Workpiece with hard coating

The present invention is directed to a workpiece having a body and a wear-resistant hard coating system on at least a part of its surface, further to a process for manufacturing such workpiece and to a method of manufacturing a device.

Discussion of related art

TiAlN is a coating which is widely used to machine hardened steel and is customarily applied by a PVD process.

Definition

We understand under a physical vapour deposition process (PVD) a vacuum deposition process, wherein a plasma is used and material is filled into the processing atmosphere from solid. Thereby, under this term of PVD e.g. cathodic arc evaporation, ion plating, sputtering, thereby magnetron sputtering, all the addressed processings reactive or non-reactive are members of the PVD processing category.

In opposition thereto CVD coating processes, chemical vapour deposition, and PECVD, plasma enhanced chemical vapour deposition provide coating out of gaseous phase.

TiAlN layers used as a single layer- or in multilayer-systems with sublayers of different Ti/Al/N stochiometries, can be used up to working temperatures of 900°C at most for tooling application due to the incipient degradation of

hardness at temperatures higher than 800 to 850°C depending on the Aluminum/Titanium ratio.

Therefore, the US 2005-0003239 proposes to apply AlCrN coatings to workpieces so as to increase their oxidation resistance. This coating is known to have a good oxidation resistance and a hot hardness up to 1100°C depending on the Aluminum/Chromium ratio. It is further referred to similar proposals in the WO 2006/005217, the WO 2006/084404 and the US 2006-0222893 trying to further improve oxidation resitance and/or hot hardness of the coatings by using different multilayers and/or by introducing other elements into the AlCrN matrix.

The US 2006-0269789 discloses a hard multilayer to cut high hardness material at a high speed. The hard multilayer comprises a first TiAlCrNX-based layer, wherein X stands for C or O. A second layer consists of a mixture of TiAlCrNX and of TiAl(SiC)NX or is a multilayer of layers of these alternative materials. A third outermost layer essentially consists of TiAl(SiC)NX.

Another coating to improve cutting of hardened steels is disclosed in the EP 1 690 959. There the coating comprises a two-layer system based on (TiAlSi)N of different Al and Si stochiometries.

In spite of the approaches as outlined above there is still a need to further improve hard coating systems on workpiece bodies with respect to wear and oxidation resistance, thereby further improving performance of such workpieces, especially used as cutting tools in machining of hard material, thereby especially of hardened steels.

It is thus an object of the present invention to further improve hard coatings with respect to wear resistance and oxidation resistance. To resolve such object there is proposed a workpiece having a body and a wear resistant hard coating system on at least a part of the surface of the body, wherein the system comprises at least one layer of the following composition:

$$(Al_{1-a-b-c}Cr_aB_bZ_c)X, \text{ where}$$

X is at least one of N, C, CN, NO, CO, CNO and

Z is at least one of W, Mo, Ta, Cb (also referred to as Nb) and wherein there is valid

$$0.2 \leq a \leq 0.5$$

$$0.01 \leq b \leq 0.2$$

$$0.001 \leq c \leq 0.04.$$

Astonishingly, the addressed object is achieved by generically adding boron (B) and at least one of the addressed Z elements to a matrix of AlCrX type by fulfilling the addressed conditions with respect to stochiometry. We address this layer as HL_0.

In a preferred embodiment of the workpiece according to the invention the element Z is selected to be tungsten W and there is established

$$0.01 \leq b \leq 0.01 \text{ and}$$

$$0.01 \leq c \leq 0.01$$

We address this layer as HL_1.

We understand throughout the present description and claims under the term "coating system" or "coating subsystem" a system which consists of one single layer or of multiple, i.e. more than one layers.

The addressed at least one layers HL_0 possibly HL_1 may thereby be applied directly on the surface of the workpiece body. They further may be applied to form the outermost layer of the coating system. Clearly, if such coating system consists of one layer, then the addressed layer of HL-type resides directly on the surface of the body and is the outermost layer. The layer of HL_0-type may further be the outermost layer of a multilayer system. It further may be embedded within a multilayer system between a first layer subsystem towards the surface of the workpiece body and a second layer subsystem towards the surface of the coated body. Still further, in a multilayer system more than one of the addressed HL_o-type layers of equal or of varying stochiometry and/or material composition may be provided. Thereby, such layers of HL_o-type may reside directly one upon the other with different stochiometry and/or material composition or may be separated by respective coating layer subsystems.

In one embodiment of the workpiece according to the present invention the at least one layer HL_0 or HL_1 resides outermost of the hard coating system.

In one embodiment of the workpiece according to the present invention the at least one layer of HL_0-type resides directly on the surface of the body of said workpiece.

Still in a further embodiment the system comprises at least one interlayer of $(Ti_dAl_e)N$. Thereby, in a further embodiment at least one of the addressed interlayers is interposed between the surface of the body and the addressed at least one HL_0-type layer. We address this interlayer as IL_1.

In a further embodiment of the workpiece the addressed interlayer resides directly on at least one of the surface of the workpiece and of the at least one layer of HL_o-type.

Thus, in the embodiment wherein the interlayer is interposed between the surface of the body and the at least one HL_0 or HL_1, further interlayers of the addressed type may additionally be provided between the HL_0 or HL_1 and the surface of the system. Further, the addressed intermediate layer must not necessarily reside as the only layer between the surface of the body and the surface of the HL_1 or HL_0, additional layers may be provided therebetween, so that the interlayer is one layer of a multilayer subsystem between the surface of the body and HL_0 or HL_1. Nevertheless, in one embodiment the addressed intermediate coating directly resides upon at least one of the surface of the body and the HL_0 or HL_1. When applying the at least one interlayer of $(Ti_dAl_e)N$ in a further embodiment there is applied:

$$0.4 \leq d \leq 0.6 \text{ and}$$

$$0.4 \leq e \leq 0.6.$$

In a further embodiment of the workpiece according to the present invention the hard coating system comprises at least one interlayer of $(Al_fCr_g)N$. We address this interlayer as IL_2.

With respect to where such at least one interlayer may be provided the same prevails as was addressed above with respect to the $(Ti_dAl_e)N$ layer - IL_1 -, with the exception that for the $(Al_fCr_g)N$ interlayer, in a further embodiment there is selected

$$0.4 \leq f \leq 0.7 \text{ and}$$

$$0.3 \leq g \leq 0.6.$$

Further, both the addressed interlayers IL_1 and IL_2 may be provided in combination within the hard coating system.

Still in a further embodiment of the workpiece according to the present invention, the at least one layer, HL_0 or HL_1, exhibits a nanocrystalline glassy-like growth structure in the SEM cross-section and/or, as in a further embodiment, a relatively small fraction of AlN characterized by a crystal structure of the hexagonal type. Such hexagonal AlN phase in this embodiment resides with a percentage of Al of at least 70% within the metallic fraction of the HL_0 or HL_1 material, which fraction comprises all the elements but X of AlCrBZX or AlCrBWX.

Such hexagonal structure may be recognized by XRD analysis.

In a further embodiment of the workpiece according to the present invention the at least one HL_0 or HL_1 has a texture coefficient $Q = I(200)/I(111)$ in the range of $0.1 \leq Q \leq 1$. Such texture coefficient Q may be measured by X-ray diffraction analysis. As addressed, the term Q is defined as the ratio of the diffraction intensities I(200) to I(111) assigned respectively to the (200) and (111) planes in the X-ray diffraction of a material using a measuring

setup as e.g. described in context with fig. 4 of the present description. Thereby, in a further embodiment the addressed range of Q is even restricted to $0.1 \leq Q \leq 0.4$.

Looking back to the addressed interlayers IL_1, IL_2 it should be mentioned that in respective embodiments these interlayers may exhibit a columnar growth structure, thereby giving to the overall coating system an excellent performance, especially if used on a cutting tool.

In a further embodiment of the workpiece according to the present invention the hard coating system comprises a multilayer of alternating layers of at least one of the addressed interlayers IL_1, IL_2 and of at least one of HL_0 and HL_1, thereby preferably of (AlCrBW)X, i.e. HL_1.

Such a multilayer may e.g. comprise, departing from the surface of the body, a first of the addressed interlayers IL_1, then possibly a second of the addressed interlayers IL_2 of different type, then a first HL, i.e. HL_0 or HL_1, then again one or more than one of said interlayers IL_1, IL_2, a second HL_0 or HL_1 of same or of different material, a third HL_0 or HL_1 directly upon the former one, etc. etc. Thus, depending on the specific application there is a large variety of tailoring such multilayer hard coating system making use of the HL_0 or HL_1 and of the addressed intermediate layers IL_1, IL_2 in different combinations.

In a further embodiment of the workpiece according to the invention the body is of high speed steel, hardened steel, cemented carbide or of cubic boron nitride or in a further embodiment of a cermet or of ceramic material.

Still in a further embodiment the addressed workpiece according to the present invention is a cutting tool, thereby in a further embodiment an end mill, a drill, a cutting insert or a gear cutting tool.

A process according to the present invention for manufacturing a workpiece as was addressed, i.e. according to the present invention comprises providing such workpiece body in a plasma coating vacuum chamber, applying the hard coating system to the body by a physical vapour deposition process (PVD) during a processing time and thereby establishing a temperature of at least 550°C to the surface of the coated body during at least a predominant part of processing time.

In one embodiment of such process the addressed temperature is selected to be at least 600°C.

Still under a further aspect the present invention is directed on a method of manufacturing a device which has at least a part of a hard material. Such method comprises a cutting process of the hard material of the device using a cutting tool according to the present invention. Thereby, still in a further embodiment of the addressed device manufacturing method, the hard material has a Rockwell hardness of at least 52 HRC, thereby even of at least 55 HRC. Still in a further embodiment of the just addressed manufacturing method the hard material is hardened steel.

Cutting processes have been performed with cutting tools according to the present invention which showed on hard material results at least as good or even better than comparative examples performed with state of the art tools.

However, cutting operation on hardened steel or other high hardness materials having a Rockwell hardness of HRC 50, especially of HRC 52 or higher, even of HRC higher than 55, the tools according to the present invention revealed a performance which was outstandingly good as will be shown below.

The present invention shall now be further described by means of examples and with the help of figures. The figures show:

Fig 1 schematically a part of a first embodiment of a workpiece according to the present invention;

Fig 2 in a representation analogous to that of fig 1, a second embodiment of a workpiece according to the invention;

Fig 3 in a representation analogous to those of figs 1 and 2 a further embodiment of a workpiece according to the invention;

Fig 4 in a representation analogous to those of figs 1 to 3 a further embodiment of a workpiece according to the invention;

Fig 5 in a representation analogous to those of figs 1 to 4 a stil further embodiment of a workpiece according to the invention;

Fig 6 a SEM of a cross-section of a AlCrN hard coating;

Fig 7 a SEM of a cross-section of a AlCrBWN hard coating at a workpiece according to the invention;

Fig 8 a SEM of a cross-section of a TiAlN/AlCrBWN hard coating at a workpiece according to the invention;

Fig 9 XRD spectra of an AlCrN and of an AlCrBWN hard coating, latter at a workpiece according to the invention;

Fig 10 XRD spectra of AlCrBWN hard coatings at workpieces according to the present inventionb.

In fig. 1 there is schematically shown a first embodiment of a workpiece 1 according to the present invention. The workpiece 1 has a body 3 with a surface 5. The body is of one of the materials high speed steel, hardened steel, cemented carbide, cubic boron nitride, cermet or of a ceramic material.

According to the embodiment of fig. 1 one of the layers HL_o which may be HL_1 directly resides on the surface 5 of the body 3.

Thereby, the surface 7 of the resulting workpiece is formed by one surface of the addressed layer HL_o which thus, as a good embodiment, forms the outermost surface of the workpiece.

In the embodiment of fig. 2 which is shown in a representation which is analogous to that of fig. 1 there is provided a coating subsystem CSS between the addressed layer HL_o which may be HL_1 and surface 5 of the body 3. Such coating subsystem CSS may thereby according to the definition of coating subsystems as made above comprise one or more than one layers.

As may be seen in the definition of the layers HL_o and also HL_1 X, and in the case of HL_o also Z may consist of different elements. According to the embodiment of fig. 3 the outermost layer of the hard coating system is formed by HL_o in a first material composition, denoted by HL_{o1} or by the layer HL_1, in one specific material composition, denoted by HL_{11}. Propagating towards the substrate 3 there is provided a second layer HL_0 in a different material composition denoted by HL_{02} or respectively by HL_1 in a different material composition, denoted by HL_{12}.

There may or may not follow further layers of the HL_0 type and/or of the HL_1 type up to surface 5 of the body 3.

Whereas at the embodiment of fig. 3 the coating system consists of HL_{0x} layers, at least a part thereof possibly HL_{1x} layers, in the embodiment according to fig. 4 there is the hard coating system comprises a coating subsystem CSS. Such coating subsystem may or may not comprise further of the HL_o-type layers, but does additionally comprise at least one layer which is not of the addressed HL_o-type.

In all the embodiments of fig. 1 to 4 the outermost layer with the surface 7 is formed by a layer of the addressed HL_o-type. This is a good approach to form the addressed outermost surface of the workpiece.

Nevertheless and e.g. with an eye on fig. 4 for some appliances it might be advisable to provide (not shown) a further coating subsystem on top of the outermost HL_o-type layer so that the outermost surface 7 is formed by such outermost subsystem.

In the embodiment according to fig. 5 layers of the HL_o-type alternate with coating subsystems CSS. Thereby, the alternatingly applied layers of HL_o-type may be equal or different with respect to material composition.

The alternating coating subsystems again may consist of one or more than one layers, at least one thereof being not of the HL_o-type.

As exemplified by the embodiment according to fig. 1 to 5 there exists a large variety to apply HL_o layers to the body 3 of the workpiece, in dependency of the specific needs for such workpiece. Especially if the workpiece is a tool, especially a cutting tool, it is suggested to select as the outermost layer of the coating system a HL_o-type layer.

We have addressed in the introductory part of the description a first interlayer of $(Ti_dAl_e)N$ especially with d and e in specific ranges of values as IL_1 and have addressed a second type of interlayer of $(Al_fCr_g)N$, with specific ranges for f and g as IL_2.

With an eye on the embodiments of fig. 1 to 5 each of the addressed coating subsystems CSS may comprise or consist of IL_1 or of IL_2 or may comprise or consist of a combination of IL_1 and IL_2, and may comprise additional layers of the HL_o-type or of layers different from HL_o type and IL_1, IL_2.

Again, the skilled artisan recognizes from the addressed embodiments according to the fig. 1 to 5 incorporating the interlayers IL_1 and/or IL_2 a larger variety of combinations selectable dependent on respective needs.

In the following some specific embodiments of the workpiece according to the present invention are exemplified. Cutting performance of workpieces according to the invention conceived as cutting tools were compared with such tools according to the state of the art, thereby equal cutting operations and cutting parameters were applied to the respective tools according to the present invention and to the comparative tools according to the state of the art, for valid comparison purpose.

The hard coating systems applied to the specimens in the following examples were deposited under the following conditions, if not specifically and differently specified, whereby the process for manufacturing the workpieces according to the present invention was applied.

Deposition technology: Cathodic arc evaporation

Total working pressure: 5.5 Pa of N_2

Bias voltage of the body to be coated: -85V against ground potential for HL_0 type layers and -100V against ground potential for IL_1 and IL_2 layers

Surface temperature of body being coated: 600°C

Evaporation current: 200 A per evaporation target

The hard coating systems were deposited in a Balzers RCS coating machine in arc evaporation configuration. The cutting tool bodies were mounted on threefold rotating holders during the PVD deposition.

All the hard coating systems deposited on the cutting tool body had a total thickness between 2 and 2.5 µm, measured on the shank of the cutting tool.

Example 1

A first series of mono-layered hard coating systems was compared with state of the art monolayer system of TiAlN and AlCrN.

Table 1 displays the hard coating system investigated under this example. To apply each of the addressed monolayer hard coating systems the coating machine was equipped with four identical arc evaporation cathodes, also called targets. The respective compositions of these targets are also listed in table 1. The resulting composition of the coating material was within 10% of the target composition for the main elements Al, Cr, Ti and was within about 20% of the target composition for the element B and W, Mo and Ta.

Table 1

No.	Hard coating	Target composition
$1_{com.}$	TiAlN	Ti0.5Al0.5
2_{com}	TiAlN	Ti0.33Al0.67
$3_{com.}$	AlCrN	Al0.7Cr0.3
4	AlCrBWN	Al0.7Cr0.226B0.067W0.007
5	AlCrBMoN	Al0.7Cr0.21B0.07Mo0.02
6	AlCrBTaN	Al0.7Cr0.226B0.067Ta0.007

The performance of the hard coating systems was assessed in terms of wear resistance in a metal cutting operation. The amount of wear on the flank face, v_{bmax}, was measured as a function of the length of the cut. The cutting test was a milling test under finishing conditions in a hardened cold work tool steel. The cutting conditions were the following:

Cutting tool: 2-fluted ball nose end mill, 5 mm ball radius, micro grain carbide grade material

Workpiece: 1.2379 60 HRC

Spindle rotation speed: 7996 rev/min

Axial depth of cut: 0.4 mm

Radial depth of cut: 0.2 mm

Feed rate: 0.1 mm/tooth

Cutting speed: 98 m/min

Feed: 1600 mm/min

Coolant: air

Milling direction: down milling

Length of 1 pass: 43.8 m

End of tool life: v_{bmax} > 0.15 mm at the end of a pass

The results of the cutting test are listed in Table 2.

Table 2

No.	Cutting length (m)	Amount of wear v_{bmax} (mm)
$1_{com.}$	87.6	0.25
$2_{com.}$	87.6	0.17
$3_{com.}$	87.6	0.2
4	131.4	0.25
5	131.4	0.33
6	131.4	0.41

It can be seen that the incorporation of B and W, Mo and Ta in AlCrN results in an improved wear protection compared with the wear protection of AlCrN and TiAlN according to the comparative specimens 1 to 3.

Example 2

A series of double-layer hard coating systems was prepared. Table 3 lists the hard coating systems as investigated. The same tool bodies of the material as of Example 1 were coated. Thereby directly upon the surface of the tool body there was applied an interlayer IL_1 and directly upon such interlayer a layer of HL_1-type. The machine was equipped with two identical targets for the deposition of the interlayer and with four identical targets for the deposition of the outer layer of the HL_1-type. The respective target material compositions are also listed in table 3.

Table 3

No.	Hard coating		Target composition	
	Inter-layer	Outer layer	Interlayer	Outer layer
$7_{com.}$	TiAlN	AlCrN	Ti0.5Al0.5	Al0.7Cr0.3
8	TiAlN	AlCrBWN	Ti0.33Al0.67	Al0.7Cr0.226B0.067W0.007
9	TiAlN	AlCrBWN	Ti0.5Al0.5	Al0.7Cr0.226B0.067W0.007

The performance of the tools according to this second series was investigated with the same cutting test as was

applied to the example 1 tools. The results are listed in table 4.

Thereby, the interlayer IL_1 of specimen No. 9 shows a stochiometry which is well within the range of

$$0.4 \leq d \leq 0.6$$

$$0.4 < e \leq 0.6$$

of the $(Ti_dAl_e)N$ of the interlayer IL_1, whereas the interlayer as applied in example No. 8 is just outside the addressed stochiometry range.

Table 4

No.	Cutting length (m)	Amount of wear v_{bmax} (mm)
$7_{com.}$	87.6	0.4
8	267.8	0.18
9	438	0.15

When applying a IL_1 interlayer to the inventively provided HL-type layer especially tailored as HL_1-type layer with X = N, provision of such interlayer most significantly improves wear resistance and even more if the addressed stochiometry ranges for the aluminum and titanium compounds are fulfilled.

Example 3

A further series of workpieces, namely tools with a hard coating system according to the present invention consisting of two layers, was prepared, namely consisting of an interlayer TiAlN, IL_1 directly between a tool body as was already used in the examples 1 and 2 and a HL_1-type layer with X = N as already provided in specimens 8 and 9 of Table 3. Thereby, the temperature of a surface being coated was varied between 450°C and 600°C by varying heating time and/or power.

For the specimens 10, 11 and 12 as follow the same targets for the interlayer as well as for the outermost layer were used as specified for specimen No. 9.

Table 5 shows on one hand the addressed layers of the coating system and on the other hand the deposition temperatures.

Table 5

No.	Hard coating		Deposition temperature (°C)
	Interlayer	Outer layer	
10	TiAlN	AlCrBWN	450
11	TiAlN	AlCrBWN	550
12	TiAlN	AlCrBWN	600

The performance of the specimens was investigated with the same cutting conditions as Example 1. The results are listed in the following Table 6.

Table 6

No.	Cutting length (m)	Amount of wear v_{bmax} (mm)
10	223	0.55
11	350.4	0.5
12	438	0.15

The results show on one hand that specimen No. 12 which was coated identically to specimen No. 9 of example 2 exhibits equal wear resistance compared with the addressed specimen 9. Further, specimen 10 reveals that even at lower temperatures of 450°C the coating system according to the present invention is significantly superior to a comparable two-layer coating system coated at 600°C as of specimen No. 7.

Further, it is evident from comparing the specimens 10 to 12 that wear resistance significantly increases with increasing deposition temperature and achieves best performance, as of specimen No. 12, at a maximum deposition temperature of 600°C as investigated or more.

Example 4

A fourth series of double-layered hard coating systems with an interlayer IL_1 and a HL_1-type layer of the specific embodiment with X = N was prepared.

As comparison specimens prior art single layer systems of TiAlN and AlCrN were selected. The following Table 7 lists the respective coating material and the target composition.

Table 7

No.	Hard coating		Target composition	
13_{com}	TiAlN		Ti0.5Al0.5	
14_{com}	AlCrN		Al0.7Cr0.3	
	Inter-layer	Outer layer	Inter-layer	Outer layer
15	TiAlN	AlCrBWN	Ti0.5Al0.5	Al0.7Cr0.226B0.067W0.007

The performance of the resulting tools was assessed in terms of wear resistance in metal cutting application. The amount of wear on the flank face v_{bmax} was measured in function of the length of the cut. The cutting tests were performed under the conditions of semi-finishing milling operation in a heat treated tool steel. The cutting conditions were the following:

Cutting tool: 3-fluted end mill, 8 mm diameter, micro grain carbide grade

Workpiece: 1.2344 36 HRC

Spindle rotation speed: 4775 rev/min

Axial depth of cut: 10 mm

Radial depth of cut: 0.5 mm

Feed rate: 0.05 mm/tooth

Cutting speed: 120 m/min

Feed: 716 mm/min

Coolant: 6% mineral oil based emulsion, external cooling

Milling direction: down milling

Length of 1 pass: 10 m

End of tool life: v_{bmax} > 0.15 mm at the end of a pass

Table 8 reveals the cutting test results.

Table 8

No.	Cutting length (m)	Amount of wear v_{bmax} (mm)
$13_{com.}$	30	0.17
$14_{com.}$	80	0.17
15	100	0.18

Example 5

A series of tools with double-layer coating systems, namely consisting of an IL_1 interlayer and a HL_1-type layer with X

= N was prepared. They were compared with respective tools coated with state of the art double-layer coating systems, namely of TiN as interlayer and TiAlN as outermost layer or coated with AlCrN as interlayer and a TiSiN as outermost layer.

Table 9 shows the respective layer material and target material compositions.

Table 9

No.	Hard coating		Target composition	
	Multilayer			
16_{com}	TiN-TiAlN		Ti - Ti0.5Al0.5	
$17_{com.}$	AlCrN-TiSiN		Al0.7Cr0.3 - Ti0.85Si015	
	Double layer			
	Interlayer	Outer layer	Interlayer	Outer layer
18	TiAlN	AlCrBWN	Ti0.5Al0.5	Al0.7Cr0.226B0.067W0.007

The performance of the respectively coated tools was assessed in drilling operation on heat treated steel. The amount of wear on the flank face of the main cutting edge v_{bmax} was used to assess the wear protection quality. The test conditions were the following:

Cutting tool: 2-flute drill, 6.8 mm diameter, fine grain carbide grade

Workpiece:	1.7225, R_m = 1000 N/mm^2, annealed to a Brinell hardness of 240 HB
Spindle rotation speed:	4684 rev/min
Max. cutting speed:	100 m/min
Feed rate:	0.18 mm/rev
Feed:	843 mm/min
Hole depth:	34 mm
Coolant:	6% mineral oil based emulsion, external cooling
End of tool life:	v_{bmax} > 0.2 mm

The following table 10 displays the drilling results.

Table 10

No.	Number of holes	Amount of wear v_{bmax} (mm)
$16_{com.}$	2128	0.2
$17_{com.}$	2432	0.18
18	912	0.25

This example makes clear that the tools according to the present invention may not be the best choice for use in highly annealed steels and soft materials.

In the following examples No. 6 to 8 the hard coating systems were deposited again as was already addressed for the previous examples, but the total working pressure N_2 was reduced from 5.5 Pa to 3.5 Pa and the substrate bias voltage against ground was increased from -85 V to -100 V for the deposition of the AlCrBWN outermost layer according to HL_1 with X = N.

Example 6

A sixth series of tools was prepared to establish the effect of an AlCrN interlayer IL_2 instead of a TiAlN - interlayer IL_1.

The Table 11 shows the respective layer materials and the target compositions.

Table 11:

No.	Hard coating		Target composition	
	Double layer			
	Interlayer	Outer layer	Inter layer	Outer layer
19	TiAlN	AlCrBWN	Ti0.5Al0.5	Al0.7Cr0.226B0.067W0.007
20	AlCrN	AlCrBWN	Ti0.5Al0.5	Al0.7Cr0.226B0.067W0.007

Using tools coated as addressed, a cutting test with the following parameters was applied

Cutting tool:	2-fluted ball nose end mill, 5 mm ball radius, micro grain carbide grade material
Workpiece:	1.2379 60 HRC
Spindle rotation speed:	6370 rev/min
Axial depth of cut:	0.3 mm
Radial depth of cut:	0.5 mm
Feed rate:	0.15 mm/tooth
Cutting speed:	200 m/min
Feed:	1911 mm/min
Coolant:	air
Milling direction:	down milling
Length of 1 pass:	30 m
End of tool life:	v_{bmax} > 0.10 mm at the end of a pass

The results are shown in Table 12.

Table 12

No.	Cutting length (m)	Amount of wear v_{bmax} (mm)
19	270	0.11
20	240	0.12

From these results it may be seen that providing a IL_1 or a IL_2 interlayer leads substantially to the same good results.

Example 7

By the seventh series of specimens it was the aim to establish for the effect of a different B and W content at a HL_1-type layer with X = N. The following Table 13 lists the material of the interlayer as well as of the outer layer and the respective compositions of the target materials.

Table 13:

No.	Hard coating		Target composition	
	Double layer			
	Interlayer	Outer layer	Interlayer	Outer layer
$21_{com.}$	TiAlN	AlCrN	Ti0.5Al0.5	Al0.7Cr0.3
22	TiAlN	AlCrBWN	Ti0.5Al0.5	Al0.7Cr0.226B0.067W0.007
$23_{com.}$	TiAlN	AlCrWN	Ti0.5Al0.5	Al0.7Cr0.28W0.02

Using such tools, a cutting test with the same parameters as in example 6 was applied

The results are shown in Table 14

Table 14

No.	Cutting length (m)	Amount of wear v_{bmax} (mm)
$21_{com.}$	120	0.11
22	240	0.10
$23_{com.}$	150	0.11

Example 8

In the eighth series of specimens which were coated with a two-layer coating system as addressed in Table 15, prior to the cutting tests a brushing treatment was applied using a brushing machine according to the DE GM 20 2006 000 654.1 in order to adjust a state comparable to an initial homogeneous wear, which ensures afterwards a homogeneous progress of the wear during the cutting application.

The treatment of the coated tool was conducted with rotary brushes according to the addressed document. Fig. 2 and the respective description on page 5, last para., until page 6, end of the first para. of this German Utilty Model No. 20 2006 000 654.1 is specifically included and referred to by reference in the present description with respect to the addressed brushing technique. The brush angle was about 30° with reference to the tool axis, rotation speed selected to 650 turns/minute. Brushing material was SiC impregnated Nylon, SiC grain size 400 mesh, diameter of bristles 0.45mm, length of bristles 35mm. Rotation of the tool satellite was 9 turns/min, rotation of the table supporting the satellites was about 0.3 turns/min. A similar effect to dissect a few micrometers' stripe of the workpiece material along the cutting edge could have been achieved by using Al_2O_3 impregnated brushes. Nevertheless, for this latter brushing, time has to be tripled if the same parameters as mentioned above are used. This may be realized e.g. by rotation of the supporting table by 0.1 turns/min.

Alternatively or even additionally a similar honing treatment by brush, blast, grinding operations or the like can be applied before the coating process as a pretreatment.

With the tool coated according to Table 15

Table 15

No.	Hard coating		Target composition	
	Double layer			
	Interlayer	Outer layer	Interlayer	Outer layer
24	TiAlN	AlCrBWN	Ti0.5Al0.5	Al0.7Cr0.226B0.067W0.007

cutting tests were performed with the following cutting parameters:

Cutting tool: 2-fluted ball nose end mill, 5 mm ball radius, micro grain carbide grade material

Workpiece: 1.2379 62 HRC

Spindle rotation speed: 6000 rev/min

Axial depth of cut: 0.4 mm

Radial depth of cut: 0.05 mm

Feed rate: 0.10 mm/tooth

Cutting speed: 184 m/min

Feed: 600 mm/min

Coolant: air

Milling direction: down milling technique for pockets (56 mm x 26 mm)

Length of single pass: 1 pocket

End of toollife: v_{bmax} > 0.10 mm at the end of a pocket

Table 16

No.	Brushing treatment (yes/no)	Number of pockets (N)
24a	No	4
24b	Yes	10

From the examples as shown above it becomes clear that tools wherein the hard coating systems comprise the HL_0 layer in the specific form of HL_1 with X = N as in a single layer system or, and especially in connection with the addressed IL_1 and/or IL_2 interlayer, provide for an astonishing increase of wear resistance compared with state of the art coating systems e.g. with outermost TiAlN or AlCrN coating systems.

Despite the fact that the addressed HL_1 with X = N coating is applied through all the examples as the outermost layer of the coating system, it is evident to the skilled artisan that for some applications additional layers may be provided upon the addressed layer as e.g. a lubricating layer.

Further, throughout the examples the addressed HL_1 layer is, considered towards the tool body, applied either directly on the tool body or separate there from by a IL_1 or IL_2 interlayer.

Nevertheless, for some applications it is evident to the skilled artisan that such multilayer systems with the inventively proposed HL-type and IL-type layers may be conceived in a huge variety depending upon the specific needs.

Moreover, the above examples have been conducted specifically on the HL_1 layers, wherein X = N. Nevertheless, it is perfectly clear to the skilled artisan that replacing N by C, CN, NO, CO or CNO will lead to layers HL_1 with similar wear resistance qualities.

The same is valid if in the HL_1 type layer the element W is replaced by Mo, Ta, Cb (Nb).

Still further, the tools whereupon the examples have been performed have a tool body of tungsten carbide.

Nevertheless, with respect to the material of the tool body or more generic workpiece body, it is perfectly clear to the skilled artisan that the targeted increase of wear resistance by the coating system according to the present invention will also be achieved on workpiece bodies of high speed steel, cemented carbide or cubic boron nitride or of a cermet or of a ceramic material. The addressed improvement of wear resistance may be highly desirable not only for tools like cutting tools such as for end mills, drills, cutting inserts, gear cutting tools but also for other workpieces than tools.

By the method of manufacturing a device which is at least in part of a hard material, thereby especially with a hardness of at least HRC 52, comprising a cutting process of the addressed hard material using the cutting tool according to the present invention, device manufacturing becomes faster, thus throughput higher and manufacturing costs are lowered.

In fig. 6 there is shown a SEM cross-section of a AlCrN coating. This accords with a scanning electron micrograph (SEM) of a cross-section of the single layer hard coating system according to specimen 3 of example No. 1. The hard coating exhibits a very fine columnar growth structure with columns having a width in the order of 200 nm.

Fig. 7 shows such scanning electron micrograph of a cross-section of the AlCrBWN single layer hard coating system according to specimen No. 4 of example 1. This hard coating exhibits no columnar growth structure. The strong re-nucleation process during deposition leads to a nanocrystalline coating structure which appears glassy like in the SEM cross-section under a magnification of 25'000.

Fig. 8 shows a scanning electron micrograph (SEM) of a cross section of a TiAlN/AlCrBWN double-layer hard coating system according to specimen 9 of Example 2. The IL_1 interlayer exhibits a columnar growth structure, with columns having a width in the order of 400 nm.

The type HL_1 outer layer exhibits the same glassy-like growth structure as specimen No. 4 of Example 1 (see Fig. 7). The columnar growth structure is clearly interrupted at the interface between the interlayer and the outer layer.

Fig. 9 shows XRD spectra of an AlCrN single-layer hard coating system according to specimen No. 3 of Example No. 1 and of an AlCrBWN type HL_1 single-layer hard coating system according to specimen number 4 of Example 1. The spectra were recorded with a Bruker AXS equipment, using a $Cu_{K\alpha}$ incident beam (λ = a 1.5406nm) and a glancing incidence angle of 2° which delivers an appreciable quality for the spectra of nano-crystalline coatings. This configuration allows to measure even thin films without disturbing influence by the substrate and/or by an interlayer. The XRD spectrum of AlCrN exhibits peaks at around 37.5°, 43.7° and 63.7°, which are assigned to the <111>, <200> and <220> planes of an fcc-(face centered cubic)AlCrN crystal structure.

As expected for an $Al_xCr_{1-x}N$ hard coating having an $x \leq 0.7$, there is no hexagonal AlN phase in such hard coating. The AlCrBWN hard coating exhibits diffraction peaks which are assigned to the <111>, <200> and <220> planes of AlCrN as well. However Al_xCrBWN hard coatings, having the same x of 0.7, show a remarkable contribution of hcp-(hexagonal closed packed) AlN. Peaks at around 33.1°, 49.5° and 58.9° point out signals attributed to that phase. Peaks at around 31.5°, 35.7°, 48.3°, 64.1° and 65.9° derive from the WC-Co body of the carbide substrate.

Fig.10 shows XRD spectra of AlCrBWN coatings comprising a TiAlN inter

Measurement was performed using the setup as was described in context with Figure 9. The upper spectrum refers to AlCrBWN coatings deposited under the deposition conditions of example 6 to 8. Lowering the substrate bias from -100 to

-85 V against ground potential as shown in the lower spectrum of Fig 10 gives a remarkable change with respect to the Q value, however obviously induces a peak broadening. The latter can be referred to a further grain refinement.

Claims:

1. A workpiece having a body and a wear resistant hard coating system on at least a part of the surface of said body, said system comprising at least one layer of the following composition

$(Al_{1-a-b-c}\ Cr_a\ B_b\ Z_c)X$ where

X is at least one of: N, C, CN, NO, CO, CNO;

Z is at least one of: W, Mo, Ta, Cb (Nb);

wherein there is valid

$0.2 \leq a \leq 0.5;$

$0.01 \leq b \leq 0.2;$

$0.001 \leq c \leq 0.04.$

2. The workpiece of claim 1, wherein said layer system comprises at least one layer of the following composition:

$(Al_{1-a-b-c}\ Cr_a\ B_b\ W_c)X$

wherein there is valid

$0.01 \leq b \leq 0.1;$

$0.001 \leq c \leq 0.01.$

3. The workpiece of one of claims 1 or 2, wherein said at least one layer is the outermost layer of said system.

4. The workpiece of one of claims 1 to 3, wherein said at least one layer resides directly on said surface.

5. The workpiece of one of claims 1 to 4, wherein said system comprises at least one interlayer of $(Ti_dAl_e)N$.

6. The workpiece of claim 5, wherein said interlayer is interposed between said surface and said at least one layer.

7. The workpiece of one of claims 5 or 6, wherein said interlayer resides directly on at least one of said surface and of said at least one layer.

8. The workpiece of one of claims 5 to 7, wherein there is valid:

$$0.4 \leq d \leq 0.6 \text{ and}$$

$$0.4 \leq e \leq 0.6.$$

9. The workpiece of one of claims 1 to 8, wherein said system comprises at least one interlayer of $(Al_fCr_g)N$.

10. The workpiece of claim 9, wherein said interlayer is interposed between said surface and said at least one layer.

11. The workpiece of one of claims 9 or 10, wherein said interlayer resides directly on at least one of said surface and of said at least one layer.

12. The workpiece of one of claims 9 to 11, wherein there is valid

$$0.4 \leq f \leq 0.7 \text{ and}$$

$0.3 \leq g \leq 0.6$.

13. The workpiece of one of claims 1 to 12, wherein said at least one layer exhibits a glassy like growth structure in the SEM cross-section.

14. The workpiece of one of claims 1 to 13, wherein said at least one layer comprises hexagonal AlN.

15. The workpiece of one of claims 1 to 14, wherein said at least one layer has a texture coefficient Q = I(200)/I(111) in the range of $0.1 \leq Q \leq 1$.

16. The workpiece according to one of the claims 5 to 15, wherein said TiAlN or AlCrN interlayer respectively exhibits a columnar growth structure.

17. The workpiece of one of claims 1 to 16, wherein said system comprises a multilayer of alternating layer of at least one of $(Ti_dAl_e)N$ and of $(Al_fCr_g)N$ and of said at least one layer, preferably of $(Al_{1-a-b}\,Cr_a\,B_b\,W_c)X$.

18. The workpiece of one of claims 1 to 17, said body being of one of high-speed steel, hardened steel, cemented carbide and of cubic boron nitride.

19. The workpiece of one of the claims 1 to 18, said body being of one of a cermet and of a ceramic material.

20. The workpiece of one of claims 18 or 19, being a cutting tool.

21. The workpiece of claim 20 being one of an end mill, a drill, a cutting insert, a gear cutting tool.

22. A process for manufacturing a workpiece according to one of the claims 1 to 21, comprising:

a. providing said workpiece body in a plasma coating vacuum chamber

b. applying said system to said body by a physical vapor deposition process during a processing time

c. establishing a temperature of at least 550°C to the surface of the coated body during at least a predominant part of said processing time.

23. The process of claim 22, comprising selecting said temperature to be at least 600°C.

24. A method of manufacturing a device at least in part of a hard material comprising a cutting process of said hard material using the cutting tool of claim 20.

25. The method of claim 24, said hard material having a Rockwell hardness of at least HRC 52.

26. The method of claim 24 or 25, wherein the hard material is hardened steel.