IJE TRANSACTIONS C: Aspects Vol. 31, No. 6, (June 2018) 943-948

International Journal of Engineering

Journal Homepage: www.ije.ir

Evaluation of Flank Wear of Iron-rich Binder Carbide Cutting Tool in Turning of Titanium Alloy

M. Chandrashekar*[a], K. V. Sreenivasa Prasad[b]

[a] Department of Industrial and Production Engineering, Visvesvaraya Technological University, Belagavi,Karnataka state, India
[b] Department of Industrial and Production Engineering, Jagadguru Sri Shivarathreeswara University, Mysuru, Karnataka state, India

PAPER INFO

Paper history:
Received 14 October 2017
Received in revised form 30 November 2017
Accepted 15 Januray 2018

Keywords:
Titanium
Cutting Tools
Tungsten Carbide
Cobalt
Iron

ABSTRACT

Despite the fact that Titanium material has been considered as difficult to cut material, its usage has been increasing day by day in all engineering sectors; wherever criticality is encountered. Many studies are going on in view of increasing tool life at high cutting speed to improve productivity. In this study, attempt has been made to see the effect of iron as a partial substitution along with cobalt binder in cutting tool material for turning of titanium alloy. The iron-rich binder carbide tool samples were produced through powder metallurgy route using a powders with mean particle size of less than 0.5µm. Turning experiments were conducted at different speeds to evaluate the effects of iron-rich binder on tool flank wear. Results of turning experiments clearly showed that iron-rich binder tend to increase tool life in comparison to conventional WC-Co composite cutting tools

***doi**: 10.5829/ije.2018.31.06c.11*

1. INTRODUCTION

Nowadays titanium is widely used in major sectors like marine, aerospace, biomedical, automotive and petrochemical industries, where prime requirement is high strength at elevated temperature, resistance to wear and chemical degradation. Titanium alloys are broadly classified into three main categories, based on stabilizers like alpha alloys, alpha-beta alloys and beta alloys, all these alloys have different properties and can be used accordingly. Ti-6Al-4V is widely used in aerospace and medical engineering. It is an alpha-beta alloy, that is heat treatable to achieve an increase in strength [1, 2].

One drawback of these alloys is their poor machinability. Despite the several advantages, titanium and its alloys pose several challenges for machining due to properties like high strength which limits to low cutting speeds, low modulus of elasticity and poor thermal conductivity [3, 4]. At critical cutting speed, localized shear involved in the segmented chip formation leads to generation of cyclic forces which results in rough machined surface, the chatter and chipping of cutting edge [5, 6].

Investigation by Komanduri et al. [7] reported that the machining of titanium alloys is a typical case of distinct gross inhomogeneous plastic deformation involving periodic upsetting and intense shear localization in a narrow band. It is suggested that due to intense contact of chip at or near the tip of tool for substantial time leads to a reaction between tool and chip leading to high tool wear.

The low machinability of titanium alloys due to the low thermal conductivity and high micro hardness of these materials leads to severe and premature tool wear in the dry machining process. Thermal and mechanical analysis revealed two important phenomena. First, the thermal softening which results in a lowering of the yield stress when the temperature increases, and secondly the strain rate hardening which increase the hardness of the material. Increasing the hardness in machining implies systematically an increase in the level of cutting force. Indeed, an increase in the cutting speed raises the temperature at the tool–workpiece interface and increases at the same time the strain rate.

---

*Corresponding Author's Email: nie.chandrashekar@gmail.com (M. chandrashekar)

Please cite this article as: M. Chandrashekar, K. V. Sreenivasa Prasad, Evaluation of Flank Wear of Iron-rich Binder Carbide Cutting Tool in Turning of Titanium Alloy, International Journal of Engineering (IJE), IJE TRANSACTIONS C: Aspects Vol. 31, No. 6, (June 2018) 943-948

Both phenomena occur simultaneously and reflect two opposite effects. It was concluded from different analyses that the Ti–6Al–4V alloy is more sensitive to thermal softening [8].

Friedrich et al. [9] Investigated that the spring back in the milling operation is a linear function of tool edge radius and the ratio of material hardness to elastic modulus. It can be calculated using the following equation: $s = Kr\ (H/E)$ where, S is the spring back, k is constant, r is the cutting edge radius, where H and E are the hardness and Young's modulus of the workpiece material, respectively. Significantly, low Young's modulus and reasonably high hardness make titanium alloy highly elastic which cause excessive workpiece deflection and small plastic deformation. Thus, there is a bouncing action as the cutting edge comes in contact with the workpiece during machining processes under cutting pressure. The workpiece has a tendency to move away from the cutting tool unless deep cuts are performed or rigid backup is applied. This also leads to a less effective clearance angle at the flank face, enhanced friction, and chatter [10].

Kikuchi et al. [11] and Mia et al. [12] investigated the cutting temperature became higher when there is an increase in cutting speed, feed or depth of cut. Increase in cutting speed and feed was more influential on the value than the increase in the depth of cut when two cutting conditions with the same material removal rates were compared. The main reason for this is because of lower thermal conductivity and higher cutting forces.

Carbide based materials are hard in nature due to the combination of hard carbide particles together and available in straight carbides or mixed carbides in the present market. Straight carbide consists of base material and binder that is tungsten carbide (WC) and Cobalt (Co), while mixed carbide consists of additive elements in addition to base material and binder. When compared to other available tools like ceramic tools, CBN tools, PCD tools, the straight grade carbide tools are the preferred tools for machining titanium and its alloys. The ceramic tools are brittle and lack toughness, cubic boron nitride (CBN) tools are quite expensive so they are used for finishing operations. In Poly Crystalline Diamond (PCD) tools, carbon content rests with titanium forming titanium carbide layer at a high temperature, which affects the surface finish, hence straight grade carbide tools are preferred [9, 13].

Fang et al. [14] have investigated that cobalt is the most preferred binding material because it forms a solid solution with tungsten carbide, which results in hard phase in microstructure and good mechanical properties. Carbide cutting tools expose huge differences in wear resistance from series to series; addition of refractory elements like iron, nickel along with cobalt improves the performance of the WC based cemented carbides. In this regards iron has the highest affinity for carbon compared to nickel so it can form metal-to-carbon bond relationship. Moreover, iron has good wettability and solubility for WC lowering the ternary eutectic temperature than cobalt [15].

In view of the above literature survey, it is concluded that, to overcome concern related to the machining of titanium in an economical way, number of researches are in progress to improve cutting tool material. The aim of the study is to enhance the performance of cutting tool material by adding iron as a partial substitution to straight carbides (WC/Co), which is motivated by economic consideration.

2. METHODS AND MATERIALS

2. 1. Preparation of Test Samples

In the present investigation, tungsten carbide, cobalt and iron powders of average particle size less 0.5 µm [16], supplied by Guangzhou Jiechuang Trading (Company, Ltd, B319, Dong Hong Business Building, No.4 Tangdong East Road, Tianhe District, Guangzhou, Guangdong, China), was used to prepare the sample through powder metallurgy route. Titanium alloy Ti-6Al-4V class material was chosen as machining work piece. Table 1 summarizes the chemical composition of Ti alloy. The Ti alloy raw material was supplied by M/s Raghavendra Engineering (Puzhal, No. 1, 7th Street, Anna MemorialNagar, Puzhal,Chennai. TN. India).

The test samples were produced through powder metallurgy route at Central Manufacturing Technology Institute (Banglore, Karnataka). Two different samples were manufactured. As per literature survey [16], it is advisable to use 5 to 12% binder in composition, for initial study, 0.5% of iron added randomly as a partial substitution along with cobalt for sample B. Further increasing percentage will be the future scope of study. The test sample compositions are shown in Table 2.

The first stage of production is a blending of raw materials with additives and lubricants using a ball mill at a 60% of the critical rotational speed for 10 hours.

TABLE 1. shows the chemical composition of Titanium alloy (Ti-6Al-4V).

Elements	V%	Fe%	Ti%	Al%
	3.82	0.15	91.15	Balance

TABLE 2. shows the sample composition (% volume)

	Sample A	Sample B
Tungsten Carbide (WC)	95	95
Cobalt (Co)	5	4.5
Iron (Fe)	0	0.5

After blending it uniformly, the blended mixture was pressed using a universal testing machine (UTM) to a size of Dia 12mm x 6mm under pressure of 200 MPa. After pressing the samples were sintered at a temperature of 1350 ^{0}C for one hour in a furnace with a continuous flow of hydrogen. As a secondary operation, samples were brazed to a standard Tool Shank. Tool geometry was generated as per standard.

2. 2. Evaluation of Test Micro-Structures and Mechanical Properties. After sintering, mechanical properties such hardness and toughness were investigated for each sample. The Hardness of Sample B with cobalt (Co) and Iron (Fe) showed higher than sample A with only cobalt (Co) binder phase for the same tungsten carbide concentration, vice versa for fracture toughness which is derived by performing Palmquist indentation method. Also, it indicates the presence of harder binder phase in sample B. Figure 1 Shows related hardness and toughness values for each sample.

The scanning electron micrographs are shown in Figure 2 (Samples A and B) The microstructure image shows the presence of carbide and binder phases. These phases are critical to mechanical properties of the cutting tool. It consists of tungsten carbide as embedded in a binder phase, dark black cores with light gray rim. During the sintering process, tungsten carbide crystals develop well defined crystallographic facets. It is significant that grain growth of WC in cemented carbides generally occurs in two modes, namely coalescence and solution/reprecipitation process. Figure 2 (Sample B) shows a good particles fusion in microstructure, therefore the mechanical properties is better as compared to Sample A.

XRD analysis was carried out to study the crystal structure. Figure 3 shows that sample A is a WC-Co alloy, which exists in the allotrophic form of hexagonally close packed (HCP) phase.

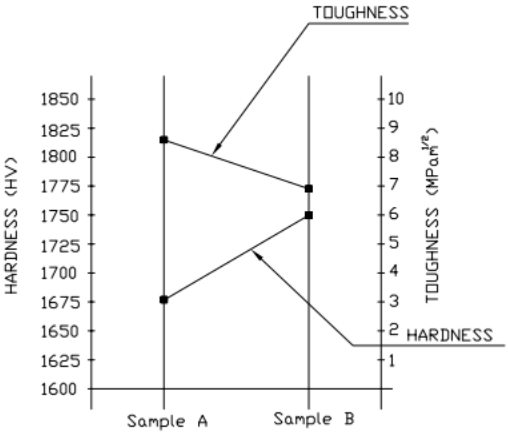
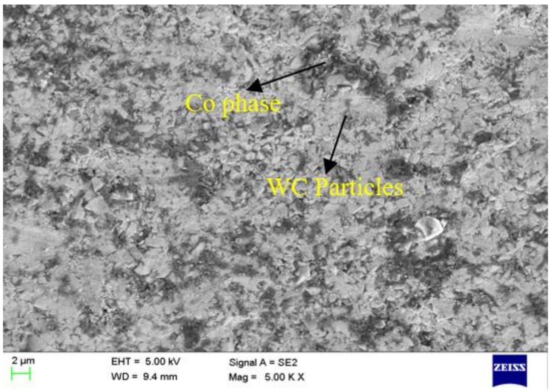
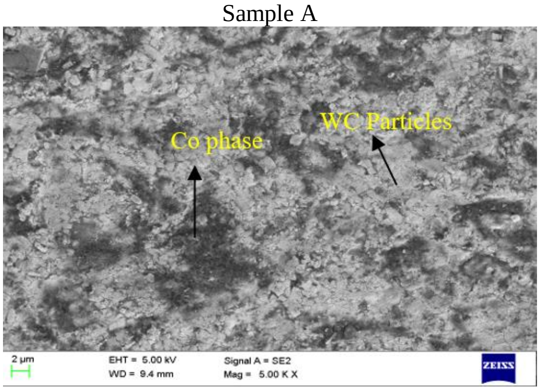


Figure 1. Harness/Toughness Vs Sample A/Sample B



Sample A



Sample B

Figure 2. SEM Images of Sample A and Sample B

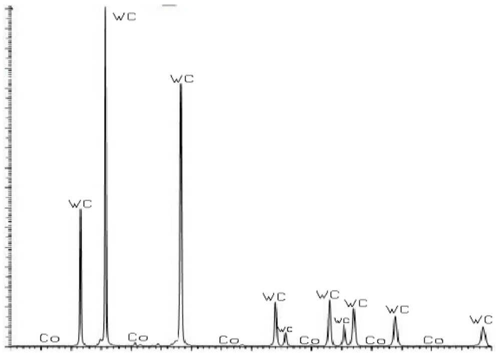
Where as in specimen B it is found the binder phase is composed of both body centered cubic and hexagonally close packed phases, that the dissolution of cobalt into iron in order to form the cobalt- iron phase (Co-Fe).

3. EXPERIMENTAL PROCEDURE

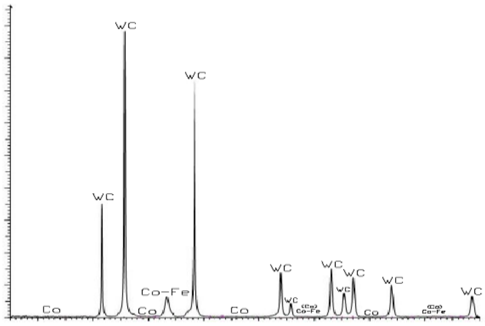
Machinability is a way to measure and classify how easily a particular workpiece material can be machined by a cutting tool in a manner such that certain predetermined levels of form, size and degree of roundness of the surface can be achieved.

The wear resistance property of the samples was evaluated in actual turning process tests under the following conditions: cutting speeds 30m/min and 60 m/min, keeping feed = 0.25 mm/rev and depth of cut = 1mm, constant at both cutting speed with coolant at a flow rate of 30 L/min and at a pressure of 12 kg/m^2 [17, 18]. The flank wear was measured at regular intervals of 30 seconds [19].

To measure cutting forces, namely Thurst force (fx), Feed force (fy) and Tangential force (fz), the lathe tool post was fitted with a dynamometer, force values were recorded through digital instrument which was interfaced with dynamometer, under the following conditions: cutting speeds 30m/min, feed = 0.25mm/rev, depth of cut = 0.5mm [20].



(a) Sample A



(b) Sample B

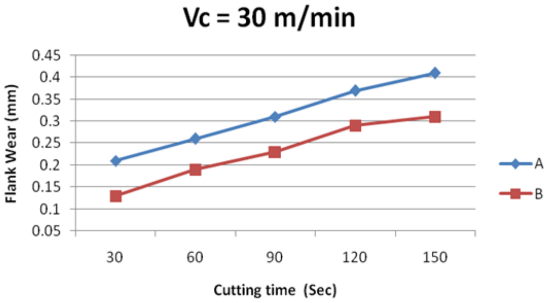
Figure 3. X-ray Spectra (a) of a WC-Co composite with 5 Wt% Co, (b) of a WC-Co-Fe composite with 4.5 Wt% Co and 0.5 Wt% Fe

4. RESULTS AND DISCUSSIONS

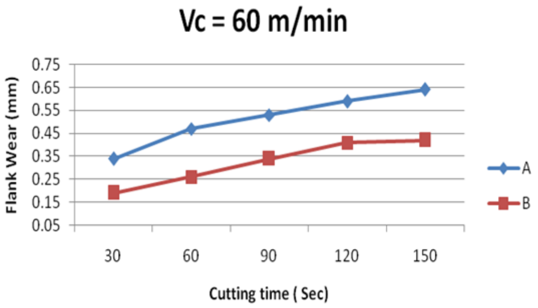
4. 1. Tool Wear Measurement Flank wear in which the portion of the tool in contact with the finished part erodes. The rate of flank wear measured with tool makers microscope is presented in Figue 4 (graph 1 to graph 4). The main reason to conduct this experiment was to investigate how the addition of iron to cobalt binder content affects the cutting tool wear while turning titanium alloy (Ti-6Al-4V). There are two samples that are important to compare in order to see the influence of iron content.

In graph 1, at cutting speed 30m/min, even though wear behavior was identical in both samples A and B from beginning to end for a set cutting time, sample A showed more wear at the beginning compared to sample B, that is for Sample A measured flank wear value was 0.21mm, whereas for the sample B it was 0.13mm at 30 m/min cutting speed.

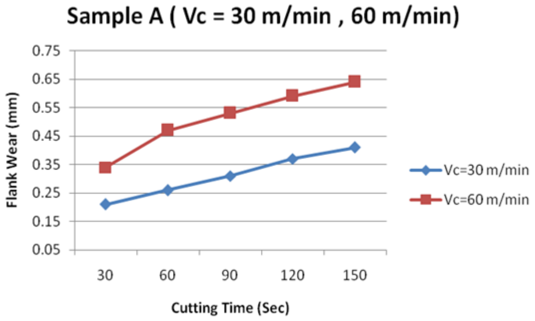
In graph 2, it is seen that at cutting speed 60m/min, sample B showed very less flank wear, also at the end of set cutting time wear remains constant when compared to sample A. The plotted graph shows that the new material with iron content under investigation show a distinct improvement in life at higher cutting speeds than one without iron at higher cutting speeds.



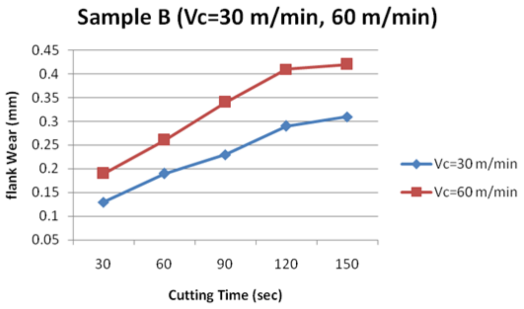
Graph 1



Graph 2



Graph 3



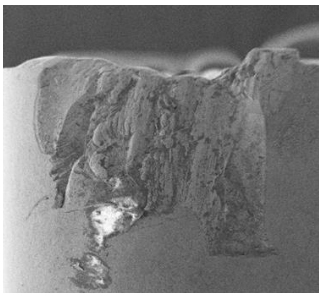
Graph 4

Figure 4. Typical Wear rate of Sample A and Sample B at cutting speeds, Vc = 30 m/min and 60 m/min

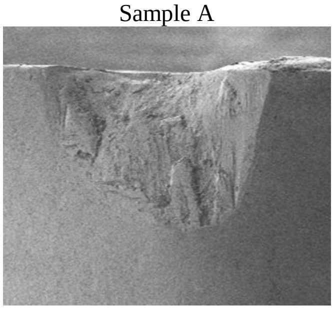
It is evident from the SEM images of cutting edges of both samples, that sample A cutting edges were chipped off at a cutting speed of 60m/min, whereas for sample B it was smooth wear. Also, it is observed in all graphs that wear on sample B was so small that it could not have a significant effect on the tool during machining, in sample B flank wear rate reached a steady state following a rapid initial wear under the same cutting condition.

Typical wear pattern of samples is seen in SEM micrographs, after turning at a cutting speed of 60 m/min. By visual examination, it is found that on sample A, local flank wear so called notch wear on the main and minor cutting edges also non uniform abrasive wear seen. Notching is mainly caused by a fracture process, it happens when excessive localized damage occurs at the flank and rake face simultaneously. The notch will cause poor surface finish, further, it leads to fracture wear. Where as for sample B wear was smooth, which does not lead to any catastrophic tool failure. Iron has good wettability and solubility for tungsten carbide. Addition of an iron enhances the fusion of tungsten carbide particles, which increases the overall strength of sample as compared to the sample without iron.

4. 2. Cutting Force Measurement The cutting forces are found due to interation of cutting tool and workpiece. These interactions lead to cutting tool wear, further leads to catastrophic tool failure, consequently all acting, cutting forces, namely thurst force (fx), feed force (fy) and Tangential force (fz) are related to tool wear. Table 3 summarizes measured cutting force values for both Samples A and B.



Sample A



Sample B

Figure 5. Typical cutting edge wear of Sample A and Sample B as seen on scanning Electron microscope

TABLE 3. Cutting force values

	Thrust Force (fx) N	Feed force (fy) N	Tangential force (fz) N
Sample A	206	569	627
Sample B	137	382	608

Cutting force values of both, Samples A and B clearly show that force over sample B is less than Sample A.

4. 3. Tool Life Based on the data from tool wear measurement and cutting force values of both Samples A and B at 30 m/min cutting speed, it is observed that Sample A takes 90 s to reach flank wear of 0.3mm, while Sample B takes 120 s to show same wear rate.

5. CONCLUSIONS

This research focus on evaluation of flank wear of iron rich binder carbide cutting tools in turning of titanium alloys. Newly developed samples were subjected to various tests in comparison to straight carbides (WC/Co). Following are the findings obtained from test results.

1) The characterization study reveals that iron rich binder carbide cutting tool material shows good mechanical properties.
2) Results from cutting force measurement shows that the cutting force over iron rich binder tool is less compared to cobalt binder tool for same cutting speed.
3) Plotted wear rate graphs at different cutting speeds reveals that iron rich binder tool shows improved tool life compared to cobalt binder tool.

6. FUTURE SCOPE OF STUDY

Additional experimentation is planned to investigate higher temperature capability of iron rich binder carbide cutting tools.

7. REFERENCES

1. Ezugwu, E. and Wang, Z., "Titanium alloys and their machinability—a review", ***Journal of Materials Processing Technology***, Vol. 68, No. 3, (1997), 262-274.
2. Leyens, C. and Peters, M., "Titanium and titanium alloys: Fundamentals and applications, John Wiley & Sons, (2003).
3. Ahsan, K.B., Mazid, A.M., Clegg, R.E. and Pang, G., "Study on carbide cutting tool life using various cutting speeds for α-β ti-alloy machining", ***Journal of Achievements in Materials and Manufacturing Engineering***, Vol. 55, No. 2, (2012), 600-606.
4. Ezugwu, E., Wang, Z. and Machado, A., "Wear of coated carbide tools when machining nickel (inconel 718) and titanium

base (ti-6a1-4v) alloys", ***Tribology Transactions***, Vol. 43, No. 2, (2000), 263-268.

5. Sun, S., Brandt, M. and Dargusch, M., "Characteristics of cutting forces and chip formation in machining of titanium alloys", ***International Journal of Machine Tools and Manufacture***, Vol. 49, No. 7-8, (2009), 561-568.
6. B., L., Y, W., H, L. and H., Y., "Modelling and numerical simulation of cutting stress in end milling of titanium alloy using carbide coated tool", ***International Journal of Engineering Transactions A: Basics***, Vol. 28, No. 7, (2015), 1090-1098.
7. Komanduri, R., "Some clarifications on the mechanics of chip formation when machining titanium alloys", ***Wear***, Vol. 76, No. 1, (1982), 15-34.
8. Nouari, M. and Makich, H., "Experimental investigation on the effect of the material microstructure on tool wear when machining hard titanium alloys: Ti–6al–4v and ti-555", ***International Journal of Refractory Metals and Hard Materials***, Vol. 41, No., (2013), 259-269.
9. Friedrich, C. and Kulkarni, V., "Effect of workpiece springback on micromilling forces", ***Microsystem Technologies***, Vol. 10, No. 6-7, (2004), 472-477.
10. Davim, J.P., "Machining of titanium alloys, Springer, (2014).
11. Kikuchi, M., "The use of cutting temperature to evaluate the machinability of titanium alloys", ***Acta Biomaterialia***, Vol. 5, No. 2, (2009), 770-775.
12. Mia, M., Khan, M.A. and Dhar, N.R., "High-pressure coolant on flank and rake surfaces of tool in turning of ti-6al-4v: Investigations on surface roughness and tool wear", ***The International Journal of Advanced Manufacturing Technology***, Vol. 90, No. 5-8, (2017), 1825-1834.
13. Gille, G., Szesny, B., Dreyer, K., Van Den Berg, H., Schmidt, J., Gestrich, T. and Leitner, G., "Submicron and ultrafine grained hardmetals for microdrills and metal cutting inserts", ***International Journal of Refractory Metals and Hard Materials***, Vol. 20, No. 1, (2002), 3-22.
14. Fang, Z.Z., Wang, X., Ryu, T., Hwang, K.S. and Sohn, H., "Synthesis, sintering, and mechanical properties of nanocrystalline cemented tungsten carbide–a review", ***International Journal of Refractory Metals and Hard Materials***, Vol. 27, No. 2, (2009), 288-299.
15. De Macedo, H., Da Silva, A. and de Melo, D., "The spreading of cobalt, nickel and iron on tungsten carbide and the first stage of hard metal sintering", ***Materials Letters***, Vol. 57, No. 24-25, (2003), 3924-3932.
16. Davis, J.R., "Asm specialty handbook: Tool materials, ASM international, (1995).
17. Ramana, M.V., Rao, G.K.M. and Rao, D.H., "Experimental investigations on tool wear in turning of ti-6al-4v alloy under different machining environmental conditions", ***International Journal of Manufacturing Research***, Vol. 11, No. 4, (2016), 339-355.
18. Zheng, X., Liu, Z., Chen, M. and Wang, X., "Experimental study on micro-milling of ti6al4v with minimum quantity lubrication", ***International Journal of Nanomanufacturing***, Vol. 9, No. 5-6, (2013), 570-582.
19. Kalidass, S. and Ravikumarb, T.M., "Cutting force prediction in end milling process of aisi 304 steel using solid carbide tools", ***International Journal of Engineering-Transactions A: Basics***, Vol. 28, No. 7, (2015), 1074-1082.
20. Ghani, J.A., Haron, C.H.C., Kasim, M.S., Sulaiman, M.A. and Tomadi, S.H., "Wear mechanism of coated and uncoated carbide cutting tool in machining process", ***Journal of Materials Research***, Vol. 31, No. 13, (2016), 1873-1879.

Evaluation of Flank Wear of Iron-rich Binder Carbide Cutting Tool in Turning of Titanium Alloy

M. Chandrashekar[a], K. V. Sreenivasa Prasad[b]

[a] Department of Industrial and Production Engineering, Visvesvaraya Technological University, Belagavi,Karnataka state, India
[b] Department of Industrial and Production Engineering, Jagadguru Sri Shivarathreeswara University, Mysuru, Karnataka state, India

PAPER INFO

Paper history:
Received 14 October 2017
Received in revised form 30 November 2017
Accepted 15 Januray 2018

Keywords:
Titanium
Cutting Tools
Tungsten Carbide
Cobalt
Iron

چکیده

علیرغم اینکه مواد تیتانیوم به عنوان موادی که به سختی برش می خورد، استفاده از آن روز به روز در تمام بخش های مهندسی در حال افزایش است، هرجا که مشگلی باشد این فلز قابل استفاده است. بسیاری از مطالعات گسترده ای در رابطه با افزایش طول عمر ابزار با سرعت برش بالا برای بهبود بهره وری از این فلز استفاده شده است. در این مطالعه تلاش شده است تا آهن را به عنوان یک جزئی جایگزین همراه با اتصال دهنده کبالت به عنوان ابزار برش برای تنظیم آلیاژ تیتانیوم استفاده گردید. نمونه های ابزار کاربید اتصال دهنده غنی با آهن با استفاده از روش متالورژی پودر با اندازه ذرات کمتر از μm0.5 تولید می گردد. آزمایش هایی جهت تنظیم سرعت های مختلف برای ارزیابی اثرات غلظت آهن غنی بر روی سایش ابزار برش انجام شده است. نتایج حاصل از آزمایش های تنظیم برش نشان می دهد که اتصال دهنده غنی از آهن باعث افزایش عمر ابزار برش در مقایسه با ابزار برش کامپوزیتی WC-Com معمولی می گردد.

***doi**: 10.5829/ije.2018.31.06c.11*