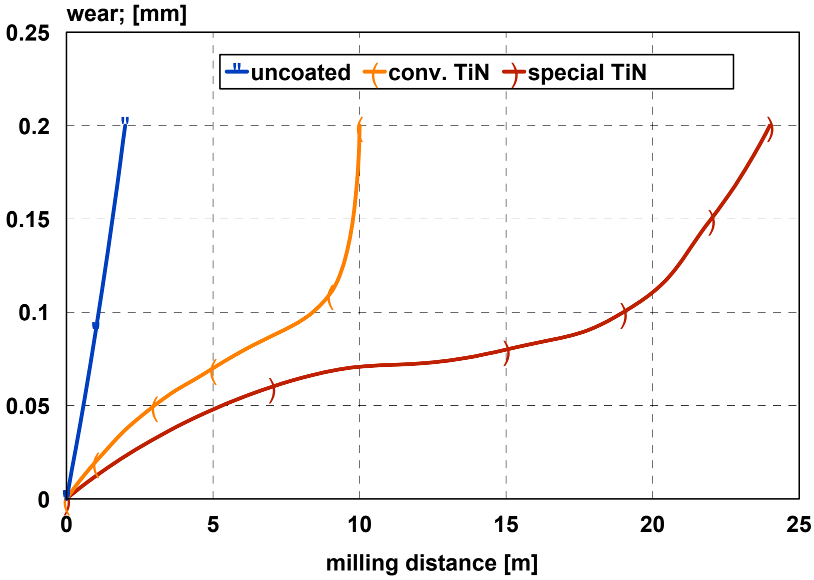
Statistics of the German Market - Source: VDMA, Frankfurt, 2000

Dedicated Coating

However a great number of **special coatings (dedicated for the application)** are covered by TiN only because of the fancy golden color, which serves as an easy wear indicator.

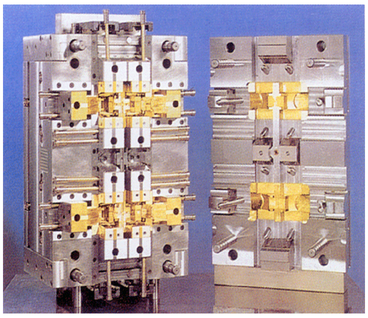
Wear Comparison for Hobbing

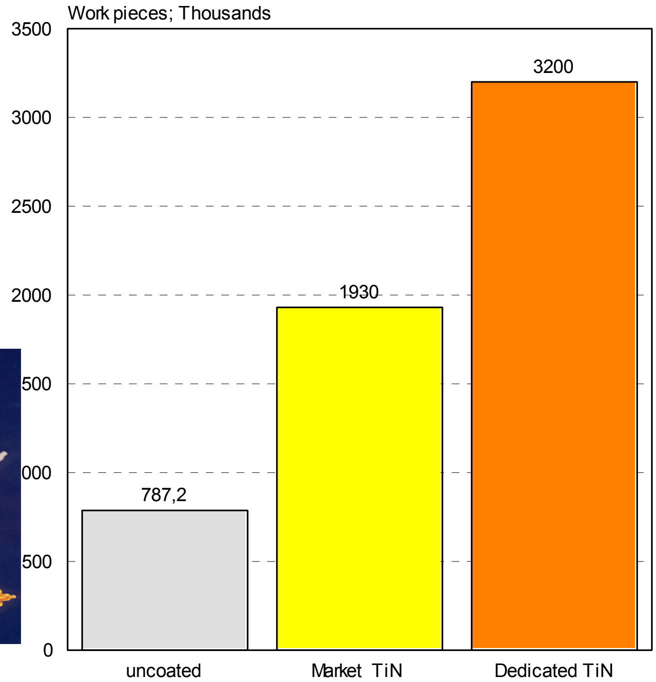




Mat.: 100Cr6 - Tools: ASP30 - d=80 x 180 mm - vc=135 m/min - coolant: emulsion
Source: Cibesse, Brescia - Vergnano, Milano, Italy

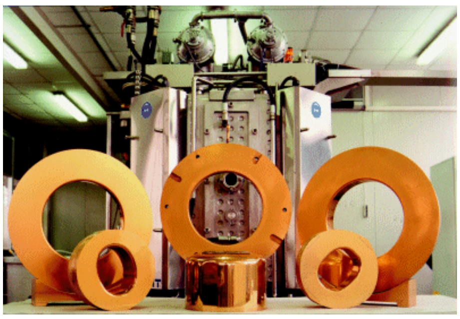
Injection Molding with Coating

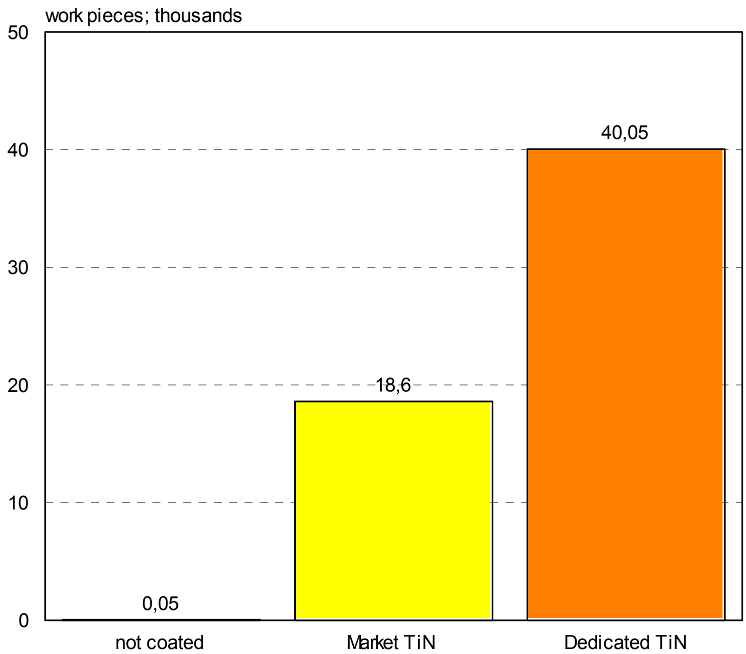




Work piece mat.: Polyamide 6.6 50% FV - Tool Mat.: Z38CDV5 - HRC 52-53
Source: Thermi-Lyon, France

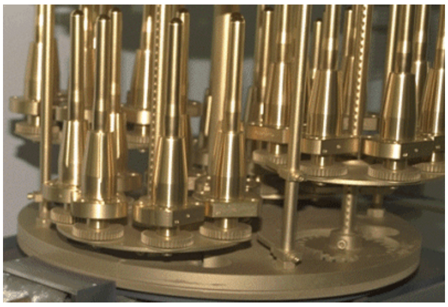
Tool Life Comparison for Deep-Drawing Dies



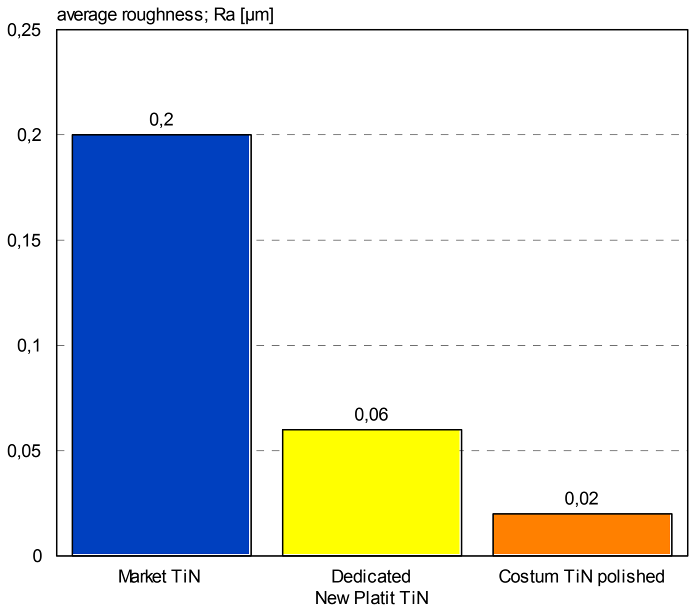


Mat: Fe42 (3.5mm) - Tools: APM23

Surface Roughness Comparison for Injection Molding Tools



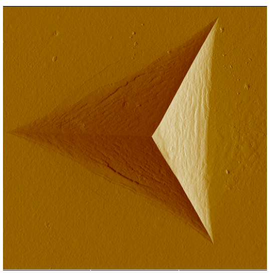
Mold for PET-bottles



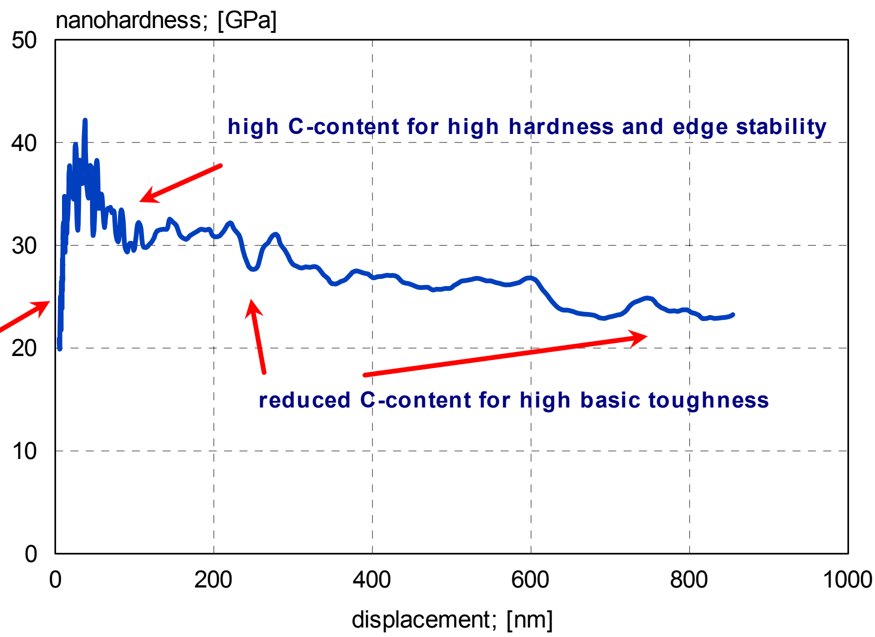
Mat: Fe42 - Tools: APM23

In addition by changing the introduction of the gas the hardness of the coating can be varied within the thickness of the coating.

Nanohardness of a Gradient Coating (TiN-TiCN)



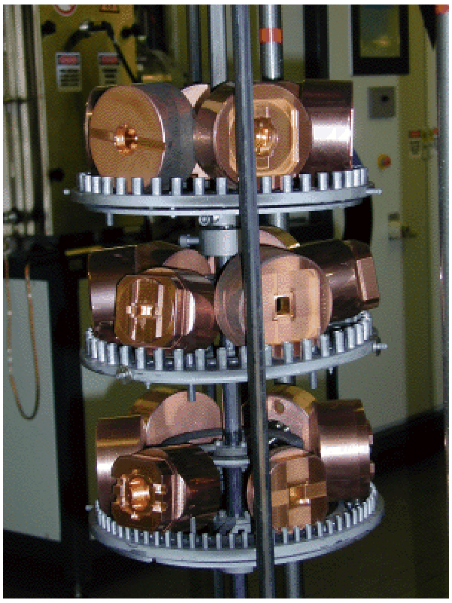
covering TiN layer

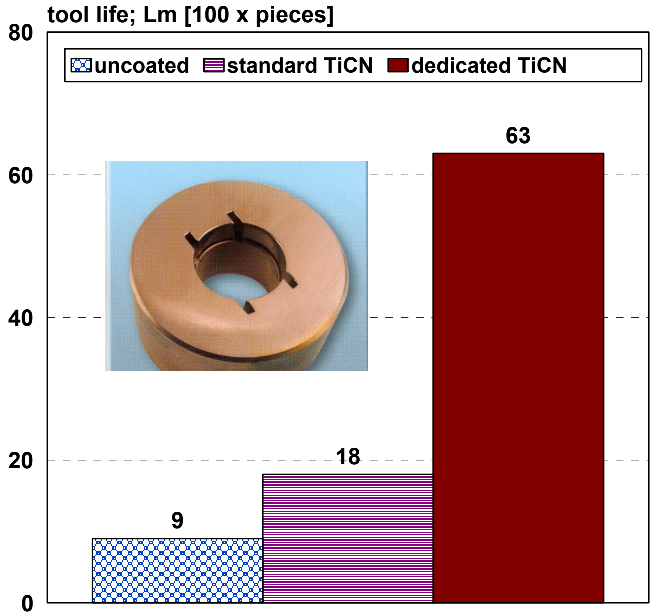


Measured by nanoidentation at University Lausenne, EF
Project: TOPNANO, Switzerland

The increasing in market share of **TiCN** seems to be stopped by the advancements of TiAlN. However TiCN is the market leader for certain applications like stamping, punching and tapping.

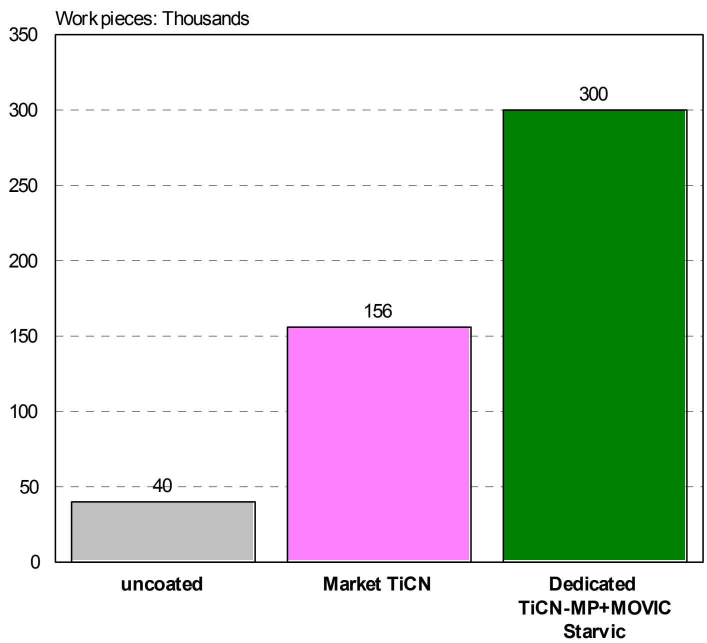
Tool Life Comparison for Stamping Watch Housing





Minimum Lubrication - Tools K340 - Mat.: INOX 304 - Source: Rolex, Biel, CH

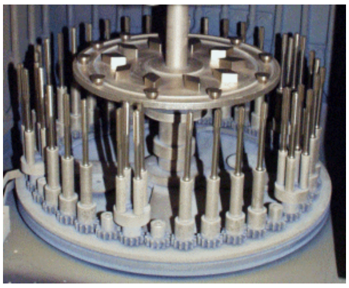
Punching with Coating

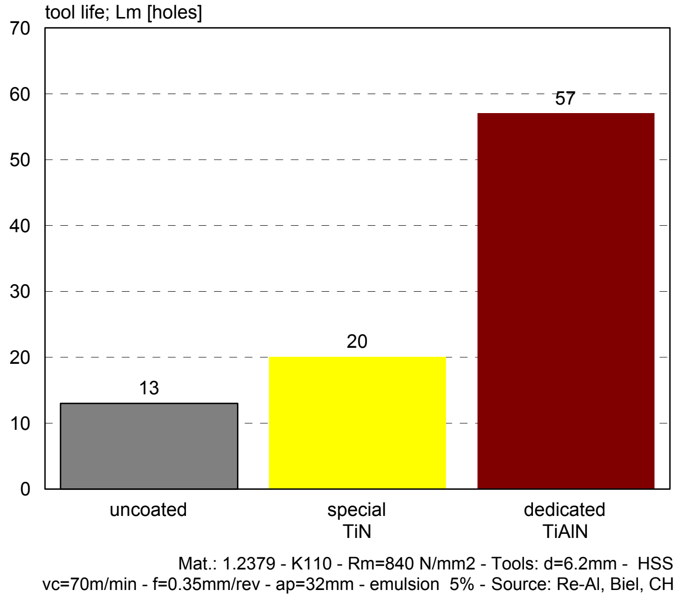


Work piece material: INOX 0.8 mm - Source: Rolex, Biel

TiAlN is the current “star” of all coatings
Its high heat resistance makes it the best coating for dry high speed machining.
End mills and carbide drills may soon be coated with TiAlN only.
Thin and hard TiAlN coating seems to achieve a breakthrough for taps and reamers.

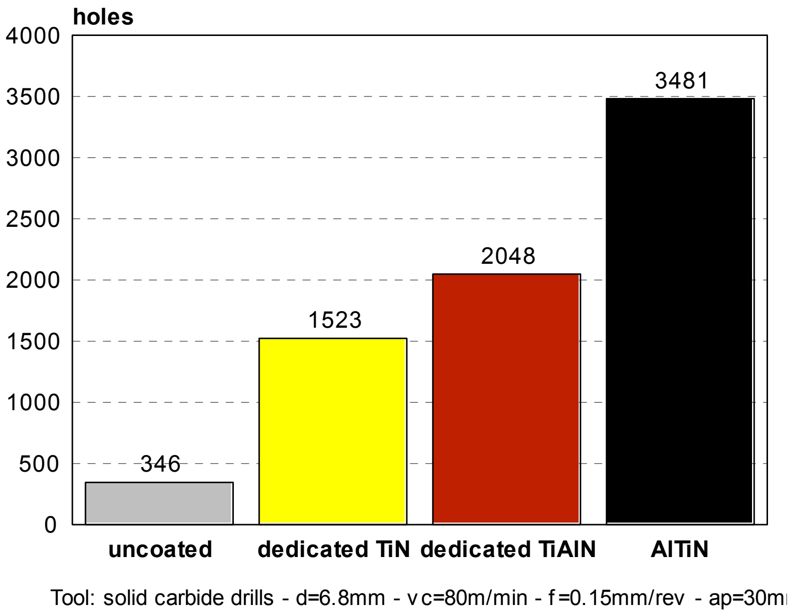
Tool Life Comparison for Reaming





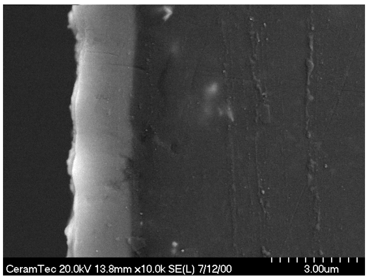
The increasing of the Al-content improves the heat resistance of the coating. Therefore the **AlTiN** coating with 67% Al is especially suitable for dry machining and for working with minimum lubrication.

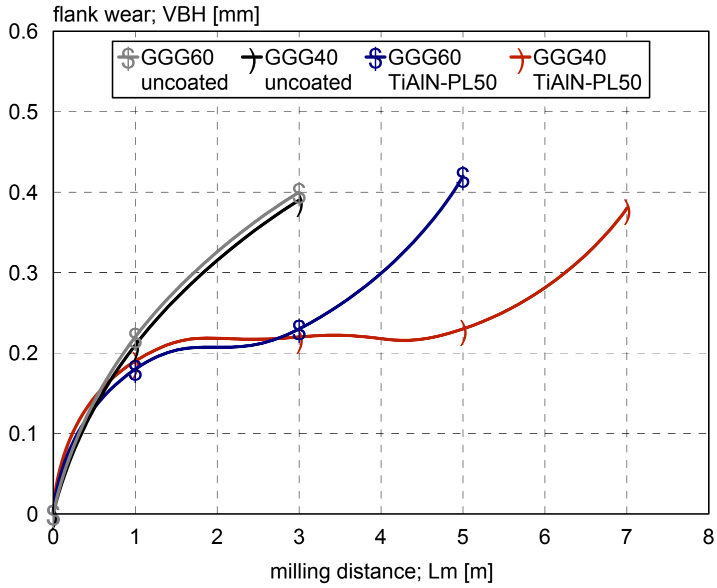
Dry Drilling in Steel; Ck45



Silicon nitride coated by TiAlN promises the optimum combination for dry machining. The difficulty is achieving good adhesion with PVD. It used to be possible with CVD coating yet…

Coating Test with Ceramic for Milling

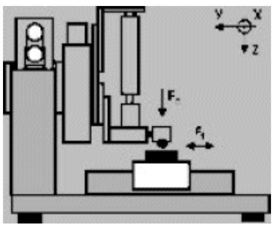




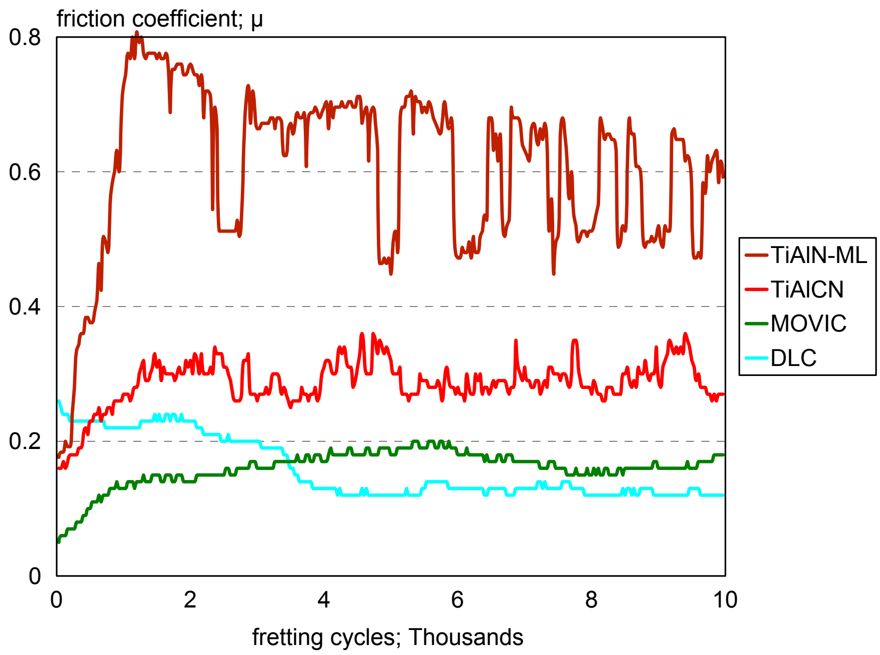
Tools: Silicon nitride ceramics inserts - SLC250C - vc=400m/min - f=0.16 mm/tooth - ap=2mm
Source: Ceramtec, Ebersbach, D

TiAlN is not without disadvantages. The most important one is the high friction coefficient.

Comparison of Friction Behaviour of Coatings



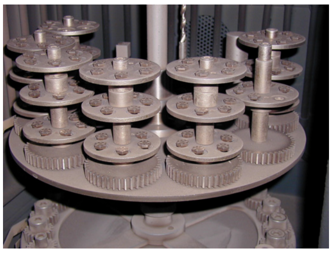
Fretting test conditions:
- **coatings on tungsten carbide; K40UF**
- **constant load: 2 N**
- **displacement: 100 um**
- **f = 10 Hz**
- **ceramic ball d=10 mm**
- **T = 23°C**
- **10% humidity**

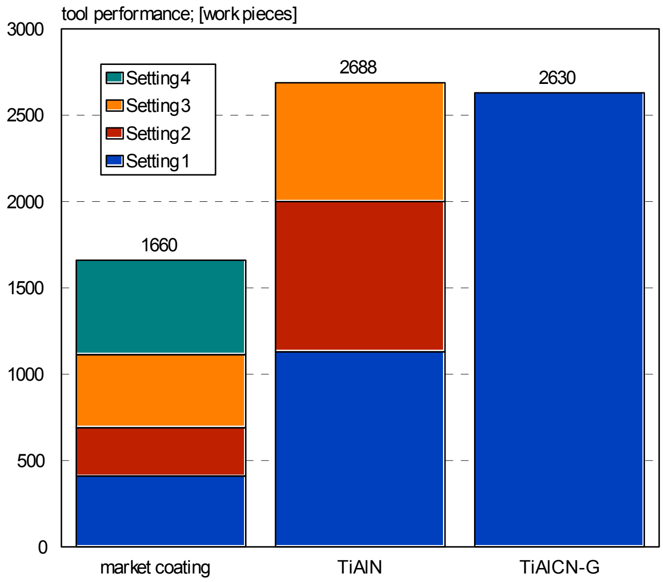


Measured at the Katholic University Leuven, Belgium

The best compromise, **TiAlCN** coating, is a very good combination for high hardness and low friction coefficient. It seems be the universal coating of the future.

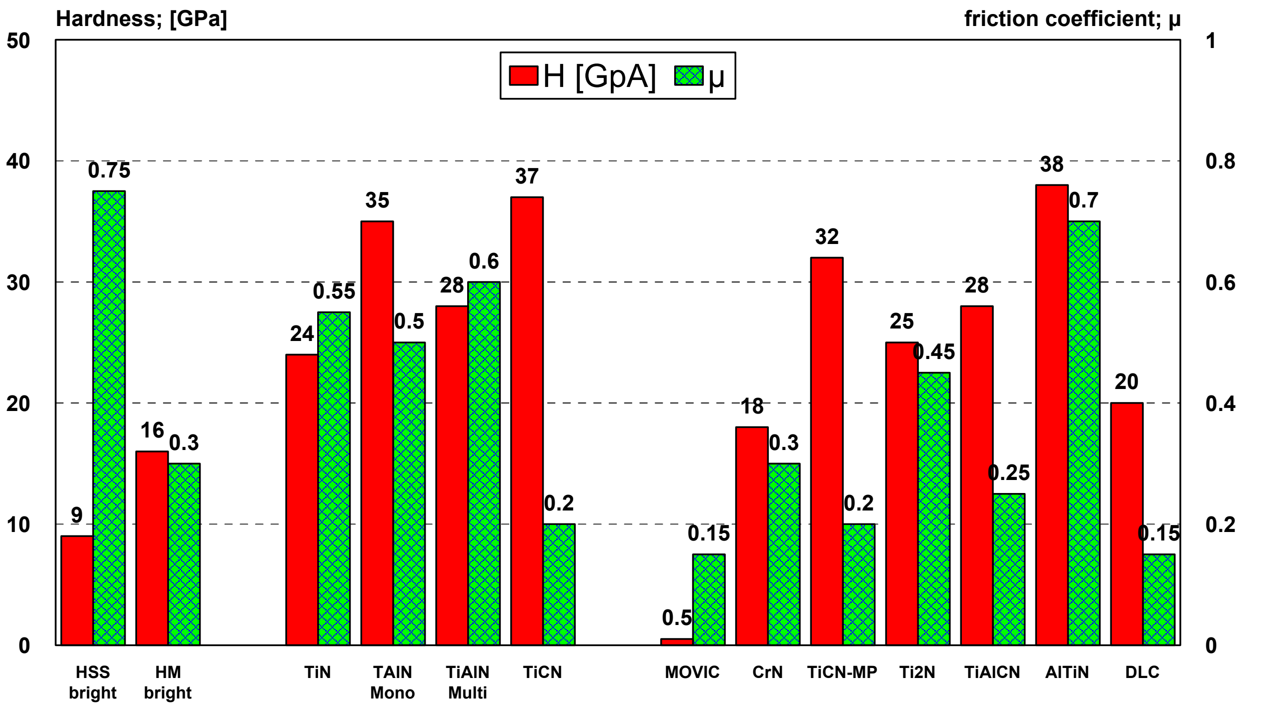
Coating Comparison for Precision Boring with Automatic Adjustme





Work piece: connecting rod, C70, large eye - d=49.59 (-0.014) mm
Source: MAPAL, Aalen, D

Nanohardness and Friction Coefficient of Coatings

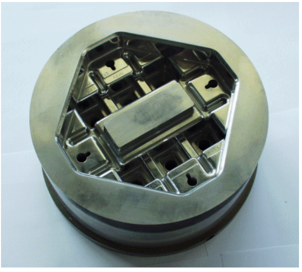


Coatings from Platit, Grenchen, CH

Not normally used for cutting, **CrN** is essential for forming tools and machine parts.

Forming Tools and Machine Parts Coated by CrN

Plastic injection mold

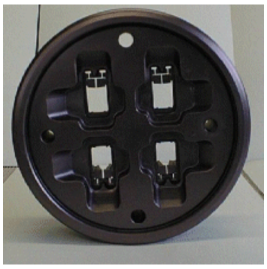


PET bottle injection molds

Deep drawing tool

Injection molds for seals

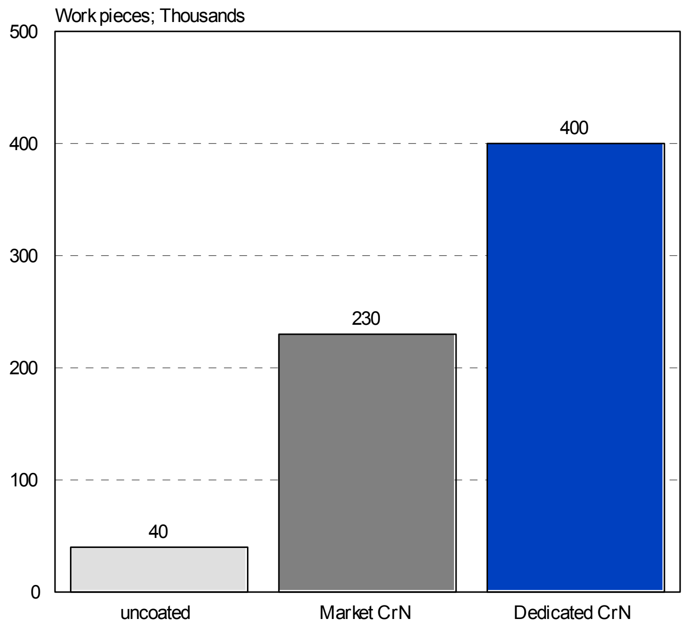
Alu extrusion mold



Gear forming tool

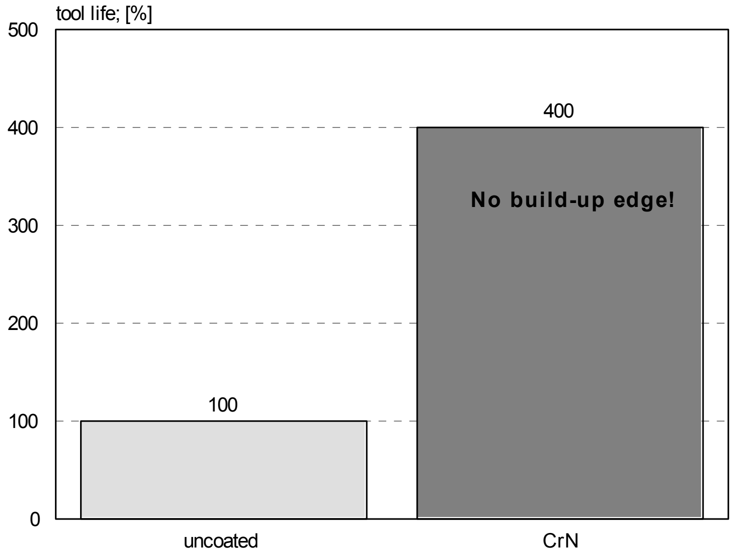
CrN can be coated at lower temperatures (~200 °C) as well and has at relatively high hardness a low friction coefficient.

Injection Molding with Coating



Work Piece Mat.: ABS

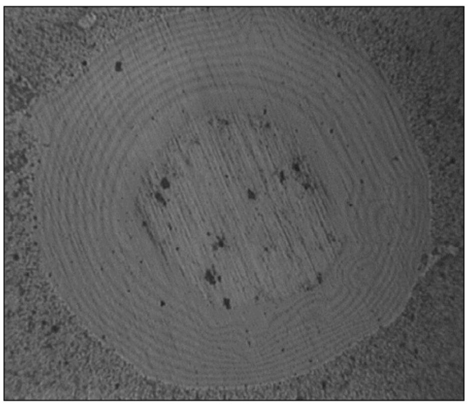
Dry Deep-Drawing

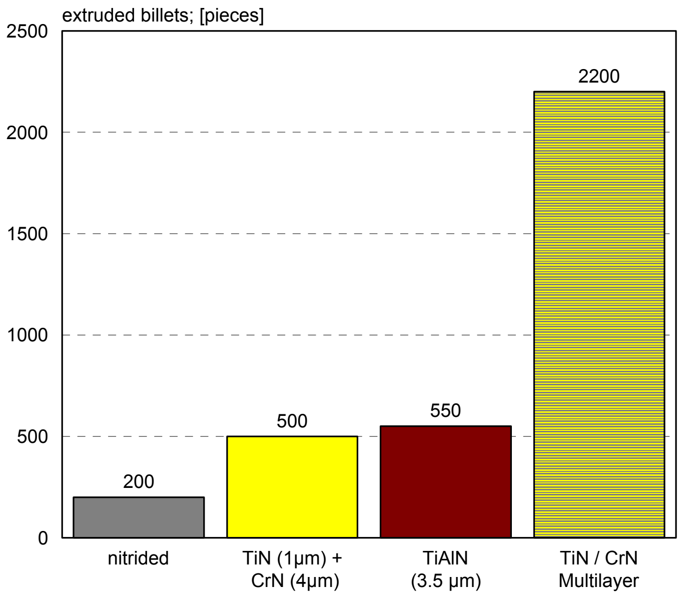


Mat.: Copper - Tool Mat.: tool steel - Coating temperature< 2
Source: MF, Thun, Switzerlar

The multilayer structure of TiN / CrN is especially good for higher temperature processes, when strong toughness is needed.

Performance Comparison for Aluminum Extrusion with Coated Molds



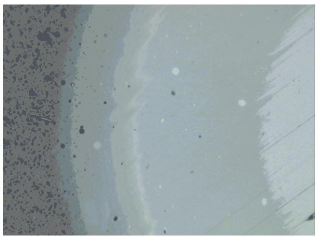


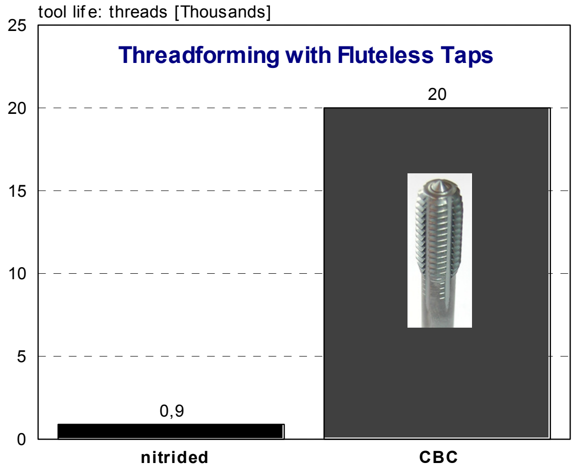
Mat.: Al 6012 - mold preheating: 400-480 °C - Billet temperature: 530 °C
Extrusion at 570 °C - Profile speed - 9 m/min
Layer Sequence: TiN=1.5/CrN=0.4 - 10x: TiN=0.25/CrN=0.35m
Total thickness 7.5um - Source: Metalba, Italy

Only **Lubrication coatings** like MoS2 and DLC (Diamond Like Coating, or Carbon Based Coatings) show lower friction coefficients.

The lubrication coatings alone can increase the performance of cutting tools if avoiding build up edges is the only important requirement for the coating. It is very typical at machining aluminum with carbide tools.

Nanostructured CBC - Special for Taps
Carbon Based Coating on CrN



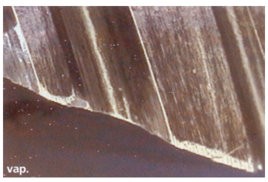


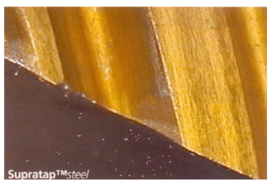
Workpiece: 356Al (7% Al) - Tools: M10x1.5 HSS - Coolant: emulsion 8%
Source: Hayes Brake, Mequon, WI, USA

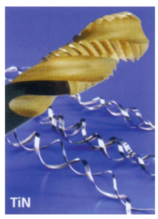
At working in harder materials the wear resistance will become important too. For these cases the combination of hard and lubrication coatings can be the solution.

Selective Surface Treatment as Dedicated Coating for Taps

Hard Coatings avoid wear on the tap's teeth



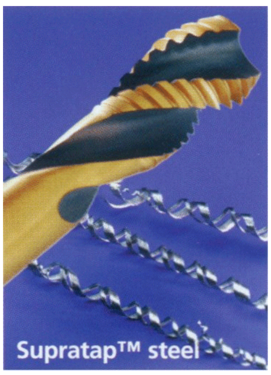




But hard coating is not the optimum in the tap's flute:

- heat insulation of the hard coating keeps heat in the chip
- thick, long chips
- lower friction required in the flute

Selective coating gives optimum dedicated solution for special requirements of taps:



- The teeth are coated by hard coating (e.g. TiN)
-> high wear resistance for the cutting edges

- The flutes are coated by a carbon based lubrication coating
-> low heat insulation by the coating
-> cutting heat can leave through the tool
-> tight chip helix; better chip breaking
-> tapping is suitable with minimum lubrication
-> low friction coefficient to move out the chips from the flutes

-> reliable process
-> the most important requirement at tapping

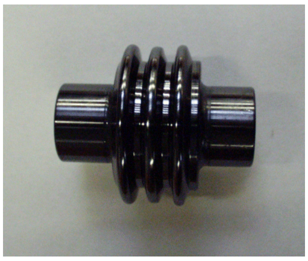
Source: Fraisa, Bellach, Switzerland

These lubrication coatings are especially important for coating moving machine parts. They demand extremely low frictional coefficients for the whole production life.

Machine Parts Coated by Lubrication Coatings

Clamping bolt for machine spindles

Roll elements for machine tools



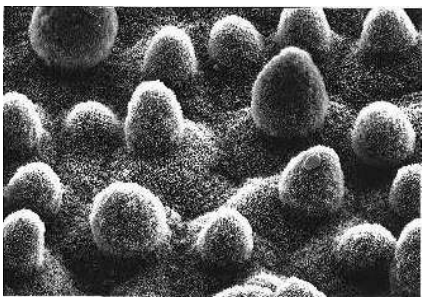
Ball join

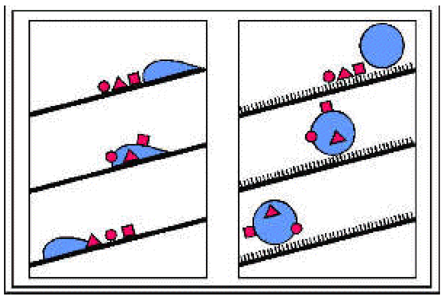
Chuck for drilling machine

Valve body for oil pipe line

The ideal ground surface for (relatively soft) lubrication coatings is the structure of the Lotus flower:

Surface of the Lotus flower

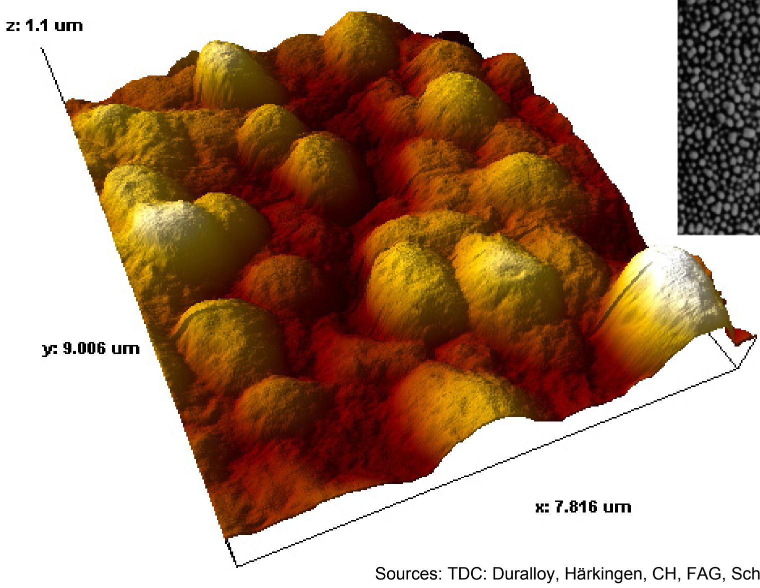


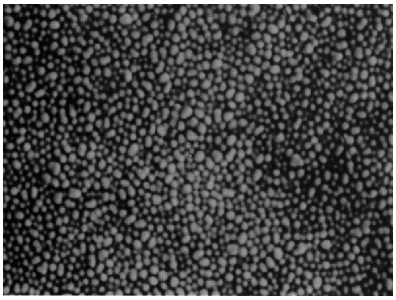


- **Minimum friction between chips and the "needles" of the Lotos surface**
- **Lotos flower: self cleaning surface**
- **The spaces between the needles are the ideal storage for lubrication; e.g. soft lubrication coating from MoS_2 - MOVIC**

The Cr-based DSV coating emulates the Lotus structure very closely.

Lotus Surface Structure by Thin Dense Chromium Coating (TDC)

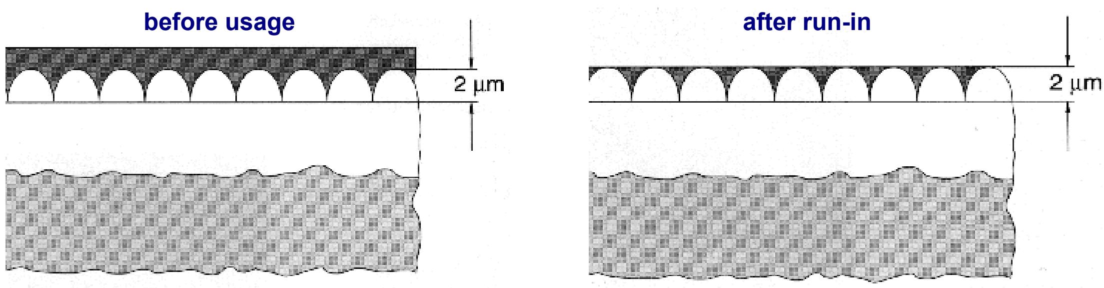


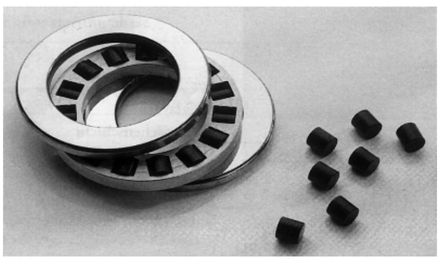


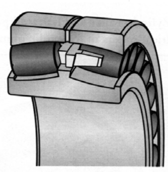
Sources: TDC: Duralloy, Härkingen, CH, FAG, Schweinfurt, D - AFM: Nanosurf, Liestal, CH

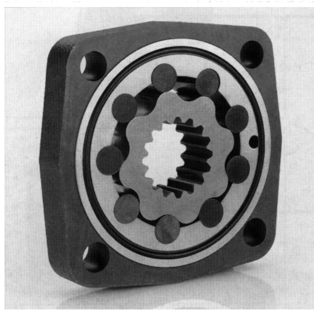
The pearl of the Lotus surface store the lubrication coating for longer time.

Double Coating: Thin Dense Chromium (TDC) plus MoS2 (MOVIC) and their Application for Bearing Bolts





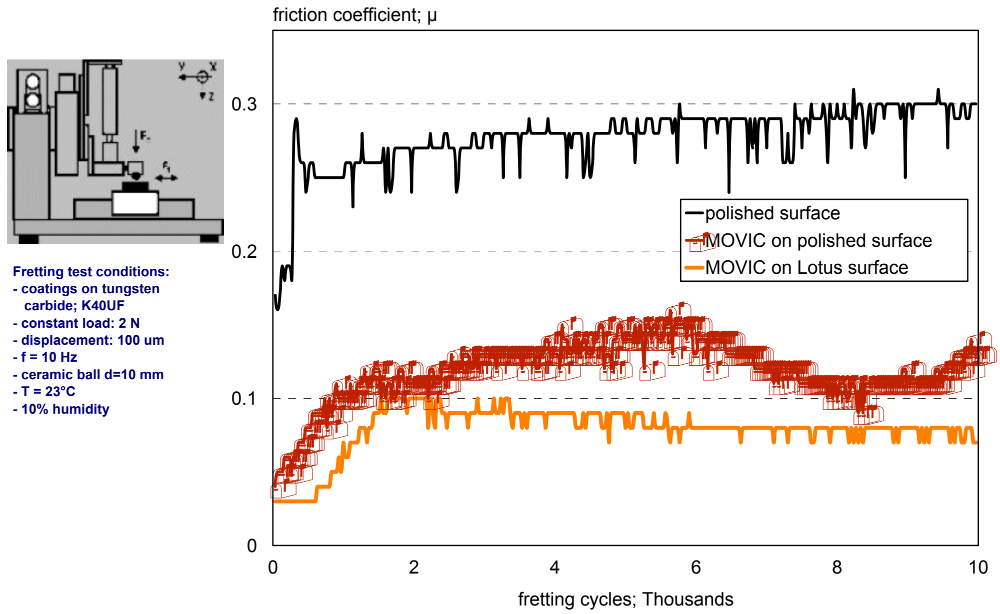




Sources: TDC: Duralloy, Härkingen, CH
FAG, Schweinfurt, D

With the help of the storage effect, the lubrication coating remains in the spaces between the Lotus pearls. It keeps the friction coefficient lower longer than on the polished surface.

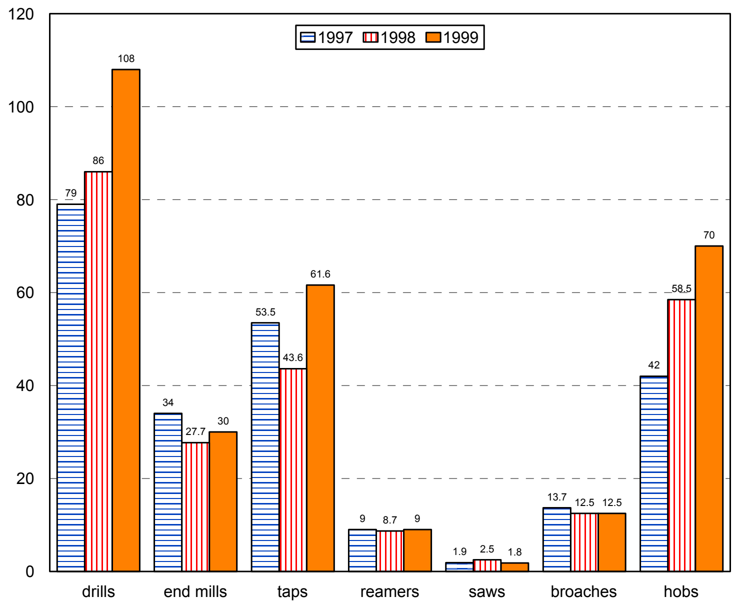
Friction Coefficient of MOVIC on Polished and Lotus Surfaces



Measured at the Katholic University Leuven, Belgium

Lubrication coatings can especially help solve chip evacuation problems at hole machining. Even these tools show the highest growth rates on the market.

Sales of New Coated Cutting Tools



Statistics for the German market - Source: VDMA, Frankfurt, 2000

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Dr. Cselle, born in Hungary, studied two different disciplines: machine tool engineering and digital electronic. He worked for the machine tool industry of Switzerland and as professor for different technical colleges and universities in Hungary and Germany. He used to work for the German tool manufacture Guhring for 12 years, finally as the head of research and development. As a consultant, he is active in the Technical Advisory Councils of the European Union and for different companies. He is a pioneer of dry high speed machining, leads several national and international research projects. He published over 200 papers, patents, books and held lectures in 22 countries. On the 1st of January 2000 he changed into the coating business and works at the Platit division, of Blösch Group, in Grenchen, Switzerland.