EVALUATION OF THE PERFORMANCE OF COATED HSS DRILLS IN MACHINING OF Al-Si ALLOY

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***Abstract**. Coatings are used in cutting tools to provide improved lubrication at the tool-chip and tool-workpiece interfaces, reduce friction and consequently lower temperatures at the cutting edge, hence increasing tool life and machining productivity. This paper evaluates the performance of four different coatings (TiN/TiCN, TiAlN, TiN/TiAlN and TiN/TiAlN/WCC) of HSS twist drills in machining of an ISO 3522 aluminum-silicon (Al-Si8Cu3Fe) alloy, which is widely employed in the automotive industry. The machining parameters employed are: cutting speed of 43 m/min and feed rate and 0.12 mm/rev. All the tests were carried out with coolant. Tool life (expressed in number of machined holes) and thrust force were the output parameters used to assess the performance of cutting tools. Comparative trials were also carried out with uncoated HSS drills. The results showed that the coated tools exhibited better performance in terms of tool life, than the uncoated tools. The ranking order for coated tools in terms of performance is as follows: TiN/TiC, TiN/TiAlN/WCC, TiAlN and TiN/TiAlN. The results also show that thrust force varied only within a narrow range for all the cutting tools investigated.*

***Keywords:** coatings, drilling, aluminum-silicon alloy, tool life, thrust forces*

1. Introduction

Since the introduction of hard coatings in the late 1960s, many improvements have been developed in coatings, especially for applications in manufacturing operations such as in die and injection molds and in metal cutting operations (cutting tools). Additionally, the combinations of coatings have been developed in order to provide qualities, covering a wide application field. The success of coatings on cutting tool substrates results from a combination of the coating's physical and mechanical properties. Coatings are used in cutting tools to provide improved lubrication at the tool-chip and tool-workpiece interfaces, reduce friction and consequently lower temperatures at the cutting edge (Prengel *et al.*, 1998). Coatings for cutting tools' applications generally provide an exceptional combination of properties such as chemical stability, higher hardness even in high temperatures, higher wear resistance and lower friction coefficient which lead to increases in tool life and consequently reduction in the production costs and increasing in machining productivity. According to Cselle and Barimani (1995) over 40% of all today's commercially available cutting tools are coated. A wide variety of coatings with single or multiple layer combinations are available for cutting tools (Grzesik, 1999).

The performance of coatings for cutting tools has been studied worldwide with application in various machining processes such as drilling by Santos (2002) and Chen and Liao (2003), turning by Jindal *et al*. (1999) and Prengel *et al*. (2001), milling by Dolinsek *et al*. (2001) and Holzschuh, 2002), reaming by Kerkhofs *et al.* (1994) and threading by Reis (2004).

It has been reported that coatings employed in twist drills allowed increase in productivity by increasing both cutting speeds and feed rates (Rauscher, 1990). Coatings was also found to have a significant effect in determining the final hole size, producing holes with tighter tolerances than uncoated HSS drills (Kalidas *et al*., 2001).

TiN coating grade is widely employed in machining processes because it provides good physical, chemical and mechanics properties. Recent developments in coating technology for cutting tools (third generation of coatings) have provided coatings capable to cut materials where TiN coatings generally can not. TiAlN is an example because it can be employed in tools to work at High Speed Machining (HSM) as well as in dry machining. Other coatings of this generation contain Titanium Carbonitride (TiCN) and/or Titanium Aluminum Nitride (TiAlN).

Beyond those hard coatings, there is a tendency in shop floors of the solid lubricating calls, such as Carbon Tungsten Carbide (WCC), Molybdenum Bisulphate (MoS_2) and Diamond Like Carbon (DLC) because they possess low hardness and offer low friction coefficient against most work materials. It can be categorically affirmed that these new coatings technologies are especially suitable for highly aggressive machining conditions.

Aluminum-silicon, Al-Si8Cu3Fe, alloy is typically employed in the production of automotives components such as headstocks of engine motors, admission collectors and gearboxes. Uncoated HSS twist drills are the tool materials generally employed in drilling of this alloy. These tool materials generally exhibit high wear rates when machining such aluminum alloys because of the high silicon concentration in their composition. The literature offers few studies of machining of aluminum-silicon alloys, therefore, this work aims to evaluate the performance of different PVD coatings, TiN/TiCN-multilayers, TiAlN-monolayer, TiN/TiAlN-doublelayer and TiN/TiAlN/WCC-triplelayer, deposited on high-speed steel twist drills when machining aluminum-silicon, Al-Si8Cu3Fe, alloy. Tool life (expressed in number of machined holes) and thrust force were the output parameters used to assess the performance of the cutting tools.

2. Experimental Procedure

2.1. Tool life tests

Drilling tests were carried out on a transfer line of serial production of FIAT-GM Powertrain Company. Continuous sequences of holes were machined until the drills reached the end of their lives. Tool rejection criterion adopted was the quality of the machining holes, using for that a hole caliper. The workpiece material was gearboxes support of aluminum-silicon alloy ISO 3522 Al-Si8Cu3Fe. Three holes were simultaneously machined, identified within the square in black in Figure 1, with three tools, allowing, thereby, three tests to be carried out at the same time. Four different PVD coated (TiN/TiCN-multilayers, TiAlN-monolayer, TiN/TiAlN-doublelayer, TiN/TiAlN/WCC-triplelayer) and uncoated HSS twist drills with 8.7 mm of diameter with were used. All the tools are M-2 grade. The depth of the holes was 33 mm.

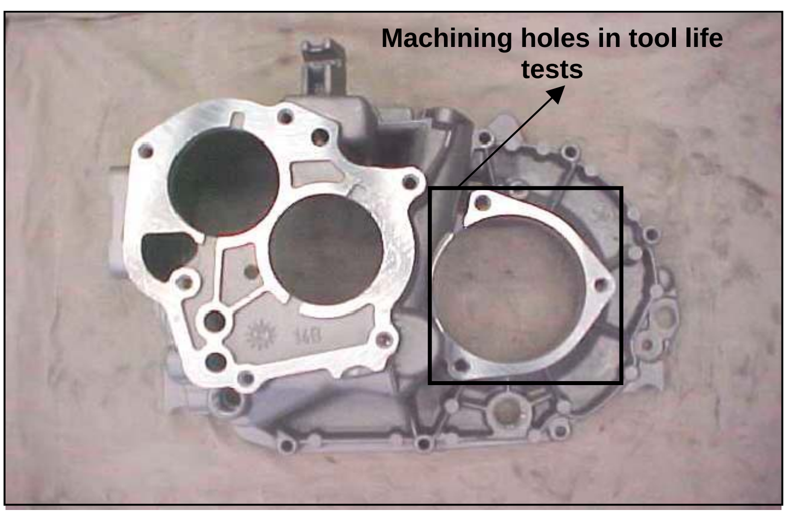

Figure 1. Gearbox support and the three holes machined in each workpiece for the tool life tests

The cutting conditions used were as follows: cutting speed of 43 m/min, feed velocity of 187.5 mm/min (0.12 mm/rev), and with coolant.

During the experiments and at the end of tool lives, optical microscope (OM) and scanning electronics microscope (SEM) were used to inspect tool wear conditions.

2.2. Thrust force tests

Specific thrust force tests were designed to evaluate the tools' performance in laboratory environment. Measurements were done with the new tools and after machining 1000, 2000, 3000, 4000 holes and at the end of the drills lives. A Kistler dynamometer, model 9265 was used together with a NI-DAQ PCI-6035E data acquisition board and a computer with LabView 7.0 software. All the experiments were carried out on the same work material used in the tool life tests, but in bars with dimensions of 250x100x40 mm^3 mounted onto the dynamometer fixed onto the machine tool table, ROMI BRIDGEPORT (Discovery 760), Figure 2. The data acquisition rate was 1000 Hz during a machining time of 10 seconds. The tests were repeated twice for each tool, using three tools, thus resulting in 9 tests for each tool material. The average value of the thrust force derived from these tests was then considered. The cutting conditions used were: cutting speed of 43 m/min, feed velocity of 187.5 mm/min, hole length of 20 mm and using cutting fluid.

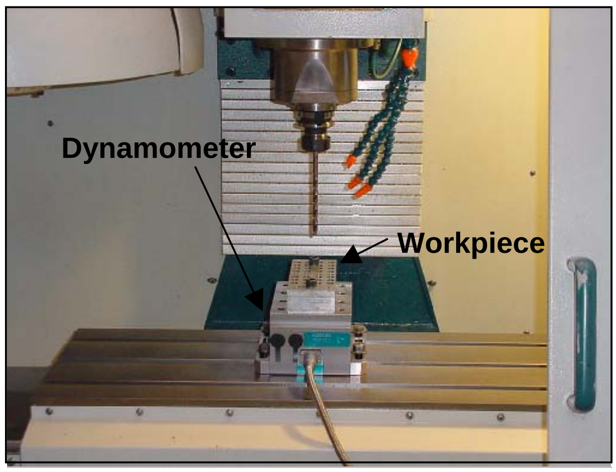

Figura 2. View of the equipment ready to perform a thrust force test

3. Experimental Results and Discussion

3.1. Tool life tests

Figure 3 shows the number of drilled holes for all tools used. Coated tools outperformed uncoated ones. The TiN/TiCN-multilayers showed the best result, increasing the productivity in 252 % in comparison the uncoated drills (28,733 holes against 8,152 holes). These results should be taken for grant only for the cutting conditions used as the effect of coatings on machining, particularly when TiAlN coatings are involved, has shown to be very dependant on the cutting conditions (Paldey and Deevi, 2003; Prengel *et al.,* 2001).

The chemical composition of the aluminum-silicon alloy shows characteristics of an abrasive material due to the precipitation of Si plates on the aluminum matrix, therefore the choice of coatings with high hardness is the right one since a more wear resistance will give longer tool lives. Besides their hardness, the structure and architecture of the coatings are also important parameters to be taken in consideration, according to Nordin *et al.*(1999).

The multilayer structure and architecture of the TiN/TiCN coating showed to be the most efficient in this aggressive application. The deposition of multilayer structures, of variable thickness and chemical composition can be design to tackle the adversities encountered in each application. Usually, it's possible to obtain for these coatings superior hardness and wear resistance than for individual monolayers. The deposition of multilayers is applied to enhance adhesion between the coating and the substrate and to obtain coatings of low chemical reactivity, low friction coefficient, high hardness and high wear resistance (Tschiptschin, 2004).

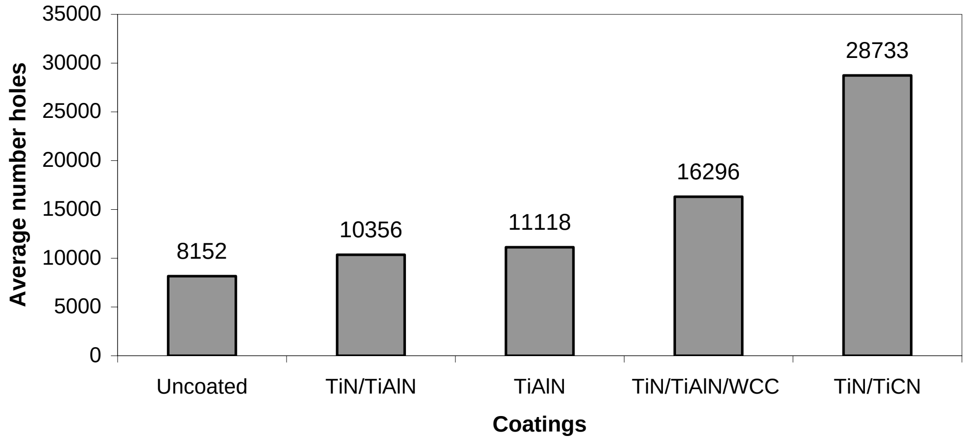

Figure 3.Tool life results for all tools used in the tests

The excellent properties of the multilayer coatings have been explained (Tschiptschin, 2004) by the differences of the modulus of elasticity of the two materials at the layer's interfaces, by the effects of tensions and elastic deformations due to the misalignment of the crystalline reticulates and by the restriction of dislocation movement interposed by the interfaces.

The best performance of TiN/TiCN-multilayers is therefore a summing up of the good characteristics of each individual layer. The characteristics of TiN has already been exhaustively discussed in several works (Bartsch *et al.*, 1997; Hedenqvist *et al.*, 1990). The perfect balance of their properties (hardness, low friction coefficient, low chemical reactivity) guarantees status of a universal coating for several applications. TiCN presents a compact and homogeneous structure, offering a good balance between the hardness and toughness properties, acting as a shock absorber preventing crack propagation until the substrate.

Figures 4 and 5 show the wear pattern of TiN/TiAlN and TiN/TiAlN/WCC tools, respectively. The process of coating deposition might have influenced the performance of these tools. The detachment of the TiAlN (black) layer from the surface, exposing the TiN (gold) layer is clear from these figures. Although better than the substrate, the TiN has less wear resistance than TiAlN layer, particularly when abrasion is involved. The loss of the resistant layer thus compromises the lives the TiN/TiAlN and TiN/TiAlN/WCC tools, what makes the TiN/TiCN tools to outperform them.

Analysis of the worn areas of the TiAlN-monolayer coated drills has shown that coatings were chipped out, exposing the substrate more rapidly to the action of the abrasive wear.

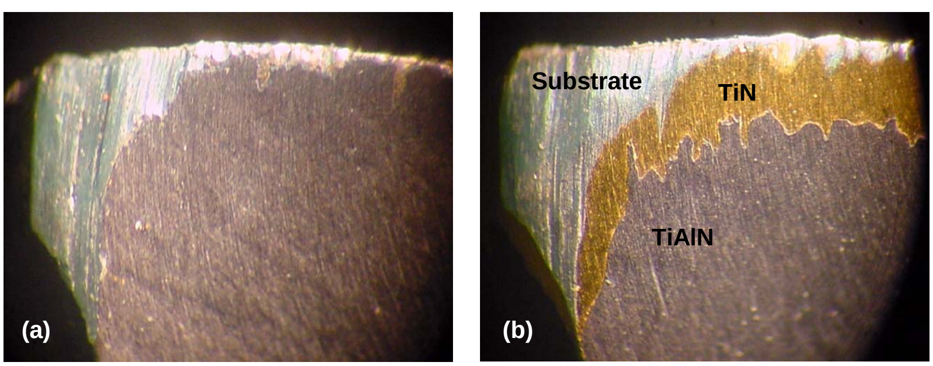

Figure 4. Optical microscope aspect of the cutting edges (a) and (b) of a TiN/TiAlN coated drill after 4000 holes machined (40x magnification)

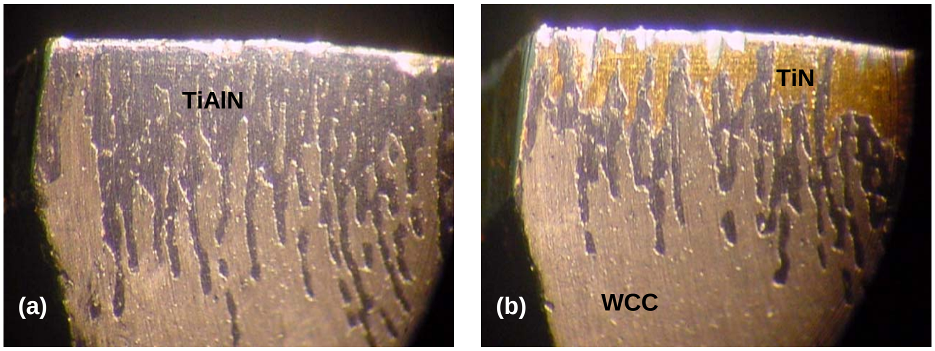

Figure 5. Optical microscope aspect of the cutting edges (a) and (b) of a TiN/TiAlN/WCC coated drill after 4000 holes machined (40x magnification)

The aspect of the wear land of the tools are close related to abrasion mechanism and probably accompanied by attrition. They are strongly influenced by adhesion of the workpiece material onto the tool surfaces. The relative low cutting speeds, the presence of hard silicon particles and also the detachment of the coating layers from the tools are important facts that encourage these two wear mechanisms. The rough pattern of the worn area of the tools with the presence of ridges, characteristic of attrition and abrasion respectively, are clear evidences them.

Figure 6 shows the aspect of the wear on the margin of one of the wedges of a TiAlN coated drill. A large wear area is observed full of ridges, running perpendicular to the secondary cutting edge and parallel to the flow of the work material which are strong evidences of abrasion.

Scattered micro chippings can also be observed at the margin of TiN/TiAlN/WCC and TiN/TiCN coated drills (Figures 5 and 7, respectively). At the latter though, the wear land is smaller, with the coating being preserved closer to the secondary cutting edge. This means that the TiN/TiCN coating is more wear resistant, giving longer tool lives.

Since pronounced wear dwells at the margin a reduction on the drill's diameter is unavoidable and this threatens the tolerances of the holes machined, demanding attention of those responsible for the quality control at the production line.

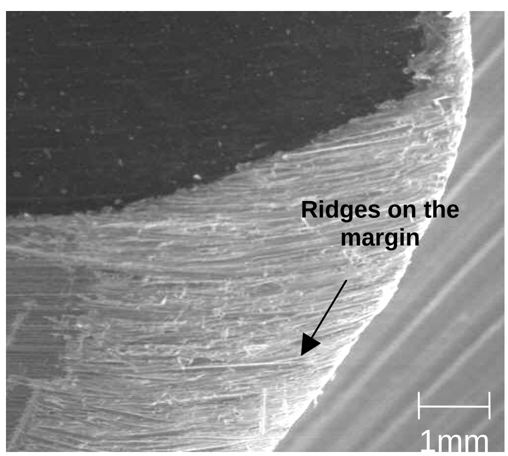

Figure 6. Aspect of the wear on the margin of a TiAlN coated drill at the end of its life

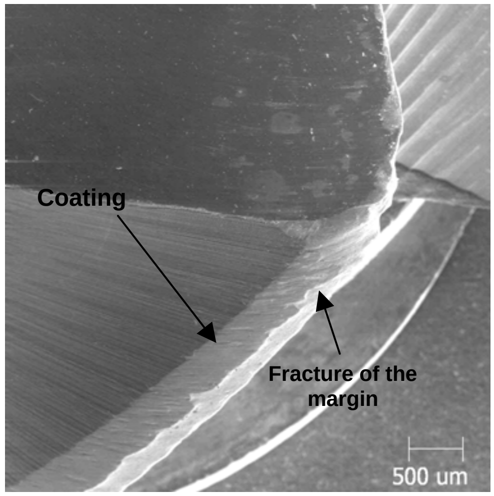

Figure 7. Aspect of the wear on the margin of a TiN/TiCN coated drills at the end of its life

For the tool life results obtained in this work it is important to point out that the high hardness and strong adherence onto the substrate made the TiN/TiCN multilayer coated tools to have this excellent performance when drilling this aluminum alloy.

3.1.2. Thrust force tests

Figure 8 shows the results of thrust forces for all tools tested. At a first glance the coatings are not efficient enough to reduce drilling forces and for the TiN/TiCN the forces are even higher than the uncoated drill. Exception of this is the TiAlN coating that showed the lowest thrust force among all.

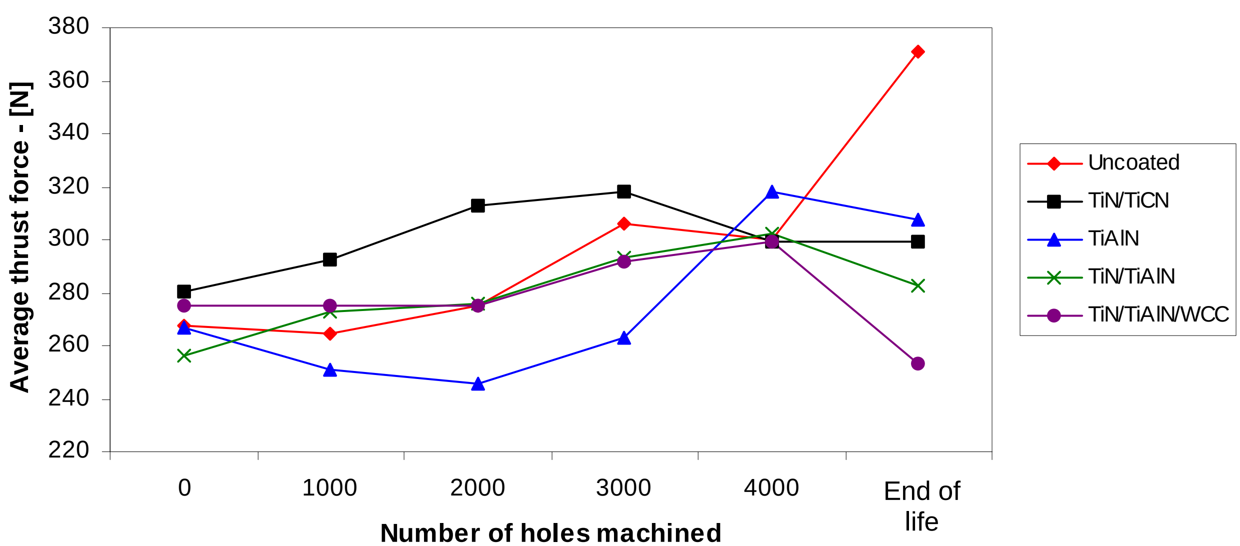

Figure 8. Thrust force when drilling aluminum-silicon ISO 3522 - Al-Si8Cu3Fe alloy

Up to 4000 holes machined which means that the wear is still small (the tool lives were always higher than 8000 holes machined and for the one coated tool it was more than 28000 holes, see Figure 3), the thrust forces for the uncoated and for the TiN/TiAlN and TiN/TiAlN/WCC coated drills are practically the same. Only at the end of the drill's lives the value of the force component scattered. The jump presented by the uncoated drill (peaks up to 600 N were registered) is caused by the localized plastic deformation observed at the chisel edge of this tool as illustrated in Figure 9. The wear on the chisel edge has a great influence on the drilling forces because in that area the cutting speed is practically zero and the function of the chisel edge is to track the way down the hole. If the wear eliminates or damages this edge the thrust force is tremendously affected.

The TiN/TiCN and TiAlN coated drills presented different behaviors from each other when within the initial interval of 4000 holes machined. The TiAlN coating presented the smaller thrust force whereas the TiN/TiCN coating the highest. These results are probably linked to the ability that the work material has to adhere against the tool surfaces rather than any sort of wear influences. As shown before the TiN/TiCN coating has the highest wear resistance among all and gave the highest forces. Only at the end of the tool's lives the wear might have influenced, as observed in Figure 8 where the force values have dispersed accordingly.

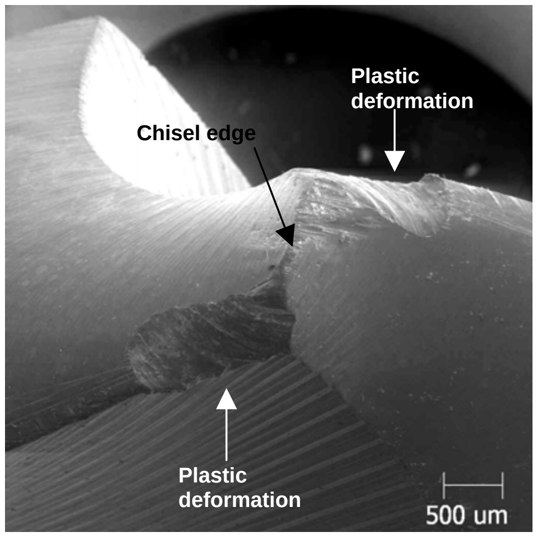

Figure 9. Close chipping traverse cutting edge, SEM.

The thrust force therefore, although being reduced by TiAlN coating, has demonstrated to be a senseless parameter for indicating tool lives. This is typical of machining of aluminum alloys. They possesses high tendency to adhere onto the tool's surface but not frequently this implies in toll life reductions. It is important, however, to be aware of the high potential of these work materials to seize and gall on the tool and this is function of the chemical affinities with the tool material. The cutting conditions cannot be neglected in the analysis and are important too. It is well known that potential protection of a coating depends upon the cutting temperature (Paldey and Deevi, 2003; Prengel *et al.,* 2001). In the present investigation they were kept constant, and are not high for aluminum machining. This means that different results will not be surprise if different cutting conditions are used. The coatings possesses chemical and physical properties that are activated by the heat sources of the machining processes what make them to be more effective, reducing friction and wear particularly the more temperature dependant wear mechanisms.

4. Conclusions

The results obtained at the cutting condition tested allow the following conclusions to be drawn:

1. The coated drills presented superior performance when compared to the uncoated tools.
2. Among the drills tested the best performance was given by the TiN/TiCN coating that allowed the highest number of holes machined.
3. Abrasion and attrition are the two main wear mechanisms observed.
4. Wear of the margin land was predominant and this compromises the diameter tolerances of the hole.
5. TiAlN and TiN/TiCN coatings have influenced the thrust force but it was not a threat for the tool lives.

5. Acknowledgements

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6. References

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