CVD COATING OF CERAMIC LAYERS ON CERAMIC CUTTING TOOL MATERIALS

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Abstract- When forming cutting tool materials based on ceramic components , one must take into considration the combination of wear resistance and mechanical properties which can withstand unfavorable cutting conditions at the same time maintaining high strength and fracture toughness.

Ceramic cutting tools which are designed for machining at high cutting speeds and which have high strength and fracture toughness can be formed by applying a thin layer of ceramic materials on the substrate in order to increase tool life.

The good adhesion of the C.V.D. layer and the good mechanical properties of the combined coating cutting tools enable the same increase in efficiency by cemented carbide coated cutting tools. In this paper we show results for the mechanical properties , the machining results and metallographic microstructures for C.V.D coatings of aluminum oxide on different ceramic materials such as Si_3N_4 base materials and Al_2O_3 base material.

1. INTRODUCTION.

In order to achieve an increase of tool life for cutting tools based on cemented carbide thin layers are applied by C.V.D. processes, typical materials are TiC , TiN , TiCN and Al_2O_3. This is usually done by applying individual layers ir a combination of the above mentioned materials in varying sequences ([3]).

The advantages of coated cutting tool material are based on resistance to diffusion wear , adhesive wear , and abrasive wear ([2]).

Also the coating behaves like a thermal barrier to protect the cutting edge from plastic deformation , since the low heat conductivity ([4]) protects the tool. In this case we can increase the cutting speed without causing mechanical failure of the substrate. Normally coated cutting tools can run at twice the speed of that used for cutting tools without a coating. A speed limit is still reached , at which a catastrophic failure to the cemented carbide cutting tool material occurs. This cutting speed limiting value is 350m/mm([6]). Above this cutting speed the temperature is too high and causes immediate damage to the substrate before any wear mechanisms start to take part.

A coating applied to a ceramic material , which can already machine at very high cutting speeds ([5]) show the same phenomena that causes the substrate to fail from plastic deformation ([1]). This is the first time performance of coated cutting tools at high cutting speeds, even for cutting speeds in the range of 1000 m/min, can be evaluated.

In regard to ceramic cutting tools we deal with two groups of machined material ;

1 - Cast iron that can be machined with ceramic materials e.g. ; Al_2O_3 , Al_2O_3 + AlN and especially with Si_3N_4 ceramic materials.

2 - Steels can be machined , with ceramic materials e.g. ; Al_2O_3 , Al_2O_3 + TiC or Al_2O_3 + TiN , or Al_2O_3 + TiCN.

For machining steel it is not possible to use a cutting tool material based on Si_3N_4. Since a reaction that occurs within several seconds takes place between the steel and silicon which creates a catastrophic failure with high wear.

Any coating has to allow the interaction tool material and work piece material, which gives the lowest wear. For the best choice of materials we take the best wear resistant materials and apply them as thin layers on tough ceramic materials for an improvement in tool life or, to the utmost efficiency, to increase cutting speed.

2. EXPERIMENTAL PROCEDURE

Standard turning cutting inserts prepared from different ceramic cutting material were coated with the C.V.D. process with one single layer of Aluminum oxide.
The bonding between the coating and substrate was investigated by using a scanning electron microscope (S.E.M.). The crystalographic structure was checked by X.R.D. The machining tests were done by turning steel and cast iron.

2.1. SUBSTRATE

Table 1 : Composition and properties of Ceramic Substrate

	Si_3N_4	Y_2O_3	Al_2O_3	TiCN	Hardness	TRS	KiC
Grade					HV 10	N/mm2	MPa m $^1/_2$
Grade H	91	8	1	---	1600	800	5.8
Grade C	90	6	4	---	1650	710	5.1
Grade A	--	--	70	30	1800	630	4.6

Grade H Hot Press

Grade C Cold Press and pressure sintering

Grade A Hot Press

2.2. PROCESS OF C.V.D. COATING

Coating was carried out in a hot wall reactor, volume of $0.07m^3$ at a coating temperature 1020 °C and a Pressure of 60 Torr and a pressure of 60 Torr.

Gas concentrations used were ; H_2 - 90 %, CO_2 - 7.6% , $AlCl_3$ - 2.4%
A total gas flow of 15 liters per minutes was used.
A coating time of 10 hours gave a coating thickness of 9mμ of Al_2O_3.

2.3. PREPARING THE INSERTS

The insert was ground to standard size SNGN 433 (12.04.12) , the corners were chamferred to the size of 0.2 mm 20°. The insert was used in the turning process , and was inclined at the following angles:
a = 6° b = 90° g = -6° k = 75°

2.4. TURNING TEST

The test was carried out on Max Miller lathe 45 kilowatts with a consistent variable speed , and the test was carried out on turning diameters in the range of 190 - 240 mm.

2.4.1. Machined material : perlitic feritic cast iron GG KFP

Table 2 : Composition of the Cast Iron

Hardness : 205 ± 5 BhN

C	Si	Mn	P	S	Fe
3.21	2.63	0.7	0.2	0.081	rest

2.4.2 . Machined Material Steel AiSi 1045

Table 3 : Composition of the Steel

Hardness 190+ 5 BHN

C	Si	Mn	P	S	Fe
0.45	0.24	0.75	0.015	0.042	rest

3. CRYSTALLOGRAPHIC STRUCTURE

X.R.D. examination showed that all coating was composed of a $Al_2 0_3$.

4. METALLOGRAPHIC MICROSTUCTURE

Fig. 1 : Grade H + CVD Al_2O_3 Layer

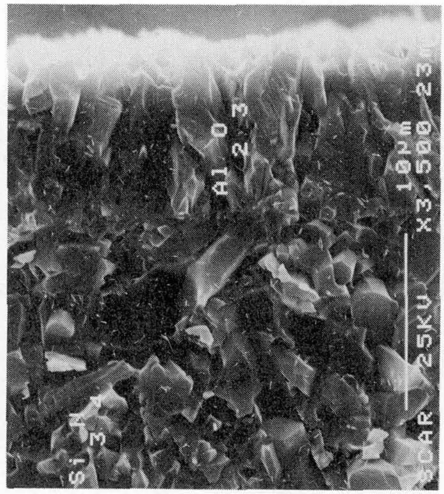

Fig. 2 : Grade C + CVD Al_2O_3 Layer

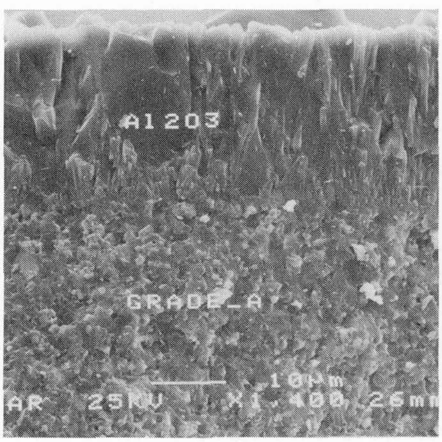

Fig. 3 : Grade A + CVD Al_2O_3 Layer

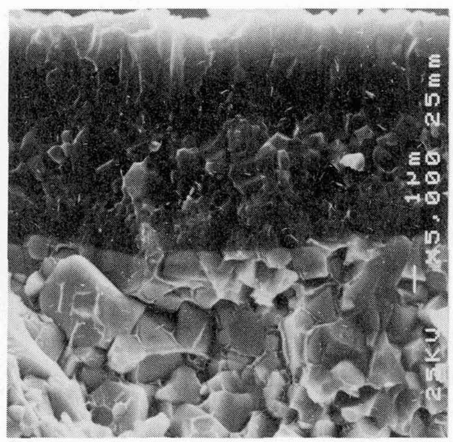

Fig. 4 : ISO M15 + CVD TiC + Al_2O_3 Layer

5. MACHINING TEST RESULTS

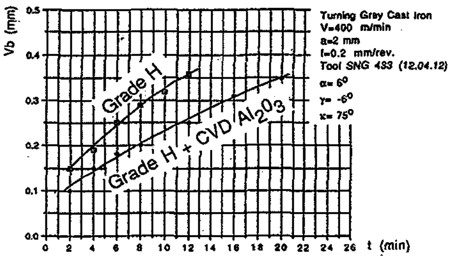

FIG. 5 : Turning Cast Iron 400m/min
Grade H Coated and Uncoated

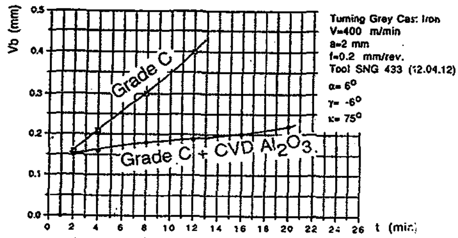

Fig. 6 : Turning Cast Iron 400m/min
Grade C Coated and Uncoated

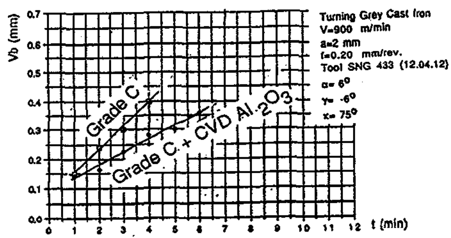

Fig. 7 : Turning Cast Iron 900m/min
Grade C Coated and Uncoated

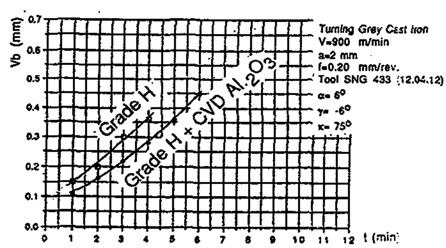

Fig 8 : Turning Cast Iron 900m/min
Grade H coated and Uncoated

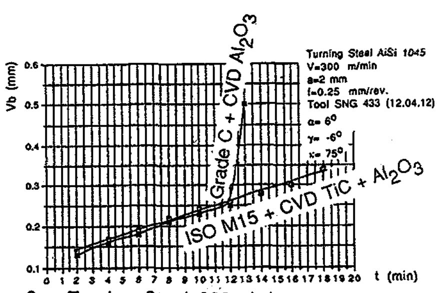

Fig. 9 : Turning Steel 300m/min
Grade A Coated Compared
To Cemented Carbide ISO M15
Coated with TiC + Al_2O_3

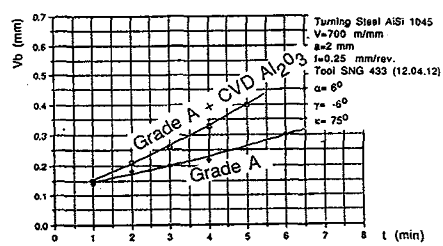

Fig.10 : Turning Steel 700m/min
Grade A Coated and Uncoated

6. DISCUSSION OF RESULTS

6.1. TURNING CAST IRON at 400m/min

Looking at the flank wear measurement we can see, primarily that the coated silicon nitride substrate together with Al_2O_3 CVD layer have a better tool life than the uncoated substrate. Grade C coated shows significantly better wear properties than grade H coated ,and even the uncoated substrate grade H is better than grade C as far as wear properties are concerned.

6.2. TURNING CAST IRON AT 900m/min

When machining at high cutting speeds , temperatures are very high and the chips leaving the shearing zone are very close to melting temperatures. It would seem therefore that there are not any advantages with a coating , since one would not expect any coating could withstand this high cutting speed. However the results show that the coated cutting tools are significantly better than the uncoated. We can see the same phenomena that occurs with the coated cutting tools at low speeds which again prove to be better than the uncoated, and here also grade C coated is better than grade H coated . For example , after 6 minutes the grade C coated flank wear was Vb=0.36mm while the grade H coated showed Vb=0.45 mm. Here again the uncoated grade H behaved slighty better than the grade C uncoated.

6.3 TURNING STEEL WITH MATERIAL BASED ON SILICONE NITRIDE

Normally in machining steel with Silicon nitride cutting tools , at any speed, or in this case at 300 m/min., tool life is below 15 seconds and one has catastrophic wear phenomena, as mentioned in the introduction.
When we apply Al_2O_3 to the silicon nitride we can attain a tool life of 12 minutes. Later on when the steel starts to partly adhere to the substrate we then have an immediate catastrophic failure which happens after 13 minutes.

To compare the results we made machining tests with cemented carbide coated on ISOM15 ,a substrate coated with TiC 5µm and Al_2O_3 3µm . These inserts, according to Fig. 5, have a similar rate of wear but can withstand more than 13 minutes thus having a longer tool life . However the essential idea of this test was to show that Al_2O_3 was a very good wear barrier that eliminated any reaction between silicon nitride and steel, thus enabling them to withstand a high speed for 12 minutes.

6.4 MACHINING STEEL AT 700m/min

Grade A coated does not show any advantages in this case to grade A uncoated, but we found that the uncoated Al_2O_3 + TiCN substrate have a better tool life than the coated Al_2O_3 cutting tools. We can say that it was poorly coated thus being the reason it could not withstand this cutting speed , but when we look more deeply at an explanation for this high wear we find it is related to the composition of cutting tools. In wear properties of machining steels , Al_2O_3 coated cutting tools behave like solid Al_2O_3 or Al_2O_3 + ZrO_2 cutting tool materials. Normally Al_2O_3 + TiCN cutting tool materials have better tool life than cutting tool material composed of oxide only and for this reason the grade A uncoated shows better results than the coating Al_2O_3 on grade A substrate.

7. SUMMARY

We have found we can build a thin layer with a CVD process of ceramic material , on ceramic based tool materials. The coating is perfect and continuous , as shown by the system by the success in machining steel with coated silicon nitride material. Applying Al_2O_3 on silicon nitride based material for machining cast iron can help to increase the tool life of cutting tool materials. We can apply Al_2O_3 CVD coatings to Si_3N_4 substrates which are not the best wear resistant material and they can be produced with a low priced technology such as cold pressing and sintering instead of hot pressing . The coated cutting tools introduced in this way have better properties than the expensive coated hot pressed substrates.

Cutting Tools coated with Al_2O_3 CVD can machine cast iron successfully with an economic tool life at a speed of 900 m/min. Coated Al_2O_3 on Ceramic materials, which are composed especially for machining steel , will not improve tool life since it behaves like pure solid aluminum oxide cutting tools. No advantage is evident in wear properties of new cutting tools based on alumina , with derivatives of titanium materials.

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