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Research Article

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PROCESSING AND PROPERTIES OF Ni/YSZ COMPOSITE COATING ON HIGH SPEED STEEL CUTTING TOOL

N. B. Baba[1,*], M. F. Omar[1], S. Sharif[2] and S. B. Mohamed[3]

[1]Faculty of Manufacturing Engineering Technology, TATI University College (TATIUC), 24000 Kemaman, Terengganu, Malaysia

[2]Faculty of Mechanical Engineering, University Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

[3]Faculty of Innovative Design and Technology, Universiti Sultan Zainal Abidin (UniSZA), 21300 Kuala Terengganu, Terengganu, Malaysia

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ABSTRACT

The study involves coating the high speed steel (HSS) tool with Ni/YSZ composite via electroless nickel co-deposition. Common commercialized coated cutting tool are AlN, TiN, TiAlN and in this study Ni/YSZ is investigated. Ni/YSZ composite was successfully coated onto the HSS cutting tool via electroless nickel co-deposition. The performance of Ni/YSZ composite coated tool was compared to the uncoated and TiN coated tools for its surface tolerance in milling of mild steel. Five samples of each type of cutting tools were run by using Deckel Maho DMU50 CNC machine with five different levels of spindle speed ranges between 800-1200 rpm and five different cutting lengths between 120-600 mm. The machined work material surface tolerances were recorded using Mitutoyo SJ-301 surface roughness tester. SEM/EDX analysis confirmed the existence of Ni and YSZ in the coating.

Keywords: electroless; co-deposition; nickel; YSZ; composites; cutting tool.

Author Correspondence, e-mail: bahiyah@tatiuc.edu.my

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1. INTRODUCTION

The Milling is a common machining process for metal cutting purposes. The performance of cutting process is determined by the cutting tool quality. There are many cutting tools available in industry and it can be generally divided into coated and uncoated. The coated cutting tools are usually performed better than the uncoated ones. Common commercialized coated cutting tool are AlN, TiN, TiAlN and others but in this study Ni/YSZ is investigated. Besides, most coated cutting tools were manufactured by thermal spraying techniques but coated by electroless nickel co-deposition is new.

Most coated cutting tools are ceramics or metallic alloy such as titanium nitride (TiN), titanium-aluminum nitride (TiAlN), aluminum chromium nitride (AlCrN), carbide, boride, diamond and others [1]. A recent coating materials combination of element and diamond-like carbon film was studied by [2]. Thus in this study, a new approach of nickel (Ni) and yttria-stabilized zirconia (YSZ) composite is investigated as this composite is also known as cermet with high thermal, wear and corrosion resistance as an alternative materials for the cutting tool coating. Besides, the coating will be process via electroless nickel co-deposition which is simple and less costly compared to conventional thermal spraying processes [3].

Electroless coating or autocatalytic coating is a process of deposition metallic ions into the metal state. This process is a chemical reduction reaction of metallic nickel onto the substrate. The applications of electroless nickel (EN) co-deposition which ceramic particles was added and later embedded in the deposition. Hence, it produces greater wear resistance, microhardness and corrosion resistance composite materials [4].

It is known that most outstanding surface coating was done by thermal spraying techniques. This includes electroplating, physical vapour deposition (PVD) and chemical vapour deposition (CVD) process. Out of these three processes, PVD is the most favoured. There is also a study on combining several types of method PVD becoming hybrid PVD methods in enhancing the quality of TiAlN coatings [5].

In [6] concluded the machining surface roughness is affected by cutting speed in their investigation in milling Al/SiC metal matrix composites. The best surface roughness is obtained with increasing cutting speed from 300 mm/min to 450 mm/min. The surface roughness of the work materials obtained are gradually decrease from 1.3 µm to 0.6 µm.

In other study using AlCrN coated tool on SS316L, parameters varied are cutting speed, feed rate and cutting length [7]. It was found that increase feed rate from 0.02 to 0.03 mm/tooth give rougher working material surface. The best surface roughness was obtained betwwen 0.175 – 0.3 µm at 200 mm/min cutting speed, 0.02 mm/tooth feed rate and 1200 mm cutting length.

TiAlN/TiN coated tool was used to cut 4340 Steel at cutting speed 183 and 229 mm/min showed small change in work materials surface roughness from 0.38 µm to 0.30 µm, but high impact on tool life from 28 min to 10 min [8]. Tool performance of TiAlN/AlCrN multilayer coated carbide in machining AISI D2 material at 100 m/min and 0.05 mm/tooth feed rate show variation in work material surface roughness between 0.2 – 0.45 µm [9]. Two studies were done using TiAlN coated tool machining on DIN 1.2344 [10] and Al6061-T6511 [11] at cutting speed of 251.32 m/min and 1000 rpm respectively give surface roughness of 0.58 µm and 0.675-0.98 µm. All in all, a study done comparing coated and uncoated tool showed that the coated carbide insert was outperformed the uncoated with better surface finish [12].

2. RESULTS AND DISCUSSION

The HSS cutting tool was successfully coated with Ni/YSZ composite via electroless coating. The average diameter for each cutting tool was measured after coating for 2 hours. The results show the coating thickness is varied between 55 to 64 µm. The images of Carl Ziess Stemi 2000-C Stereo microscope on HSS cutting tool before and after coating were shown in Fig. 1. HSS cutting tool coated with Ni/YSZ shows matte finish as in Fig. 1(i) whereas HSS cutting tool before coating was bright finish (Fig. 1(ii)). The coating was smooth and uniform with no sign of flaking.

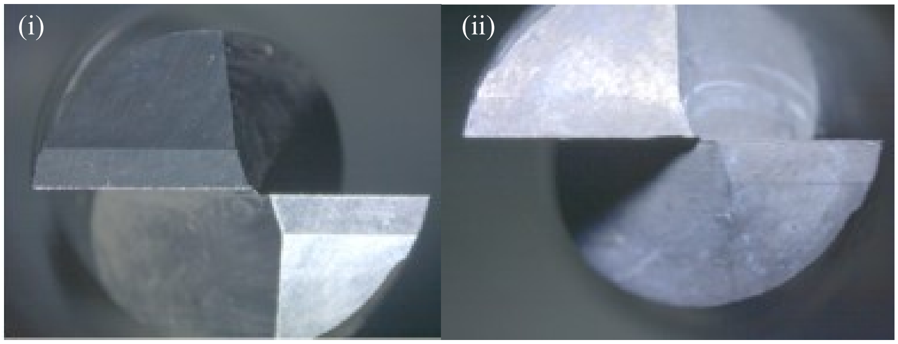

Fig.1. Cutting tool images (i) Before coating (ii) After coating

2.1. Surface Tolerance

The major indication of the machining process performance is by measuring the machined surface tolerances in terms of its surface roughness (Ra). The cutting tool quality is the main factor to contribute for better surface tolerances. The finish surface tolerances were measured by measuring the finish machined surface of the mild steel work material. The Ra of machined mild steel at spindle speed 800 rpm for machining length ranges between 120-600 mm at three different types of cutting tool were recorded and compared in Fig. 2.

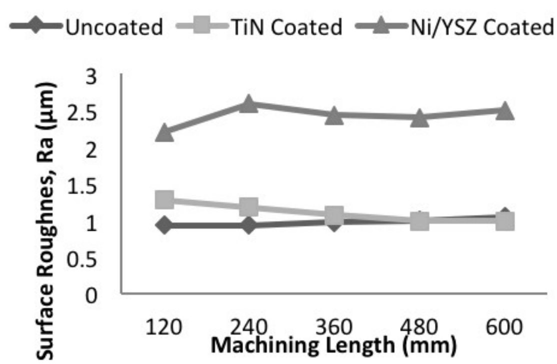

Fig.2. Surface roughness against machining length at 800 rpm

It was found that the machined Ra for the uncoated cutting tool is gradually increasing, whereas the TiN coated cutting tool is decreasing as the machining length increasing. The Ni/YSZ coated cutting tool shows a very rough surface finish with its values fluctuating between 2.19 to 2.58 µm. The best Ra obtained by uncoated cutting tool is 0.93 µm at 120 mm machining length, TiN coated tool bit is 0.98 µm at 480 mm and 600 mm and Ni/YSZ coated cutting tool is 2.19 µm at 120 mm. The graph clearly shows Ni/YSZ coated cutting tool poorly performed among the others with significantly high value of Ra. This observation was due to poor adhesion between coating and HSS substrate. HSS substrate is a carbon based steel that will smudge upon activation by acid solution.

Similar experiment was conducted at 900 rpm and the result is shown in Fig. 3. It shows that machined Ra is generally increasing slightly with machining length regardless of the type of cutting tools. TiN coated shows the best machined Ra with its values fluctuating between 0.51 to 0.62 µm, while the uncoated tool shows the worse Ra with its values fluctuating between 1.90 to 2.14 µm. On the other hand, Ni/YSZ coated tool shows moderate Ra with its values increasing from 0.73 to 0.90 µm. As shown in the graph, both coated tool recorded very good surface finish compared to the uncoated. This observation was supported by Gauruv and co-authors [6]. The performance of Ni/YSZ coated improves so much compared to the one at 800 rpm.

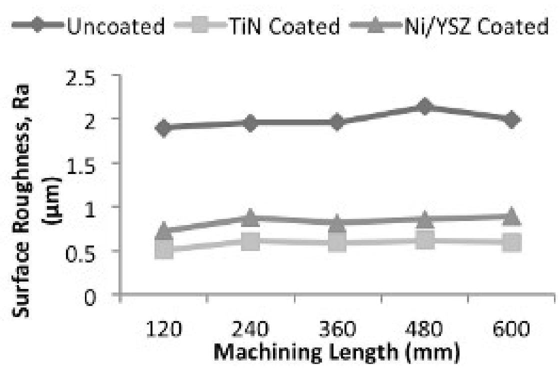

Fig.3. Surface roughness against machining length at 900 rpm

Fig. 4 shows the Ra of three different types of cutting tool against the machining length between 120-600 mm at 1000 rpm spindle speed. TiN coated tool shows the best Ra with its value fluctuating between 0.71 to 0.84 µm. The Ni/YSZ coated tool bit shows very small increment of Ra at every machining length. The value of machined Ra of Ni/YSZ coated tool is very moderate with the peak value of 1.07 µm. The uncoated cutting tool shows very significant high value of Ra ranges between 1.24 to 2.12 µm. This indicates that the machining performance for all types of cutting tools at 1000 rpm was similar to the 900 rpm.

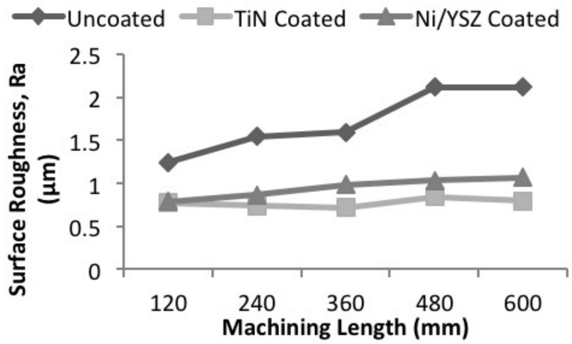

Fig.4. Surface roughness against machining length at 1000 rpm

At spindle speed of 1100 rpm with the other parameters were kept constant, the machined Ra was recorded in Fig. 5. It shows that Ni/YSZ coated cutting tool shows the best machined surface finish at every machining length compared to the TiN coated and the uncoated tool. The uncoated tool shows the highest machined Ra which indicates rougher surface finish. The lowest Ra values obtained is 0.64 µm, 0.92 µm and 1.17 µm for Ni/YSZ coated, TiN coated and uncoated HSS cutting tool respectively. The machined Ra for the uncoated is rigorously increased up to 480 mm machining length before decreasing at 600 mm. The highest value of Ra for Ni/YSZ coated tool is 0.91 µm at final machining length compared to 1.20 µm for TiN coated tool at 240 mm machining length. The Ra value for TiN and Ni/YSZ coated tools show they are not really affected by machining length compared to the uncoated tool. This indicates that the wear resistance of these coated tools was comparable. At this spindle speed, Ni/YSZ has outperformed the TiN coated cutting tool.

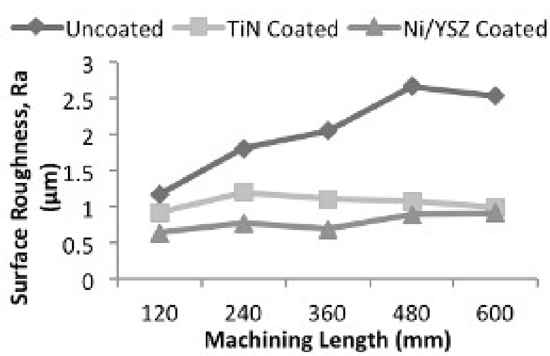

Fig.5. Surface roughness against machining length at 1100 rpm

The machined Ra at spindle speed 1200 rpm for three different types of cutting tool were recorded in Fig. 6. TiN coated and Ni/YSZ coated tools both show increasing trend throughout the process and this increment is less compared to the uncoated. The best Ra is obtained by using TiN coated tool with value 0.72 µm. The worse Ra is obtained at 600 mm machining length for uncoated, Ni/YSZ coated and TiN coated at 1.73 µm, 1.33 µm and 1.05 µm respectively. All in all, at this spindle speed, the TiN coated and Ni/YSZ show comparable machining performance. The Ni/YSZ coated tool is performing poorly at 600 machining length which indicates that wear occurred.

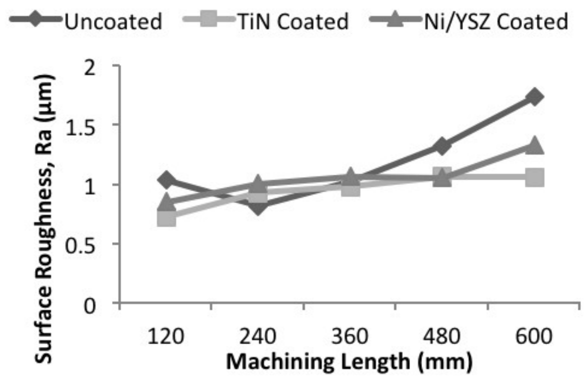

Fig.6. Surface roughness against machining length at 1200 rpm

All in all, it is observed that at lower spindle speed (800 rpm) the uncoated performed better than the coated cutting tools. The result is agreed to the work done by Jawaid et al. which found that as the spindle speed increases, the coated cutting tools outperformed the uncoated [11]. TiN coated cutting tool generally shows the most consistent machined Ra as the spindle rate increase from 800 to 1200 rpm similar to the study done by [6]. The Ni/YSZ coated tool bit shows improved performance as the spindle rate increases. At spindle speed 1100 rpm, Ni/YSZ cutting tool outperformed the TiN coated tool. Overall, the performance of the Ni/YSZ coated is shown to be comparable to TiN coated cutting tool.

2.2. Characterisation

The sample of Ni/YSZ coated was placed under SEM coupled with EDX. SEM micrograph SEM surface morphology of the coated area at 1000x magnification is given in Fig. 7. This micrograph shows smooth surface with no agglomeration of ceramic YSZ powders over the entire surface. The area gives an elemental spectrum with the presence of Ni, Zr and Y elements with Ni as the highest peak followed by Zr. This confirms that the area is coated with Ni/YSZ coating.

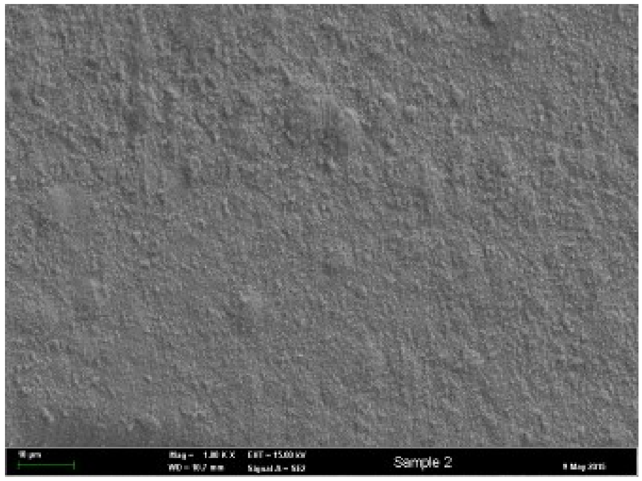

Fig.7. SEM micrograph of coated NI/YSZ composite

The SEM micrograph of Ni/YSZ coated cutting tool at 800 rpm sample at the 15x magnification shows in the Fig. 8. The area labeled ***a*** is the Ni/YSZ coated area, whereas area labeled ***b*** is where the coating was flaking out due to poor adhesion between coating and the HSS substrate. The defect was occurred during machining process.

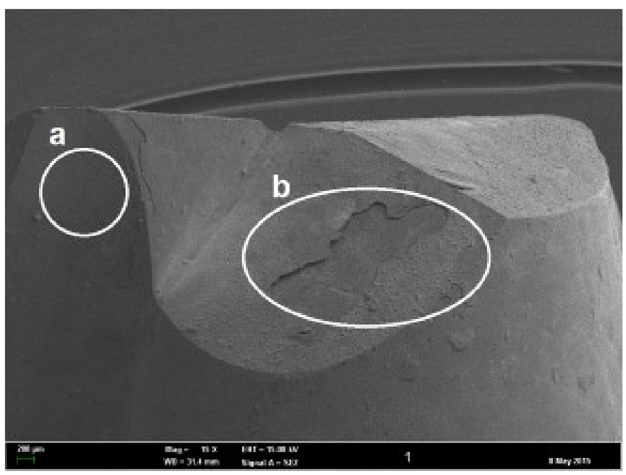

Fig.8. SEM micrograph of cutting tool surface at 15x magnification with coated area ***a*** and flaking area ***b***

EDX analysis for both areas ***a*** and ***b*** were given in Spectrum 1 and 2 respectively as shown in Fig. 9. Area ***a*** is the coated Ni/YSZ composite. The EDX detected elements of nickel (Ni), phosphorus (P), zirconium (Zr), yttria (Y), carbon (C) and oxygen (O) on the spectrum 1. The phosphorus, carbon and oxygen elements are obtained from the pre-treatment process of the electroless coating. Area ***b*** where the coating was flaking out, detected iron (Fe), chromium (Cr), tungsten (W), vanadium (V) and carbon (C) elements which are the main elements in

HSS.

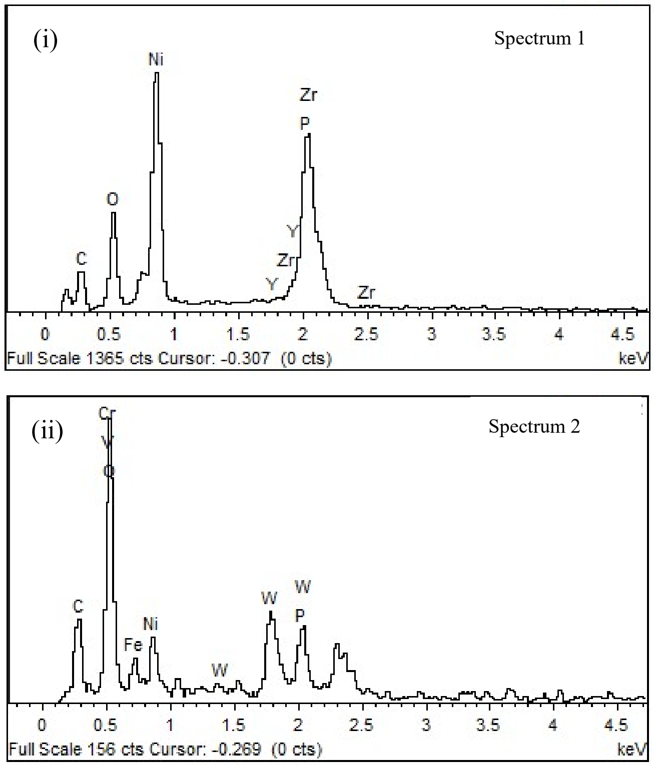

Fig.9. Elemental diffraction X-ray of (i) area ***a*** and (ii) area ***b***

3. METHODOLOGY

3.1. Electroless Coating

The high speed steel (HSS) cutting tool is a manufacturer standard with a diameter of Ø9.94 mm. The end mill requires sensitising to activate the HSS cutting tool surface by the four pre-treatment processes consecutively. Then, the cutting tool was immersed in electroless nickel EN Slotonip solution for the co-deposition of Ni/YSZ coating.

A 50g/l of YSZ powder manufactured by Tosoh Corporation was added to the electroless nickel solution along with cutting tool. The powder is set in suspension by magnetic stirring agitation. The coating process was takes places in a beaker and the temperature was kept constant at 89^{o}C ±2. The coating time was kept constant at 2 hours. The whole coating process sequence is simplified in Fig. 10.

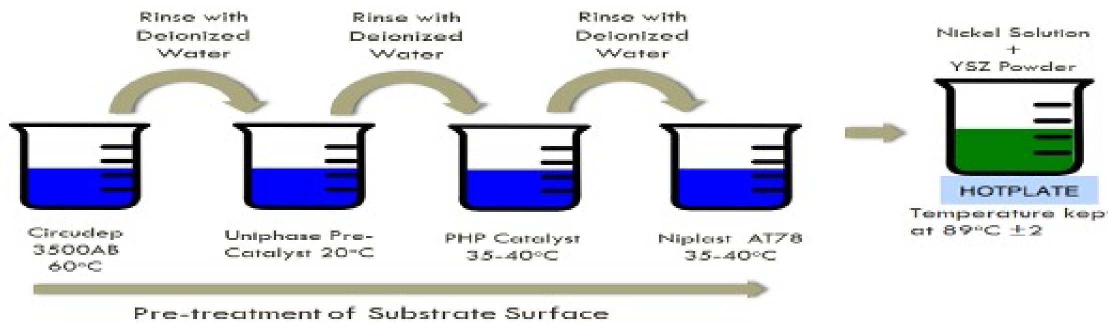

Fig.10. Schematic diagram of electroless nickel coating

3.2. Machining

Once the coating was done, the diameter of Ni/YSZ composite coated cutting tool was measured at its solid shank. The characteristic of uniform thickness of electroless coating enabled the measurement. Three readings were taken by using micrometer for each tool bit to get average thickness. The images of cutting tool before and after coating process were recorded using Carl Ziess Stemi 2000-C Stereo microscope for comparison and to view the quality of the coatings.

Later, the cutting tools were tested for its machining performances. The Deckel Maho DMU50 CNC machine was used. Machining was done on five ranges of machining length using five ranges of spindle speed and a constant depth of cut using the profile as shown in Fig. 11.

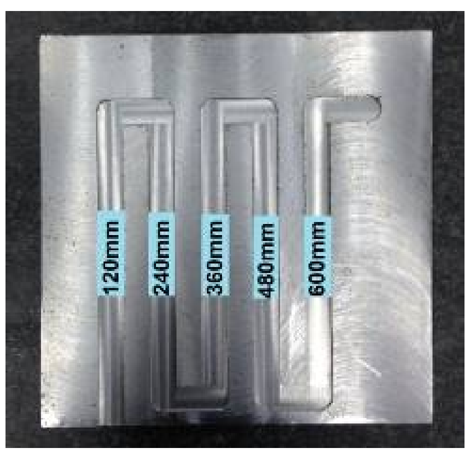

Fig.11. Machining profile on mild steel work material

The feed rate was kept constant throughout the end milling process. The work material used was mild steel. The machined profile was used as the basis of the surface roughness measurement. Three different types of coating were used for machining in this experiment including Ni/YSZ coated. TiN coated and uncoated end mill tool bits were manufacturer specification. Wet cutting process was applied in the study. The cutting parameters selected were tabulated in Table 1.

Table 1. Cutting parameters

Parameter	Value(s)	Unit
Spindle speed	800, 900, 1000, 1100, 1200	rpm
Machining length	120, 240, 360, 480, 600	mm
Depth of cut	1	mm
Feed rate	60	mm/min

The work materials were test for surface roughness after machining and the cutting tool were examined on scanning electron microscopy (SEM) coupled with energy dispersive X-ray (EDX). The machined surface was measured using Mitutoyo surface roughness tester SJ-301 shown in Fig. 12. Three surface roughness measurements were taken in each column for each machining length by the center line average approach observation.

Fig.12. Surface roughness tests on machining profile

4. CONCLUSION

HSS cutting tool was successfully coated with Ni/YSZ composite via electroless nickel co-deposition process. The average thickness of the coating is 59 µm with uniform and smooth surface as captured by Carl Ziess Stemi 2000-C Stereo microscope. Three types of cutting tools were selected and compared; there are HSS uncoated, TiN coated and Ni/YSZ composite coated. The performance of these three types of cutting tools was measured in terms of their machined surface tolerance. The uncoated tool is performed better at lower speed as it outperformed TiN and Ni/YSZ coated cutting tool giving the best surface roughness result. Among the three types of cutting tools, TiN coated shows the most consistent performance. Ni/YSZ coated tool shows comparable surface roughness results to TiN coated cutting tool. Both TiN and Ni/YSZ coated generally outperformed the uncoated tool bit at higher spindle speed. SEM/EDXA testing confirmed that Ni/YSZ was coated on the HSS cutting tool. Elemental analysis shows the presence of coating elements on the spectrum. The flaking issues will be the future work to overcome by focusing on the adhesive layer between HSS substrate and Ni/YSZ coating layer.

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