Recoating

When it first came about, TIN (Titanium nitride) coating was only performed on cutting tools. In the field of high speed steel, it substituted a whole series of processes which were previously performed to harden the tool surface and improve wear resistance. This with the ultimate aim of prolonging tool life and reducing manufacturing costs.
These processes, which had enjoyed a certain level of success in the past, were: carburising, nitriding, boriding, vanadising, chromising and vapour oxidation, all of which modified the surface characteristics of the tool and in some way improved its performance but the end results were, in any case, modest.
The difference in performance, for example, between an untreated helicoidal drill and one which had been nitrided was, in the best of cases, around 15 - 20%.
The same gap existed between two hobs, one ground and the other ground and nitrided. Basically there was a certain level of improvement but it was not revolutionary.
The real revolution, on the other hand, began around the seventies with the first experimentation and commercialisation of TiN (Titanium nitride).
This was later to prove extremely important in the field of gear cutting tools, probably even more so than the introduction of carbides although initially coating was only performed on carbide tools.
The impact that coating had on turning and milling operations was extraordinary, so much so that it was necessary to build faster and more powerful machinery in order to exploit the full manufacturing potential of these tools, as indeed was the case in much later years with hobs.
How this process was then also developed for high speed steel tools, consequently bringing forth a whole series of changes in manufacturing operations, will be examined in the following paragraphs.
Nowadays coating with various elements is not only carried out on tools but also on any type of mould or part that is subject to wear in the aeronautical and automotive industries.
Let us therefore examine the main types of coating available.

The CVD Method (Chemical Vapour Deposition)
This technique basically transforms the elements which are to be deposited into vapour and it places them in contact with the workpiece in an environment where the pressure is 10 - 100 mbar and the temperature is between 800 and 1000°C.

Chemical reactions occur under these conditions which cause the elements to adhere to the surface of the workpiece.
The first and most widespread application of coating technology was TiN coating of the carbide inserts that are used in turning and milling operations.
As the temperature at which coating is performed is relatively high and more precisely it is higher than the tempering limit of high speed steels, for some time this process was only used for carbide tools.
Basically high speed steels cannot be recoated with the CVD process because not only do they lose their hardness properties but, at temperatures of 800 - 1000°C, the workpieces deform and lose their original precision. It would therefore be necessary to regrind them to the required accuracy but this would mean removing the coating film.
Another reason which renders the CVD method problematic is that it utilises titanium tetrachloride as a chemical agent and disposal of this chemical is difficult.
CVD coating may be summarised as having the following characteristics:

- *Excellent adhesion of the film on all surfaces.*
- *Good coating quality also on complex shapes and on dead holes*
- *Temperatures too high for steel and therefore deformation and hardening*
- *Basically limited to coating carbide*
- *Problems in disposal of waste chemical agents*

The PVD Method (Physical Vapour Deposition)
The big advantage of this coating method is that it is performed at temperatures no greater than 500℃, which is under the tempering limit of high speed steel, with the added advantage that, at these temperatures, there is practically no workpiece deformation.
This method can therefore also be used for almost all high speed steel tools and on components used in extreme conditions in the aeronautical and automotive sectors.
This coating technology has therefore enjoyed widespread diffusion also because it is a physical process (not chemical) and therefore there are not difficulties in terms of waste disposal of pollutants.
The impact on the environment from an ecological point of view is therefore not an issue. This is a very important advantage nowadays.
Whilst the adhesion of the coating film to the workpiece is slightly inferior to that obtainable with the CVD process, this method has the following advantages:

- *Greater process flexibility and ability to coat any type of material*
- *Possibility to recoat for industrial use and for decorative purposes*
- *No dimensional or structural variations so the coating process is performed on finished workpieces.*
- *No ecological problems.*

Various coatings are performed with the PVD method and the different types will be briefly analysed here. It is, however, necessary to consider that theoretically there are no particular limits with the PVD method in the sense that many other types of coating elements could be used on workpieces of varying natures. The only fundamental condition is that the workpiece (or as it is more commonly referred to, the substrate) can withstand the process temperatures without its structure deforming. The following list gives us an idea of the wide range of applications that can benefit from this technology:

- *Optics: optic lasers, architectonic glasses and mirrors, absorbent and reflecting coatings, selective glasses etc.*
- *Electronics: conductors, contacts, isolators, solar cells etc.*
- *Mechanics: lubricating films, antiwear coatings, anticorrosion, antifriction, diffusion barriers, hard coatings for tools etc.*
- *Chemistry: anticorrosion coatings and catalysts, battery components, components for marine use etc.*
- *Decorative: watches, spectacles, costume jewellery, bathroom and kitchen taps and fixtures, building industry, kitchen utensils etc.*
- *Bio-materials: bio-compatible or bio-neutral coatings for implants (e.g. dental implants), surgical instruments.*

The widest diffusion of PVD coatings, however, apart from in the decorative sector, has been in industry where increasingly high material performances are required and where large scale coating has brought about enormous benefit.
To understand just how important the impact of coating technology has been on the world of mechanics with the introduction of elements such as TiN, it is sufficient to say that a whole generation of high speed hobbing machines has been engineered as a direct consequence. These have more than halved manufacturing times. Furthermore TiN has dramatically reduced the consumption of tools on a worldwide level causing serious problems for many tool manufacturers.
Lastly, coating technology has also changed the philosophy behind the use of many types of tools. For example it has led users to applying a new coating layer to tools after they have been resharpened.
The success of the PVD recoating process is thanks to the following characteristics:

- *Great level of hardness and therefore high resistance to wear and crater formation*
- *Very low friction coefficient*
- *Poor chemical affinity with other elements which means good resistance to corrosion*
- *Resistance to high temperatures*
- *Better external appearance of the tool.*

Excluding, therefore, the decorative sector, recoating is able to significantly improve the technical characteristics of tools in particular and of mechanical elements in general.
As stated above, it would seem that coating films give extraordinary performances due to their hardness, their low friction coefficient, their good chemical stability and their strong resistance to corrosion. This alone, however, does not guarantee good results since the film deposited must also be able to withstand substrate deformation as much as possible without getting damaged or separating from the workpiece itself.
The various coating types therefore have to be studied so that the thermal dilation coefficient and the elasticity modulus are as close as possible to those of the workpiece.
The coatings available with the PVD method drastically reduce wear in the following types of tools.

1. Tools for chip removal: hobs, shaper cutters, milling tools of all types, taps, helicoidal drills, centring drills, counterbores, reamers, constant profile tools, inserts, broaches, blades etc.
2. Tools for cold machining: for operations such as punching, drawing, extrusion, cold cutting, moulding, bending, sintering, that is tools such as punches, dies, blank holders, counterpunches, pullers, bending presses, drawplates, rolling tools, threading dies, minters, blades, shears, seaming rollers, deburring tools for die-casted elements, etc.
3. Tools for hot machining: for operations such as injection moulding and compression of plastic materials, blowing, thermoforming, hot-pressing of metals i.e. on tools such as core moulds, inserts, dies, punches, pullers, hot channel components etc.
4. Various components for the mechanical industry, for the fabric industry, the chemical, pharmaceutical, medicinal (surgical instruments) industries, the automotive and aerospace industries, electronics, etc.

Clearly such different sectors have very different needs and requirements. Depending on the end use of the tool or part, the technical characteristics of the coating are chosen to highlight the particular properties of the coated tool or part as much as possible. It is

therefore understandable that various processes have come about to satisfy the needs of end users.
Let us examine, for example, what processes have been developed by Samputensili of Bologna in its laboratories. The names of these different types of coatings are also exclusive to Samputensili. Others companies have different names.

SUNITE Carbonium - TiCN (Titanium carbonitride)
This type of coating became popular after the introduction of TiN. It differs from the latter due to its superior hardness levels which can reach up to 3300 $HV_{0,05}$.
This high level of hardness is due to the presence of carbonium in the crystalline lattice of the titanium nitride which, coupled with high resistance to friction, make this coating suitable for many applications such as: tools for chip removal operations, i.e. milling tools, taps, helicoidal drills, reamers, when these must machine materials which have high mechanical characteristics such as hardened and tempered steels, aluminium allot as well as bronze and cast irons.
The characteristics of TiCN make it suitable for manufacturing at high cutting speeds but only for wet processes. It is interesting to note that the best results have been obtained by adapting the tool geometry to the characteristics of the coating, exploiting the fact that the high cutting speed and feed attainable allow a higher quantity of heat to be released through the chips, reducing the thermal stress placed on the tool.
Good hardness and a low friction coefficient also make TiCN suitable for use in other sectors such as moulds for metal punching in general.

SUNITE Gold-TiN (Titanium nitride)
This is the most widely used coating and it was the first to be applied on a widespread level, principally in the gear cutting tool sector thanks to its technical characteristics. It has a hardness level (around 2500 $HV_{0,05}$) which is superior to that of carbide, a low friction coefficient, good resistance to corrosion, poor chemical affinity with most materials machined and a nice gold colour which also makes it suitable for decorative purposes.
The high hardness level of this coating gives the tool strong wear resistance properties both against abrasive-type and crater-type wear. This has enabled users to dramatically increase working conditions and improve the performance of tools such as hobs and shaper cutters in gear manufacturing.
The low friction coefficient helps the material to run smoothly along the coated surface and therefore the stress of the operation and the heat produced is reduced. This clearly also increases the life of the tool and there are notable advantages, particularly in the mould sector, both in terms of the performance of the moulds themselves and in the quality of the finished product.
The poor chemical affinity of TiN with most materials reduces phenomena of welding and seizure of the parts which are in contact during machining. Not only does this reduce crater formation in chip removal operations but it also greatly favours operations such as moulding, punching and extrusion.
The good chemical stability of TiN, even at high temperatures, prevents the tools or other coated parts from oxidation and corrosion, even under adverse conditions such as in salty environments or when the tool is in contact with aggressive coolants or hot gases for example. It is also possible to keep tools in stock for long periods without treating their surfaces in any particular way.

SUNITE Silver-Ti2N (Bi-titanium nitride)

This type of coating is suitable for machining inoxidable steels and alloys with a high nickel content.

Its friction coefficient is particularly low so it may be particularly suited to some types of application.

This type of coating also improves resistance to crack formation when machining under harsh conditions.

The prevalent use of this coating, which is still in expansion, is in the alloy machining sector such as in aeronautics, in drawing and punching of inoxidable steel sheets.

SUNITE Chromium-CrN (Chromium nitride)

This type of coating has become extremely popular in recent years due to greater demand in terms of performance in the sector of moulds for the drawing of plates, especially on materials which have a tendency to stick such as inoxidable steels and aluminium.

Good results have also since been obtained in coating moulds for injection moulding of plastic materials thanks to its resistance to oxidation at high temperatures.

SUNITE UniversAl-TiAlN (Titanium aluminium nitride)

This coating is part of the so-called three compound types. It has come to the attention of technicians in recent times since it improves the performance of tools during dry machining, that is without coolant.

This is of particular importance nowadays since problems that arise from stocking, using and disposing of coolants are becoming increasingly serious and costly.

By adding aluminium to the coating film, it becomes much more resistant to heat oxidation since the oxidising temperature of TiAlN is around 800 °C.

Typical fields of application are therefore those where a great deal of heat is released or where it is released with difficulty, that is in those operations where the temperature of the active part increases to levels that can endanger the coating layer.

This coating is in fact used in die-casting of aluminium alloys, in deep drilling of cast iron as well as naturally in all dry machining operations that involve chip removal.

SUNITE Futura-TiAlN (Titanium aluminium nitride)

This coating differs from the previous one in that the film is thicker (in the region of 6 – 8 microns). It is suitable for high speed steel hobs both for wet and dry machining and where the hob is placed under particular stress.

SUNITE X-Treme-TiAlN (Titanium aluminium nitride)

This coating is characterised by a low film thickness of between 1 and 2 microns and by a higher level of hardness. It is suitable for coating carbide hobs both for wet and dry machining.

SUNITE Hardlube – TiAlN+WC/C (Titanium aluminium nitride + Tungsten carbide)

This type of double coating is used to reduce the friction coefficient which is typical of TiAlN. It is used in applications where it is important that the chip is expelled smoothly and where it is necessary to have a good level of resistance to high temperatures.

Table No.1 - Summary of the technical characteristics of Samputensili coatings

Denomination	**Composition**	**Max temp. °C**	**Hardness HV0,05**	**Friction coefficient**	**Film thickness** (micron)
SUNITE Gold	TiN	600	2500	0,35	6 - 7
SUNITE Carbonium	TiCN	450	3300	0,35	3 – 4
SUNITE Silver	Ti_2N	600	2300	0,35	1 – 4
SUNITE Chromium	CrN	700	1750	0,35	1 - 5
SUNITE UniversAl	TiAlN	800	3000	0,4	1 – 4
SUNITE Futura	TiAlN	800	3000	0,4	6 – 8
SUNITE X.Treme	TiAlN	800	3500	0,4	1 - 2
SUNITE Hardlube	TiAlN+WC/C	800	2600 (TiAlN) 1000 (WC/C)	0,2	2 - 6

Nowadays, however, it is very rare to cover the surface of a tool with just one type of film since the advantages that are obtained are only relative to the elements of that specific coating.
In other words, with the technology available today, it is possible to apply so-called multi-layer coatings which allow the user to benefit from an accumulation of the advantages that each different type of coating has to offer.
For example, if you coat a tool with just TiN, as can be seen in the following table, the temperature of oxidation would be 600 °C and the elasticity modulus 260 Kg/mm^2 , that is near that of the high speed steel from which the substrate is made. The advantage is that the TiN film flexes in the same manner as the steel or rather it behaves like a layer of paint. Instead of flaking off, it withstands the deformation of the support without getting damaged.
On the other hand, however, when the temperature at the contact point between the chip and the tool reaches 600 °C, the film starts to oxidise and consequently loses its physical characteristics, flaking off and revealing the support underneath.
There is therefore a specific limit in terms of the cutting speed that can be reached with this type of coating.

Table No. 2 – Elasticity Modulus of some types of coating

Type of coating	Oxidation temperature	Elasticity modulus	Hardness
TiN	600 °C	260 Kg/mm^2	2300 HV
TiCN	450 °C	450 Kg/mm^2	3000 HV
TiAlN	800 °C	450 Kg/mm^2	2600 HV

If, on the other hand, the tool is coated with TiAlN, the temperature of film oxidation increases to 800 °C and therefore the loss of physical properties occurs at a much higher cutting speed. The elasticity modulus is, however, in this case 450 Kg/mm^2, that is the film is more rigid and less flexible than the steel from which the support is made.
This means that if the steel flexes, the coating film does not follow suit and there will therefore be the danger of cracks forming within the film itself.
Since the structure of the coating is column-type, as shown in figure No.1, when a crack forms on the surface it reaches as far as the support, making it possible for the coating itself to flake off.

This problem can be resolved by alternating different types of coating layers as indicated in figure No.2.

If, for example, layers of TiAlN and TiN are alternately applied, the surface of the tool will be resistant to high temperatures. If the different moduli of elasticity of the coating and the support cause a crack in the first layer, this will continue until the second layer and then stop.
It is therefore possible to fully exploit the physical and chemical characteristics of the two different types of coatings.

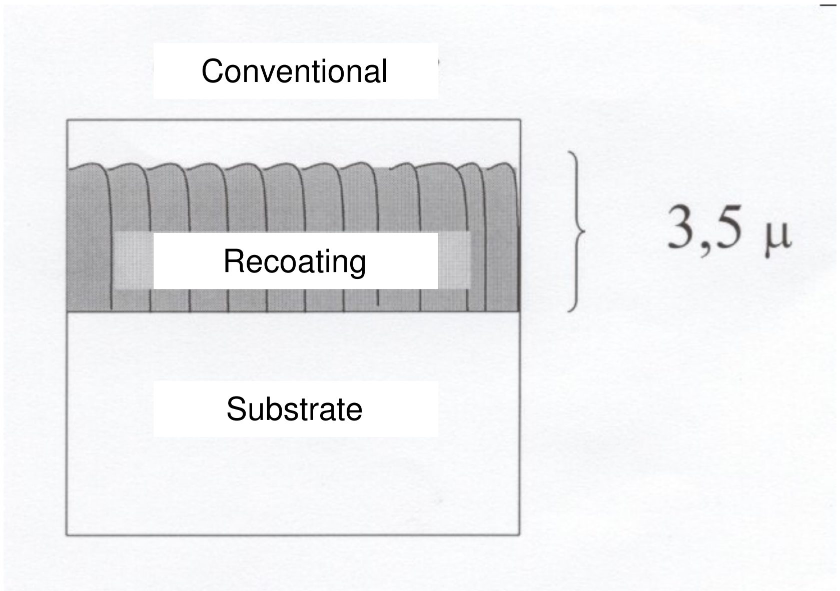

Figure No.4

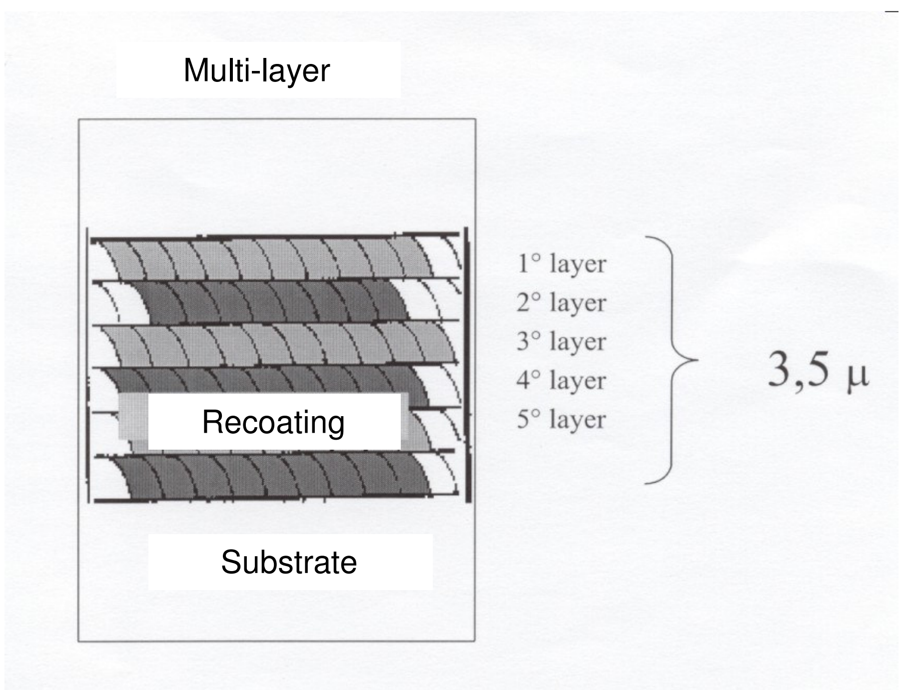

Figure No. 2

The multi-layer recoating technique also makes it possible to solve a problem that can arise when utilising TiAlN. This coating has a rather high friction coefficient. Chip formation is therefore difficult and more heat is produced especially in those operations where the coolant cannot easily access the contact area or even more so when machining dry. This problem is solved by applying a coating of MoS_2 (molybdenum bisulphide) as the last layer. Having good lubricant properties, this compound has a particularly low friction coefficient.
This coating technique together with the recent launch onto the market of superalloy high speed steels has made it possible to adequately challenge carbide and cermet hobs especially when dry hobbing.
It is a well known fact that with this type of operation cutting speeds are extremely high and a great quantity of heat is therefore generated, creating consequent high temperatures in the contact zone between the chip and the tool.
In the diagram shown in figure No.3 it is possible to observe how hobs in superalloy high speed steel which are recoated with multi-layer TiAlN coating, can achieve cutting speeds of 160 m/1' whilst at the same time maintaining greater tenacity.
This makes it possible, for example, to use multi-start hobs or hobs with a greater number of gashes which easily compensate for the higher cutting speeds that are possible with carbide or cermet hobs but at the same time the tools are much less costly.

Basically it is possible to obtain very similar overall cutting times but the costs and the risks involved are much lower. This matter will be examined in another chapter.

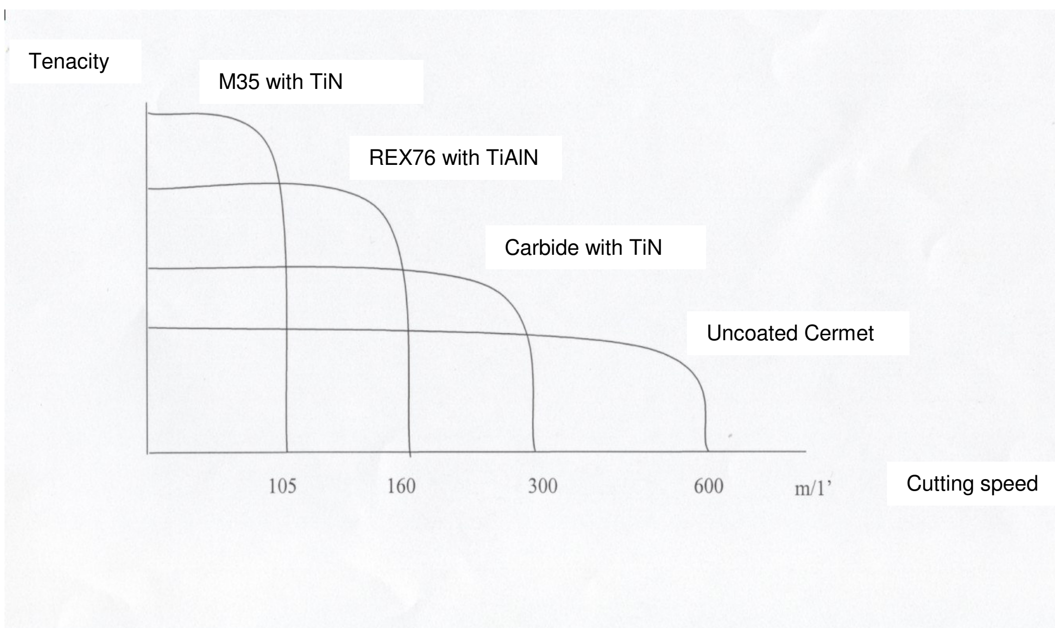

Figure No.3

The Electrodeposition process
The PVD (Physical Vapour Deposition) electrodeposition process basically consists in making contact between the workpiece to be coated and the particles of the compound which constitutes the coating. This is performed through kinetic energy which is at such an entity as to cause the adhesion of the particles to the workpiece.

Metal vaporisation (titanium, aluminium, zirconium etc.) may occur by using different procedures. The most well-known are:

- *Vaporisation by means of an electron gun*
- *Sputtering (powdering with magnetron)*
- *Vaporisation with an electric arc*

With the first system an electron gun bombards the titanium and it vaporises it. The cathode from which the electric discharge is released is not a filament. It is a hollow cathode made from tantalum and it must resist temperatures of around 3000 °C without deforming.

The titanium, which acts as an anode, is hit by the discharge of the electron gun and it vaporises and ionises in a very small area. Due to the difference in potential between the anode and the tools that are to be coated, an ionic flow forms and moves towards the tools which are placed above a protective screen. This is removed once the operative parameters are stable.

These operative parameters are: pressure, gas flow, current intensity and tension.

A few minutes after the titanium vaporises and ionises, pure nitrogen (N) is released into the chamber. This reacts with the titanium vapours both within the chamber itself and on the surface of the tools.

The Ti vapour flow is prevalently directional that is from the crucible to the workpieces and it is therefore necessary to rotate the workpieces so that they are exposed in a uniform manner to the vapour current.

The ions and the atoms of Ti, N and TiN travel at very high speeds and deposit on the surface of the workpiece, forming a layer. The thickness of this layer depends on how long this process lasts.

The maximum thickness of the coating layer is 2,5 - 3 micrometers although it may be larger with some types of coating.

From a conceptual point of view, this process is relatively simple but satisfying and reliable results can be obtained only after all operative parameters have been carefully checked.

Furthermore, it has also be ascertained that even in optimum deposition conditions, the coating will adhere to the substrate effectively only if the latter is prepared with great care with thorough shot blasting and washing cycles before it is placed in the chamber.

In particular, very important progress has been made in the field of shot blasting (or sandblasting or corundum blasting), since removing just a slight amount of material from the surface layers of the steel before coating produces a vast improvement in tool performance and overall consistency in terms of the results obtained.

In fact, in the past, tool performance greatly varied and it was never possible to understand the cause of this inconsistency. The results only became stable when this cleaning operation was put into practice.

It is clear that a ground surface is not particularly suited to this coating process since too many marks are left on the tool. These may be more or less deep depending on the plastic deformation of the steel.

Tension is always associated with these marks which presumably decreases gradually underneath the surface.

Apart from this, there are often burn marks from the grinding operation on the tool surface. These are due to localised heating and they make good adhesion of the TiN layer difficult.

By performing a wet blasting operation, the external layers, where burns and micro-oxidation may be present, are removed.

It is sufficient to remove 2 - 3 microns in order to obtain a good enough surface for the coating to adhere.
The last phase before the tools are placed in the chamber is the washing cycle. This is also very important if the steel and the TiN are to bond solidly. Washing is carried out in various stages and has the objective of freeing the surface from any type of deposited impurity such as greasy substances or dust.
In spite of all of this, the tool surface is still not ready to receive the actual TiN layer.
Before the titanium ions are released, the workpieces are bombarded with argon ions which are accelerated by a potential difference of a few hundred volts.
The duration of this process may vary depending on the state of the surface although it is always necessary to avoid the risk of heating.
Normally a tension of 200 - 500 V for about 15 minutes is applied with a pressure level of the argon gas of around 10 Pa.
This phase destroys any residual oxide traces or other impurities that are still present on the surface that could compromise the adhesion of the coating to the substrate.
See figure No.4.
In the arc deposition process, a unit which has a chamber made of inoxidable steel is used in which there is a certain number of titanium cathodes. These emit ionised Ti atoms as shown in figure No.5.
During the initial phase a vacuum of about 5 mPa is created using a rotating pump in series with a turbo molecular pump.

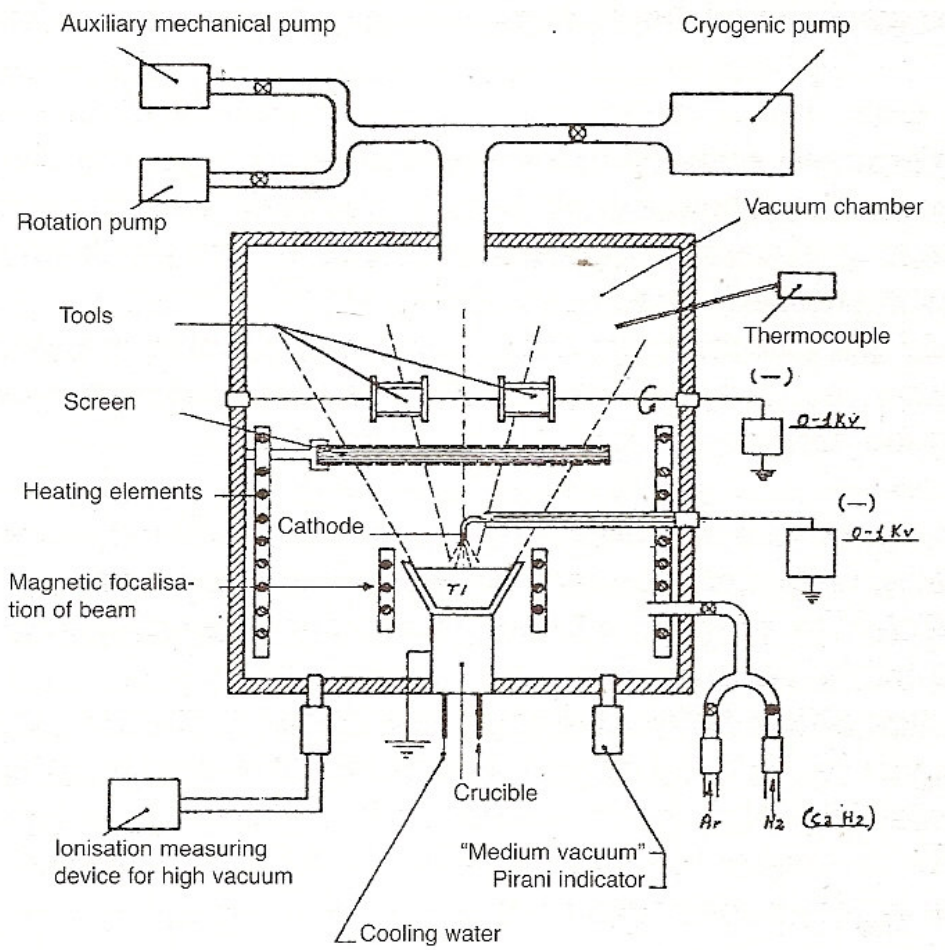

Figure No.4

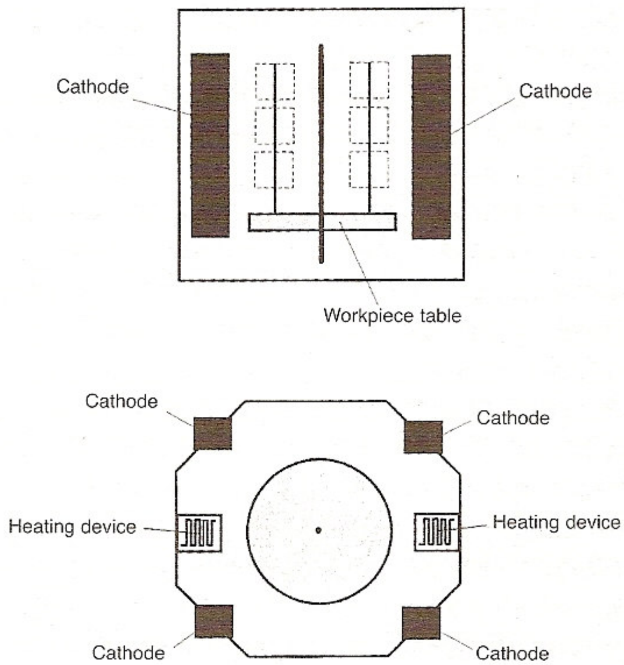

Figure No.5

At the same time, the chamber is heated up to 450 °C and the temperature is monitored by a water cooling jacket.
The Ti ionised atoms are accelerated towards the support where the tools to be coated are held (negatively polarised) and they react with the gas that is emitted into the chamber. This reaction produces a coating which adheres particularly well to the workpieces.
In arc-type processes, the metal (Ti, Cr, etc.) which is used to form the coating is made to evaporate by an arc that is generated in a plasma atmosphere.
The arc moves on the surface of the ion chamber attacking the cathode spot, which has a diameter of just a few nm, from time to time for a period from 5 to 40 ns.
The electric current of the arc which is concentrated on such a small area for such a short amount of time reaches a density of 10^9 W/cm^2 which causes the immediate vaporisation of the material from which the cathode is made.
Sometimes small drops of melted metal form which may get trapped in the coating which is forming. (Figure No.6).

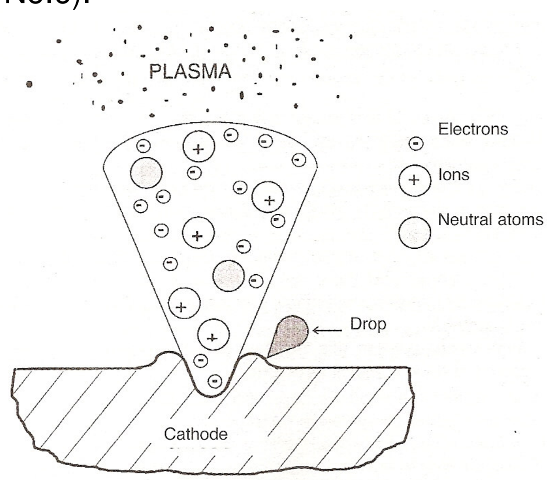

Figure No.6

Partially ionised vapour is produced by the vaporisation that the arc induces. The arc then endures an acceleration caused by the difference in potential between cathode and anode. The ionised vapour is therefore characterised by an energetic content higher than the factor 10^2 in comparison to the vapour that is produced in conventional evaporation.
The differences in potential involved in the process are around 250 V with a current intensity of about 80 A.
This is one of the reasons why with this method it is possible to obtain coatings with good adhesion properties even at relatively low temperatures and tensions.
Even in processes like this, the actual deposition phase follows a careful washing cycle which is carried out in various stages.
The first phase is corundum blasting (previously called shot blasting) where particles of Al_2O_3 are projected at high speeds against the surface to be cleaned and they remove a small layer of steel. This eliminates all traces of oxidation and any surface burns that might compromise the adhesion of the coating film.
An alkaline wash is then carried out followed by an acidic wash and then an electrolytic cleaning operation and a series of rinses in de-ionised water of increasing purity. The workpieces are then dried in the oven.
This cleaning cycle also avoids any difficulties from an ecological point of view since Freon is not used. This was widely used in old-style coating equipment.
One of the big advantages of this method is that more electrodes are placed around the periphery of the chamber covering its whole height.
The titanium ion currents therefore coat the workpieces in a more uniform manner and there are no so-called shadow zones, that is those areas that are unavoidably present when using just one titanium ion chamber.
With this equipment, it is therefore possible to effectively coat workpieces that have complex structures.