ISSN 2179-3956

WEAR OF CARBIDE TOOLS IN MACHINING INCONEL 751[1]

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Abstract

The aim of this work is to study the types of wear and the wear mechanisms that predominates in carbide tools (WC/Co, WC/6%Co TiAlN and WC/10%Co TiAlN) during turning of nickel base alloy - Inconel 751. DOE technique with the following input variables: tool material (WC/Co, WC/6%Co TiAlN and WC/10%Co TiAlN), cutting speed, tool geometry and lubri-cooling atmosphere (dry, argon rich and oxygen rich). In each machining test a new tool edge was used up to the end of the tool life with interruptions for wear measurements. At the end of the tests the tools were analyzed with the help of optical microscopy. The results showed that the cutting speed, the tool geometry and the lubri-cooling atmospheres have influenced the types of wear and the tool life. Average flank wear (VB_B) and nose wear (VB_C) prevailed depending upon the cutting conditions and tool material used. Overall the WC/6%Co TiAlN tools showed the best performance, followed by the WC/Co and the WC/10%Co TiAlN. The lowest tool lives were found in dry condition and nose wear was accelerated in WC/10%Co TiAlN, particularly at higher cutting speeds. Attrition, abrasion and diffusion were the dominant wear mechanisms found.
Keywords: Wear; Carbide; Inconel.

DESGASTE EM FERRAMENTAS DE METAL DURO NA USINAGEM DA LIGA INCONEL 751

Resumo

O objetivo deste trabalho é estudar os tipos de desgaste e os mecanismos a eles associados em ferramentas de metal duro (WC/Co, WC/6%Co TiAlN and WC/10%Co TiAlN) durante o torneamento da liga a base de níquel – Inconel 751. A técnica de planejamento de experimentos foi utilizada com as seguintes variáveis: material da ferramenta (WC/Co, WC/6%Co TiAlN e WC/10%Co TiAlN), velocidade de corte, geometria da ferramenta e atmosfera lubri-refrigerante (a seco, rica em argônio e rica em oxigênio). Em cada teste de usinagem foi utilizada uma aresta de corte nova até o fim de vida da ferramenta com interrupções para as medidas de desgaste. Ao final dos ensaios as ferramentas foram analisadas com auxílio de microscopia ótica. Os resultados mostraram que a velocidade de corte, a geometria da ferramenta e as atmosferas lubri-refrigerantes tiveram influência nos tipos de desgaste e na vida das ferramentas. O desgaste de flanco médio (VB_B) e o desgaste de ponta (VB_C) foram predominantes dependendo das condições de corte e do material da ferramenta utilizada. Em todos os ensaios, as ferramentas com WC/6%Co TiAlN em sua composição mostraram o melhor desempenho, seguido pelas WC/Co e WC/10%Co TiAlN. As menores vidas foram observadas na condição a seco, o desgaste de ponta (VB_C) foi acelerado nas ferramentas WC/10%Co TiAlN, particularmente em altas velocidades de corte. Attrition (adesão), abrasão e difusão foram os mecanismos de desgaste encontrados.
Palavras-chave: Desgaste; Metal duro; Inconel.

1 *Technical contribution to the First International Brazilian Conference on Tribology – TriboBr-2010, November, 24th-26th, 2010, Rio de Janeiro, RJ, Brazil.*
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TriboBR
First International Brazilian Conference on Tribology – TriboBr-2010 and ITS - IFToMM 2010 - 2nd International Tribology Symposium of IFToMM
24th to 26th november, 2010
Copacabana, Rio de Janeiro/RJ, Brazil
ISSN 2179-3956

1 INTRODUCTION

The nickel base alloys, also called superalloys are used in the manufacture of mechanical components in the aerospace and automotive industries, due to their high mechanical strength at high temperatures, high creep resistance and fatigue strength and excellent corrosion resistance. Its field of application includes components working at temperatures above 500°C, such as blades, discs and turbine components and elements of the exhaust system of engines.[1,2] Currently, nickel alloy 751 is widely used for making the exhaust valves of diesel engines.[3] The superalloys are known as low machinability materials due to high hardness, high mechanical strength that is maintained at high temperatures, affinity to react with tool materials and low thermal conductivity. Several tools were used over time for machining the nickel-based alloys, such as cemented carbides coated and uncoated, ceramics - pure or mixed, and the ultrahard tools. Although currently cutting tools incorporate advanced technologies in its design, the problems historically encountered in machining of superalloys persist. Breakdown phenomena such as cracking, spalling and cracking can be observed more frequently in interrupted cuts, such as in milling. But the wear occurs in both continuous and interrupted cutting processes. The main forms of wear on a cutting tool are: crater wear, flank wear and notch wear.[4,5] The flank wear and the notch wear are the main causes of rejection of the cutting tools in continuous cutting operations and, although the interaction of the mechanisms is complex, there may be development of diffusion wear, abrasion, adhesion, and others.[6]

2 MATERIALS AND METHODS

For the study two types of supports with different cutting geometries – Table 1,[7] three types of carbide inserts [(WC/Co, WC/6%Co TiAlN and WC/10%Co TiAlN) – ISO SNMG120412][8,9] and three types of lubri-cooling atmospheres (dry, argon rich and oxygen rich) were used. The cutting speeds selected for the experiments were 45 m/min and 60 m/min. A depth of cut of 2 mm, feed rate of 0.2 mm / rev and nose radius of 1,2 mm were repeated constant.

Table 1. Cutting geometries of tools

Angles	Cutting geometries	
	CG1 (ISO CSSNR2525M12)	CG2 (ISO CSXNR2525M12)
ξ_r	45°	85°
ξ'_r	45°	5°
α_o	8°	6°
β_o	90°	90°
γ_o	-8°	-6°
ε_r	90°	90°
λ_s	0°	-6°

The Ni alloy tested has approximately 30 HRc hardness and the following chemical composition (wt%):[10] Ni 71.12%, 16.70% Cr, Fe 6.97%, 2.34% Ti; Al 1.33%, 0.88% Nb, Mn 0.27% Si 0.13%, Mo 0.08% C 0.06%, Cu 0.04% Co 0.04%, W 0 , 02%, V 0.01%, S 0.001%, P 0.001%. The workpiece had a cylindrical shape in the following dimensions ∅ 105 x 250 mm.

The turning tests were performed on a CNC lathe Romi Multiplic 35D model, belonging to the Machining Research Laboratory – LEPU of the Federal University of

ISSN 2179-3956

Uberlandia – UFU – Brazil. Analyses of wear were done by optical microscopy using a stereomicroscope Olympus model SZ6145TR with digital camera and image analysis software Image-Pro Express 5.1, also belonging to the LEPU. Figure 1 shows the assembly system for the tests.

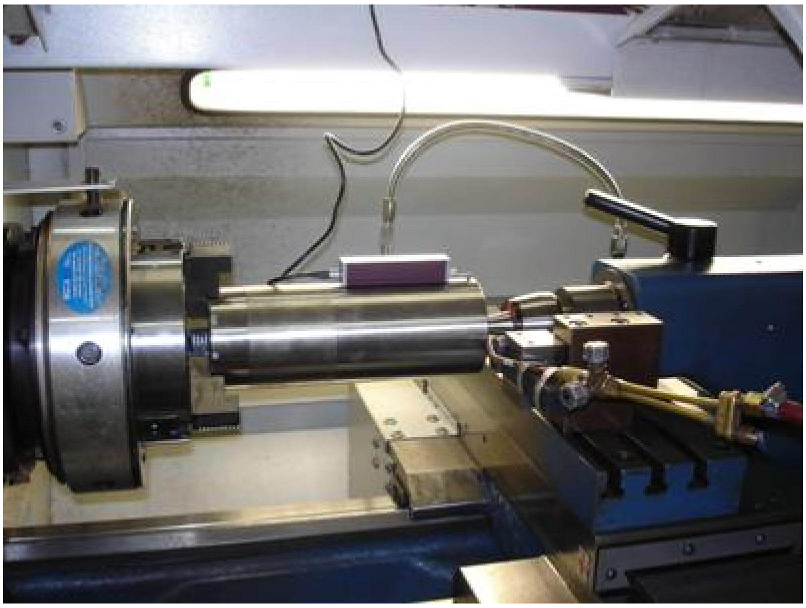
Figure 1. System mounted for tests.

Figure 2 illustrates the parameters considered for investigating their effects on the tool wear (cutting speed, tool geometry and the atmospheres). For the design of the experiments and statistical analysis the software Statistica 6.0 and Microsoft Excel 2003 were used.

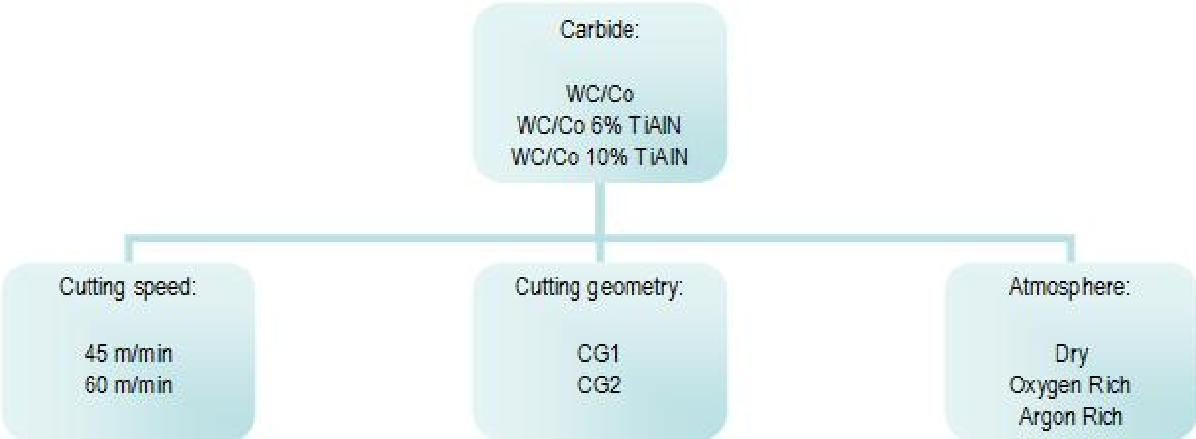

Figure 2. Scheme of tests with carbide inserts.

Table 2 presents the end of life criteria that were used for the tool life tests.[11]

Table 2. Criteria for the end of life tools for development of the maximum tolerated wear

Wear	Value max. (mm)
Notch wear (VB_N)	1,00
Average flank wear (VB_B)	0,40
Max. flank wear (VB_{Bmax})	0,60
Nose wear (VB_C)	0,60

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3 RESULTS AND DISCUSSION

During the tests with carbide inserts two types of wear were detected:

- Average flank wear (VB_B);
- Nose wear (VB_C).

3.1 Considerations on the wear of carbide inserts.

In the tool life tests the best performance was presented by the TiAlN coated (WC/6%Co) inserts, followed by the uncoated straight grade of cemented carbide (WC/Co) and the TiAlN coated (WC/10%Co).The dominant type of wear for the two firsts inserts was the average flank wear (VB_B). The dominant type of wear on the WC/10%Co inserts was the nose wear, as presented in Figures 3, 4 and 5.

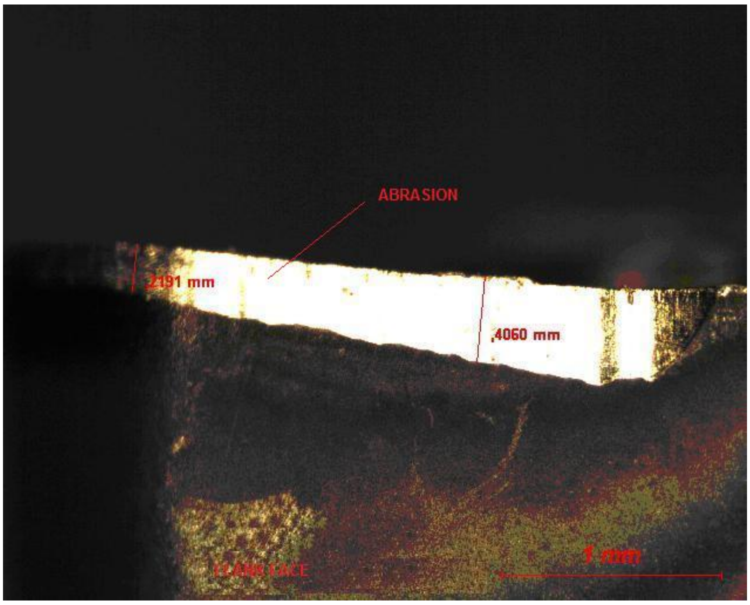

Figure 3. Average flank wear in carbide tool (WC/Co) uncoated, after 270s.

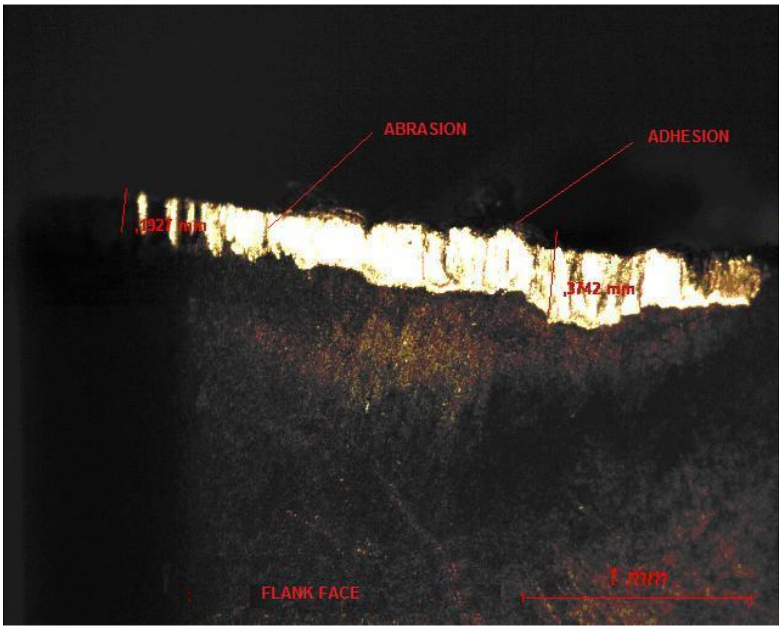

Figure 4. Average flank wear in carbide tool (WC/6%Co TiAlN), after 720s.

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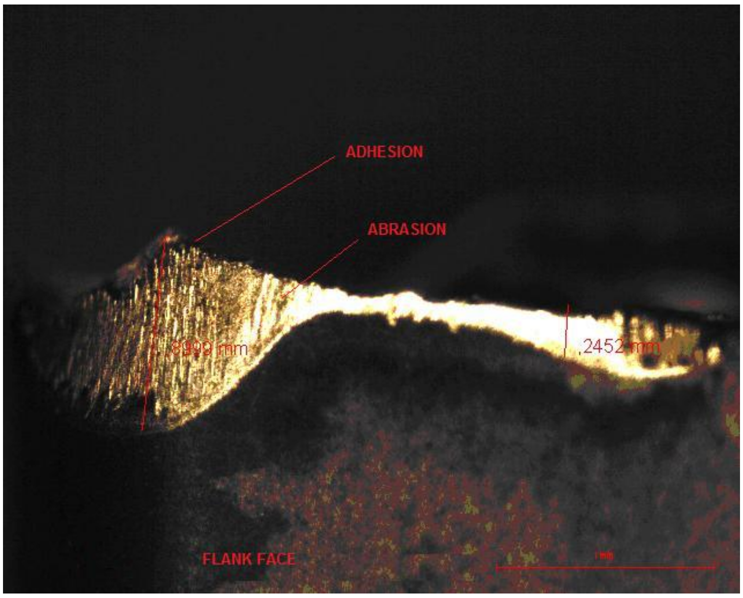

Figure 5. Nose wear in carbide tool (WC/10%Co TiAlN), after 240s.

Close observations of these figures show parallel ridges on the flank wear of the tools in the direction of the material flow, giving evidences that abrasion is the dominant wear mechanisms. However, adherent workpiece material is also observed, particularly on the nose wear area of the tool of Figure 5, indicating that attrition (or adhesion) wear is also a mechanism present.

3.2 Influence of Cutting Speed, Cutting Geometry and Atmosphere Onr the Tool Life of Carbide Inserts

For studing the influence of the input variables cutting speed (Cs), cutting tool geometry (CG), atmosphere (A) and the insert material (IM) the estimation of the effects on tool life (t) of carbide inserts was considered.[12]

The materials of the inserts were compared in pairs in two different atmospheres, varying the cutting speed and the cutting tool geometry. The maximum values of p accepted was $p < 0.20$ and correlation coefficient $R^2 > 0.90$ for all comparisons.

Tables 3 to 8 show the influence of the input variables on the tool life of the cemented carbide inserts.

Table 3. Estimation of the effects of inserts WC/Co x WC/6%Co TiAlN in Dry x Oxygen rich

Var.	Effect	Std. Err.	t	p
Cs	-294,50	37,58	-7,83	0,000050
CG	-61,75	37,58	-1,64	0,139052
IM	228,00	37,58	6,06	0,000301
Cs by IM	128,25	37,58	3,41	0,009197

Table 4. Estimation of the effects of inserts WC/Co x WC/6%Co TiAlN in Dry x Argon rich

Var.	Effect	Std. Err.	t	p
Cs	-314,50	20,79	-15,12	0,000023
CG	-104,25	20,79	-5,01	0,004063
A	-72,75	20,79	-3,49	0,017329
IM	215,50	20,79	10,36	0,000144

ISSN 2179-3956

Table 5. Estimation of the effects of inserts WC/Co x WC/6%Co TiAlN in Argon rich x Oxygen rich

Var.	Effect	Std. Err.	t	p
Cs	-305,00	44,28	-6,88	0,000072
CG	-67,50	44,28	-1,52	0,161796
IM	222,50	44,28	5,02	0,000715
Cs by IM	120,50	44,28	2,72	0,023670

Table 6. Estimation of the effects of inserts WC/Co x WC/10%Co TiAlN in Dry x Oxygen rich

Var.	Effect	Std. Err.	t	p
Cs	-260,87	32,59	-8,00	0,000012
IM	-222,12	32,59	-6,81	0,000047
Cs by IM	161,87	32,59	4,96	0,000565
CG by IM	123,87	32,59	3,80	0,003483

Table 7. Estimation of the effects of inserts WC/Co x WC/10%Co TiAlN in Dry x Argon rich

Var.	Effect	Std. Err.	t	p
Cs	-239,75	35,75	-6,70	0,000276
CG	-73,50	35,75	-2,05	0,078867
IM	-199,50	35,75	-5,57	0,000834
Cs by IM	158,50	35,75	4,43	0,003033

Table 8. Estimation of the effects of inserts WC/Co x WC/10%Co TiAlN in Argon rich x Oxygen rich

Var.	Effect	Std. Err.	t	p
Cs	-265,62	38,20	-6,95	0,000221
CG	-55,37	38,20	-1,44	0,190507
IM	-136,62	38,20	-3,57	0,009024
Cs by IM	159,87	38,20	4,18	0,004114

Table 9. Estimation of the effects of inserts WC/6%Co x WC/10%Co TiAlN in Dry x Oxygen rich

Var.	Effect	Std. Err.	t	p
Cs	-132,62	27,48	-4,82	0,002923
CG	62,12	27,48	2,26	0,064501
A	42,12	27,48	1,53	0,176216
IM	-450,125	27,48	-16,37	0,000003

Table 10. Estimation of the effects of inserts WC/6%Co x WC/10%Co TiAlN in Dry x Argon rich

Var.	Effect	Std. Err.	t	p
Cs	-156,00	18,07	-8,62	0,000012
IM	-415,00	18,07	-22,95	0,000000
Cs by IM	74,75	18,07	4,13	0,002542
GC by IM	91,00	18,07	5,03	0,000706

Table 9. Estimation of the effects of inserts WC/6%Co x WC/10%Co TiAlN in Argon rich x Oxyg. rich

Var.	Effect	Std. Err.	t	p
Cs	-145	30,37	-4,77	0,001004
CG	36,62	30,37	1,20	0,208600
IM	-359,12	30,37	-11,82	0,000001
Cs by IM	63,12	30,37	2,07	0,067439

ISSN 2179-3956

The most influent variables on the tool life were cutting speed (Cs) and principally the insert material (IM). The cutting tool geometry and principally the atmosphere (lubri-cooling condition) had less influences.

The chemical interactions between the Ni alloy and the carbide inserts under low cutting speeds is weak, which does not favor the diffusion wear mechanism. However, higher cutting speeds for these materials (Cs = 60 m/min) heat generation is intense and can be spread among the materials,[5,13,14] accelerating tool wear.

The influence of cutting geometry (CG) on the average flank wear (VB_B) and nose wear (VB_C) on carbide inserts was most favorable to the first geometry, where there was a reduction in the wear rates as a consequence of inhibition of the wear mechanisms at both cutting speeds tested. Under the lower cutting speed (Cs) of 45 m/min attrition predominates and when the higher cutting speed (Cs) of 60 m/min was used, adhesion, followed by abrasion and possibly diffusion are present. The 45° approach angle tool is more appropriate than the counterpart 85° tool.

The TiAlN coating greatly increases the hardness of tool, when compared to uncoated carbide, therefore the effects of abrasive mechanisms are minimized.[15,16]

4 CONCLUSIONS

The results showed that the cutting speed, tool geometry and atmospheres influenced the types of wear and the tool life of the carbide inserts tested. The dominant types of wear were average flank wear (VB_B) and nose wear (VB_C).

Contrary to expectations, the lowest tool life were found in normal atmosphere (dry), but the development of average flank wear (VB_B) was higher in an inert atmosphere (argon rich) at low cutting speeds.

The interaction of the cutting geometry and higher cutting speed favored the development of nose wear (VB_C) of the inserts tested, mainly in the inserts with higher content of Co (10%).

The inserts with 6% Co in the matrix and coated with TiAlN were those with the highest life in all tests. For this type of material the dominant was the average flank wear (VB_B), followed by nose wear (VB_C). The inserts with 10% Co coated with TiAlN showed marked nose wear (VB_C). The uncoated inserts showed intermediate performance.

The wear mechanisms that predominate were attrition (adhesion), abrasion and possibly diffusion due to high temperatures generated during cutting.

Acknowledgments

The authors are grateful to the following companies and institutions: Villares Metals S.A.; Kennametal Inc.; CNPq; CAPES; IFM; FAPEMIG; LAPROSOLDA – UFU.

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