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ALTERNATIVE BINDER CARBIDE TOOLS FOR MACHINING SUPERALLOYS

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ABSTRACT

This study examines the performance of a new class of wear-resistant but economical cutting tools produced by varying the binder composition of standard cemented carbide composites. By replacing some or all of the cobalt binder with rhenium and nickel-based superalloy, a stronger composite tool results, potentially capable of machining heat-resistant superalloys at significantly higher cutting speeds. Sample tools with alternative binder were produced and compared to standard tools bound with cobalt only. Turning experiments on Inconel 718 were run to evaluate wear resistance and tool life for several grades. The experimentation also examined the effects of varying the relative proportions of each binder constituent as well as the overall binder percentage in the composite. Results show a clear advantage of the alternative binder tools as evidenced by a 150% increase in tool life or the equivalent of an 18% increase in cutting speed. Although increasing amounts of rhenium in the binder show a positive effect on performance, the effects of superalloy and overall binder % are inconclusive.

INTRODUCTION

New abrasive, hard, and heat-resistant materials such as superalloys are increasingly being machined in the aerospace, power generation, and oil and gas industries. Turbine disks are a key product made from superalloys and often require slow and expensive processes that machine away up to 90% of the starting billet. The superalloy with the most commercial usage by weight is the nickel-iron-based superalloy Inconel 718. This metal has extremely high tensile strength (1,250 MPa) and actually reaches its peak hardness at around 600°C. Further, it retains much of its strength (345 MPa) at temperatures as high as 900°C. Inconel 718 and other superalloys are very difficult to machine and wear down cutting tools very quickly. Both ceramic and carbide tools are currently used for cutting superalloys, but the more economical carbides are losing favor as demands increase for faster processing speeds.

Sintered carbide tools have been the subject of much research since their introduction beginning in the 1930's (especially WC-Co, tungsten carbide particles sintered in a cobalt binder). "Straight" grades of WC-Co composite are still in widespread use [1,2] for cutting nearly every kind of metal. The WC provides high hardness and wear resistance while the Co binder adds toughness needed for the mechanical and thermal shock of machining. Small amounts of titanium carbide (TiC), tantalum carbide (TaC), and/or niobium carbide (NbC) are often added to increase hardness and reduce chemical diffusion wear when machining steels [1,3]. Co is a preferred binding material because it forms a solid solution with WC, W, and C and forms a favorable microstructure at room temperature giving it good mechanical properties [4,5,6]. However, as new pressures for increased cutting speeds result in harsher conditions in machining, WC-Co tools are being increasingly replaced with alternatives that can last longer and hold up under the higher temperatures brought on by high speeds.

Ceramic tools, including those made from alumina and TiC (Al_2O_3-TiC) and silicon nitride (Si_3N_4) have become more common for higher speed (and typically lower feed and depth) cutting. Other ceramic-type tools include sialon (Si_3N_4-Al_2O_3), Al_2O_3 reinforced with silicon carbide whiskers (SiC_w-Al_2O_3), cubic boron nitride (CBN), and polycrystalline diamond (PCD). These materials have been investigated [7-15] in the machining of various hard work materials and are generally believed [2,16,17] to last significantly longer than carbides under certain conditions. Sialon and SiC_w-Al_2O_3 have become particularly popular with superalloys. The ceramic tools, however, are generally much more expensive than carbide tools [18] and must be used under conditions that do not promote

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cracking and chipping; i.e., light feeds and depths and non-interrupted cutting with a round insert shape. Due to these drawbacks, research has continued looking for ways to make bonded WC tools suitable for higher-speed, higher-temperature applications. Adding coatings, reducing grain size, and trying alternative binders are three of the strategies for improving performance of traditional carbides.

Coatings. Numerous ceramic coatings (usually TiN, TiC, and/or Al_2O_3) on the WC-Co base have been examined [19-25]. Most studies show that the coatings do uniformly extend the life of the carbide tools, especially for steel and iron cutting applications, though one [26] found no benefit on titanium. Heavier coatings (typically for heavier cuts and for steels) require a honed cutting edge to prevent premature chipping, though this can increase forces and leave a poorer surface finish. Nevertheless, a majority of commercial carbide tools available today include some level of coating applied to the base using a physical or chemical vapor deposition (PVD/CVD) process. The most common coating for turning of superalloys is currently titanium aluminum nitride (TiAlN) [27].

Grain size effect. WC grain size has long been known to have an effect on cemented carbide hardness and toughness. According to [1], finer grain size (e.g., less than 1 μm) leads to higher hardness and is used in cutting tools for light to medium-heavy roughing cuts. Coarse grain size (over 8 μm) carbides are much tougher and are used for forming dies rather than cutting. Medium grain size offers a tradeoff of hardness and toughness and may be used for heavier rough cutting. Smaller grain cemented carbides (.5 μm to 1 μm) have come to be known as "micrograin" carbides in the machining industry and are generally believed to offer more wear-resistance and maintain a sharper cutting edge for improved surface finish [15,28] particularly for machining hardened steels [17,29-31]. A German company reports [32] the achievement of very hard (H_V of 2100 to 2700 kg/mm^2) cemented carbides with moderate fracture toughness (5-6 MPa-m$^{.5}$) by using "ultrafine" WC powder with less than 1% Co binder.

Alternative binders. Although effective for bonding WC, cobalt has its limitations. It has a relatively low melting temperature and limited hot hardness and therefore degrades rapidly under high-speed machining conditions. It is corrosive and oxidizes under certain conditions. It can also be toxic and, as a politically strategic metal, can be subject to significant fluctuations in price and availability [6,33]. Therefore, other binder metals besides Co have been investigated and have found various uses with carbides and nitrides. For example, TiC and titanium nitride (TiN) wet better with nickel (Ni) as a binder than with Co [34]. TiC and/or WC materials bonded by Ni, molybdenum (Mo), and/or chromium (Cr) were developed in the 1960's [35] at Ford Motor Company and have been investigated since [36]. "Cermets" of TiC and TiN in a Ni binder [2,37] have been commercially developed and are currently used for finish machining of ferrous materials. Although sometimes brittle, these tools can be used at higher speeds due to their increased hardness, better wear resistance, and chemical stability [38,39] as compared to WC-Co grades. Their lack of toughness and lower thermal conductivity, however, often limit their use [1], especially in heavier rough or interrupted cutting. At least two patents (one from Denmark and one for GTE Valenite) exist for replacing Co binder in WC-Co with Ni and Cr [40,41], citing increased corrosion resistance as an advantage, in addition to increased strength, hardness, and wear resistance. A Kennametal patent [42] describes the addition of small amounts of Cr to the Co binder in WC-Co as an enrichment mechanism to improve cutting tool performance.

Bhaumik [34] tried replacing the Co binder in WC-Co with Co-Ni and Mo but had difficulty sintering the mix and got tools with porosity and inferior performance. Even after a two stage liquid sinter and hot isostatic press (HIP) for fuller density, performance was still worse than standard WC-Co. The preference for Co binder rather than Co-Ni is also echoed in current industry practice [43].

Iron (Fe) and steel have also been used as binders. Fe-Ni was investigated as a binder for WC [33,44] as has iron-manganese (Fe-Mn) [6]. The Fe-Mn bonded WC showed slightly higher hardness and slightly lower toughness than WC-Co. Gonzalez [45] was able to produce Fe-Ni bonded WC samples with similar hardness as comparable WC-Co materials but was also able to achieve relatively increased toughness by way of heat treatment of the WC-Fe-Ni samples. As in several other studies (e.g., [46]), it is stressed that a proper amount of carbon must be added to the binder for sintering and heat treating in order to produce the most advantageous phase structure of the bonded system, i.e., free of brittle η-phase carbides from insufficient carbon and free of soft graphite resulting from excess carbon. Various Kennametal patents (e.g., [33]) describe the use of Fe, Ni, and Co as binder constituents, finding that it improves the toughness and corrosion/oxidation resistance compared to Co alone. Steel-bonded carbides (i.e., with WC or TiC) have been developed [47-49] and are commercially available as wear-resistant components, though rarely as cutting tools due to somewhat lower hardness. According to [48], increasing binder content of Fe-based binder (with WC) beyond some small percentage lowers hardness and increases toughness, as it does in WC-Co systems. It was found that austenitic stainless steels provide the best binder performance.

In recent years, rhenium (Re) has also been studied as a possible binder for WC since, like Ni, rhenium does not form carbide phases in WC-Co. Re has a very high melting temperature (3180°C) and maintains high hot hardness. It readily oxidizes on its own, but can be made to resist oxidation when alloyed with Co or Ni and combined with WC [50]. A number of Re studies from Russia are referenced and summarized by Lisovskii [51]. The research indicates that a

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WC-Co-Re composite (binder has about 20% Re) has been created that has far superior properties than WC-Co alone. Microstructure analysis shows that the added rhenium increases the formation of hexagonal (hcp) structure in the Co, resulting in a significant increase in hardness (though at some cost in toughness). The author also suggests that a similar effect of Re on WC-Ni has been observed. WC-Co cutting tools alloyed with Co-Re in the vicinity of the cutting edge were found to be "two times more durable" than a commercial carbide grade in machining various hard and heat-resistant alloys [51]. The method of producing these tools, however, appears to be fairly expensive, requiring a submersion of the sintered WC-Co in a metallic melt containing Co and Re. Since the melt contains Co, the Co content in the tools often increased to an undesirable level. Lisovskii found similar results with osmium (Os) and ruthenium (Ru), which were the subjects of another promising study [52]. Based in part on Lisovskii's findings and those in [40], a US Patent for Dow Chemical [53] describes the use of pure Re (without Co) to bond WC. The patent claims the production of WC-Re with Vickers hardness (H_V) of over 2400 kg/mm^2 (compared to 1700 kg/mm^2 typical for WC-Co) using a cold press of WC and Re powders followed by a patented hot pressing process. The pressing process used (rapid omni-directional compaction, ROC), however, is still relatively expensive and not suitable for commercial fabrication [54].

The authors will examine the potential for increased productivity in machining Inconel 718 by investigating the effect of varying binder composition on tool performance. Based on the needs of modern cutting tools for machining these materials – high hardness, adequate toughness, hot hardness, and chemical stability at high temperatures – the binders to be examined include rhenium, nickel-based superalloy (Ni+Mo+Cr+Co+Al+Ti+Nb+W+Re+Zr), and cobalt. Cobalt bonds well with the carbide substrate constituents, and it brings sufficient toughness to the tool. The nickel-based superalloy combines very good high-temperature strength and excellent corrosion/oxidation resistance. It dissolves in WC and forms a good bond. The rhenium delivers high temperature stability and takes on a very hard phase with WC and with cobalt. It dissolves in the superalloy and Co and is thought to bond with the WC as well. Two US patents by one of the authors [54,55] describes the idea of using Re and nickel-based superalloy in the binder as well as the various alternatives and additive carbides and nitrides that enhance the reinforcement phase of the composite. The new binder is much harder than cobalt alone and has a much higher melting temperature, giving the composite tool greater resistance to abrasion and adhesion wear, particularly at higher cutting speeds and temperatures. Toughness remains comparable to traditional carbides so that fracture is resisted during interrupted cutting. The patent describes the production of material samples with over 2600 kg/mm^2 H_V and fracture toughness between 7 and 10 MPa-m$^{.5}$.

Besides a new binder formulation, the patent [54,55] also addresses the economics of producing the new material. Since Re would typically require an expensive, high-temperature method for liquid-phase sintering, the patent describes a new two-stage sintering method. The first sintering stage involves a relatively low-temperature *solid*-phase sintering of the powder under a vacuum condition, while the second stage involves further solid-phase hot isostatic pressing (HIP) under pressure in an inert gas medium. This procedure is performed on commonly available equipment and is meant to give the tools a comparable production cost as compared to standard WC-Co grades. Furthermore, the use of nickel-based superalloy (cost is significantly less than Co) in some proportion can help offset the relatively high cost of rhenium.

In summary, cutting tools bound with cobalt, rhenium, and nickel-based superalloy can maintain their hardness (i.e., wear resistance) at the high temperatures generated during cutting of heat-resistant materials, thus allowing for higher economical cutting speeds and feeds. Furthermore, a solid-phase sintering process can be used to produce the material in conventional sintering furnaces, thereby ensuring that processing costs are not significantly greater than for traditional cobalt-based cemented carbides. The research objectives are to

- Compare alternative binder tools to those bound with cobalt only when machining Inconel 718.
- Investigate the relative effects on performance of varying proportions of the alternative binder constituents as well as the overall proportion of binder in the composite.
- Determine the effect of speed on performance and estimate the increase in cutting speeds made possible by replacing cobalt binder with alternative binders.

EXPERIMENTATION

14 grades of tool samples were designed and produced by Genius Metal, inc., in Monrovia, CA. The compositions are listed in Table 1 by volume percentage of each constituent. Production included milling, drying, and sifting of the raw powders followed by cold pressing into industry standard insert shapes (SNG-432). After pressing, the inserts went through a solid state sintering process in a conventional sintering oven and then a hot isostatic press (HIP). The samples were then ground and honed to achieve a 0.01mm edge radius to help protect against edge chipping. Density, hardness, and toughness were measured for each of the samples. Vickers Hardness (HV) was measured with a standard Vickers indenter with four readings taken and averaged for each of 3 samples per grade. Palmquist fracture toughness was calculated for each grade based on the measured cracks from the Vickers hardness tests.

The 14 grades were selected to make up two factorial experiments. The first includes grades A1 and A4 through A12, which all have 10% binder by volume compared to the carbide

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phase. Tool A1 contains only Cobalt in the binder and is designed to mimic traditional WC-Co grades. Tools A4 through A12 were selected to create a complete two-factor, three-level (3^2) factorial experiment. The two factors were the % of Re in the binder (1.6%, 5%, and 8.4%) and the superalloy-to-Co ratio

TABLE 1 MATERIAL GRADE COMPOSITIONS BY VOLUME

	Re	Co	SA	WC	TiC/TaC
Grade	Vol%	Vol%	Vol%	Vol%	Vol%
A1		10		90	
A2		10		84	6
A3		16		84	
A4	8.4	1.2	0.4	90	
A5	8.4	0.8	0.8	90	
A6	8.4	0.4	1.2	90	
A7	5	3.75	1.25	90	
A8	5	2.5	2.5	90	
A9	5	1.25	3.75	90	
A10	1.6	6.3	2.1	90	
A11	1.6	4.2	4.2	90	
A12	1.6	2.1	6.3	90	
A13	5	2.5	2.5	84	6
A14	8	4	4	84	

in the binder (1:3, 1:1, and 3:1). The second experiment was performed using grades A2, A3, A13, and A14 to make up a 2^2 factorial design. The two factors are binder composition (cobalt-only and alternative-binder) and binder % (10% and 16%). The alternative binder samples (A13 and A14) contain Re, superalloy, and Co in a 2:1:1 ratio. In the two grades with just 10% binder (A2 and A13), the carbide phase includes 6% TiCTaC by volume and 84% WC.

Turning tests were conducted in the Advanced Manufacturing Laboratory at Cal Poly State University in San Luis Obispo. All tests were performed on a Haas SL 20 CNC turning center. Depth of cut and feed rate were held constant throughout all of the tests (2.0 mm depth and 0.01 mm/rev feed). The SNG-432 tools were held in a MSRNR 16-4D 15° lead negative-rake tool holder, and no chip breaker or cutting fluid was used. The tests were performed at two cutting speeds (50 m/min and 75 m/min) in order to determine the effect of cutting speed on tool life.

Prior to cutting, the tool edges were examined under a microscope to ensure that each sample had a consistent edge hone and was free of porous breakouts and edge grinding defects. The work material used was as-forged, solution-treated Inconel 718 (150 mm diameter bar stock). The measured tensile yield strength of the work material was 1,020 MPa and ultimate tensile strength was 1,120 MPa with a work material hardness of 36 HRC. A machine vision inspection system (OGP Smartscope 250) was used to examine the tools for wear after each cut and take measurements of the size of the wear regions.

In the two main experimental sets, the tests were designed to last for roughly 25%, 50%, 75%, and 100% of useful life of the shortest lasting tool. In this way, each grade cut for the same amount of time. A fresh cutting edge was used for each test and two replications were performed for each.

Since the tools did not all reach the end of useful life, an additional set of tests was completed in order to run some of the grades to ultimate failure. Two alternative binder grades (A5 and A6) and the corresponding Co only grade (A1) were selected. In these tests (run only at 50 m/min), the same cutting edge was placed back into service after each measurement interval until the failure point (VB = 0.3mm) was reached. In all the experimentation, the test sequences were randomized to account for possible effects of bar diameter, bar position, or other biases.

RESULTS AND DISCUSSION

Flank wear was found to be the primary wear mechanism under each test condition. Figure 1 shows typical flank wear found during cutting.

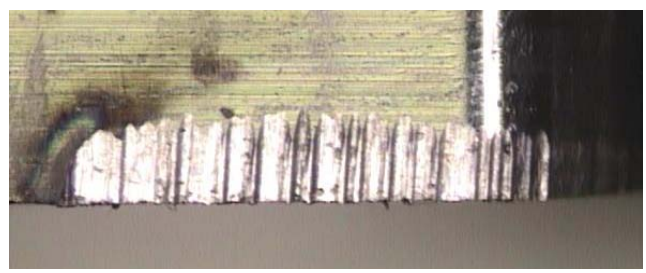

FIGURE 1 TYPICAL FLANK WEAR LAND

Material property testing results are shown in Table 2. Measured density is shown next to calculated (theoretical) density. In most cases the measured value is quite close to the expected density. The higher density of Re and superalloy compared to Co explains the large difference between the density of the first three tools and the remaining grades. Vickers hardness results are shown in the table as well. As expected, the alternative binder grades were much harder than the Co-only grades. Commercial carbide cutting tools typically have hardness in the range 1600 – 1700 Kg/mm^2. Grades A1 and A2 are slightly higher than that range and grade A3 is slightly lower (due to higher binder %). The samples with TiCTaC in the carbide phase (A2, A13) show increased hardness compared to A1 and A8, which have the same binders but only WC. Although the replacement of Co with superalloy in the alternative-binder grades is expected to increase hardness, only modest evidence is present that this was achieved. It is noted that the A4 grade did not come out as hard

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as expected. It would be expected to be much more similar to A5 and A6, just as A7 through A9 and A10 through A12 are similar.

The Palmquist fracture toughness values listed in Table 2 show how hardness typically trades off for toughness, since the toughest samples were the three Co-only grades; i.e., with

TABLE 2 MEASURED MATERIAL PROPERTIES

	Density, g/cm^3		Hardness HV, Kg/mm^2	Toughness MPa-m$^{0.5}$
	Theo	Meas		
A1	14.88	15.11±.05	1820±30	12.2
A2	14.71	14.86±.05	1900±20	11.5
A3	14.48	14.61±.1	1540±40	14.7±.5
A4	15.79	15.84±.05	2060±40	7.5±.5
A5	15.88	15.89±.05	2330±30	6.6±.5
A6	15.87	15.78±.05	2470±40	7.0±.5
A7	15.46	15.56±.05	2270±20	6.5±.5
A8	15.45	15.50±.05	2210±20	6.4±.5
A9	15.44	15.50±.05	2240±20	6.3±.5
A10	15.09	15.06±.05	2030±20	9.5±.4
A11	15.03	14.86±.1	2100±20	8.5±.5
A12	15.01	15.06±.05	2080±40	8.9±.4
A13	15.29	15.36±.1	2300±40	6.4±.4
A14	15.40	15.42±.05	2130±30	7.1±.4

lowest hardness. The highest toughnesses among the alternative binder grades are A10 through A12 since these have the least Re and hence the lowest hardness. For these three grades, their toughness approaches that of traditional carbides, and may therefore be good selections for interrupted cutting applications. Ceramic tools, including SiC_w-Al_2O_3, are typically no higher than 6 MPam$^{0.5}$ fracture toughness.

In the machining tests, the Co-only tools (A1) were nearly always outperformed by the alternative binder tools. This was true at both 50m/min and 75m/min cutting speed. Figure 2 shows the results for 50 m/min, where the Co-only curve is for grade A1, the 8.4% Re curve is an average of grades A4, A5, and A6, and the 5% Re and 1.6% Re curves are averages of grades A7-A9, and grades A10-A12, respectively. In addition to the consistent superior performance of the alternative binder tools in general, it is observed that as the percentage of Re in the binder increases, less flank wear is measured on the tool. From the lowest to the highest amount of Re (1.6% and 8.4%, respectively) the total flank wear measured is reduced by almost 40%. The tools that had the most Re showed on average less than 50% of the wear experienced by the Co-only tools, even though grade A4, which had a lower than expected hardness value, did not perform as well as A5 and A6. Its low hardness may be attributed to errors in the manufacturing process and/or defects in the inserts. Further testing on grade A4 is planned to investigate the discrepancy.

The data in Figure 2 includes error bars (95% confidence intervals) to represent the uncertainty in the data based on replicated tests. Since the bars overlap in several cases, it is difficult to confirm a statistical difference for many of the comparisons. Therefore, a standard statistical analysis of

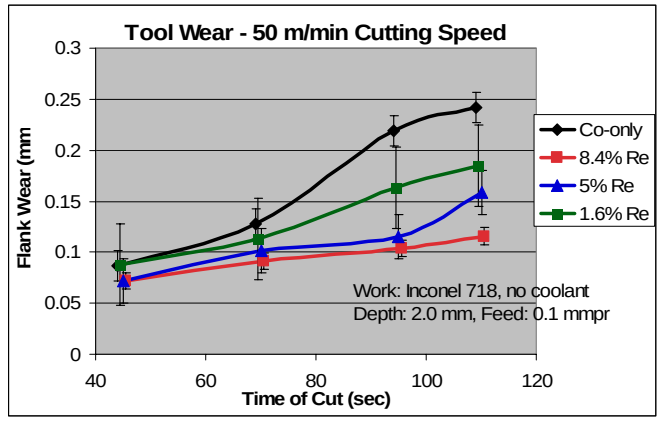

FIGURE 2 INCONEL 718 WEAR TESTS AT 50 M/MIN

variance (ANOVA) based on the 3^2 factorial design [56] was performed to confirm the differences between the alternative binder tools. Results are shown in Table 3 for tool wear after 110 seconds of cutting. The main factor effect of Re % is statistically significance (α=.05) based on the high F ratio comparing the effect variance with that due to replication. Although the main effect of superalloy-to-Co ratio (SA ratio) is also found to be significant after 110 seconds, its effect is relatively small and confounded by the similar magnitude of the Re%-SA ratio interaction. Neither the SA ratio nor the interaction was significant at other cut times. The lack of a clear effect of the SA ratio mirrors the insignificant effect on the material hardness in Table 2.

TABLE 3 ANOVA AFTER 110 SEC. CUTTING AT 50 M/MIN

ANOVA Table				
Source	Sum Sq	DOF	Mean Sq	F ratio
Re%	0.0146	2	0.00731	46.39
SA Ratio	0.00228	2	0.00114	7.24
Re/SA Int	0.00383	4	0.000958	6.08
Error	0.00142	9	0.000158	
Total	0.0221	17		

At the increased speeds of 75m/min, results show a similarly clear advantage for the alternative binder tools, but the improvement in performance is not as great. As seen in Figure 3, the best alternative binder tools exhibit a tool life (based on VB = 0.3 mm) approximately 40% longer than the cobalt-only grade, compared with a much more dramatic difference at 50 m/min. Furthermore, the effect of Re % on tool wear is not

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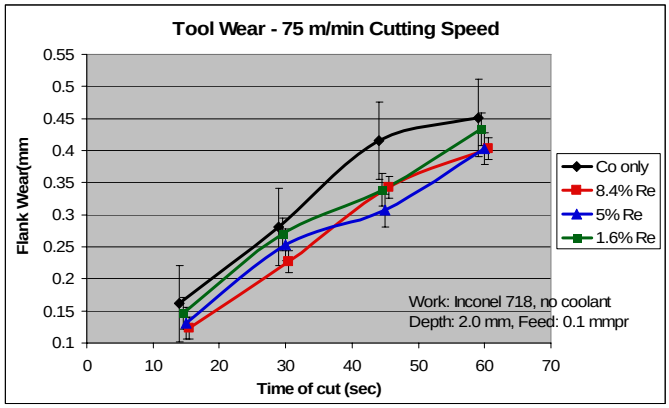

FIGURE 3 INCONEL 718 WEAR TESTS AT 75 M/MIN

nearly as clear. Although a statistical analysis confirms evidence of the beneficial effect of the alternative binder, the strength of the Re% effect appears to be dependent on the SA ratio (i.e., large interaction effect). The main effects of Re% and SA ratio are inconsistent compared to the interaction, and the overall results suggest that a few poorly performing grades (especially A4 and A12) are influencing the results. The harsher cutting conditions at 75 m/min appear to have reduced the individual effects of the binder constituents and increased the variability in performance.

Results for the second experiment (grades A2, A3, A13, A14) are shown in Figures 4 and 5 for the two cutting speeds, 50 and 75 m/min. The alternative binder tools A13 and A14 (each with 50% Re, and 1:1 SA:Co ratio) again perform significantly better (α=.05) on average than the Co-only tools (A2, A3), averaging just 60-70% of the wear at the slower speed and 80-90% at the higher speed. In these cases, however, the effect of the alternative binder is strongly dependent on the overall binder %, with its clear improvement only seen for the 16% binder grades

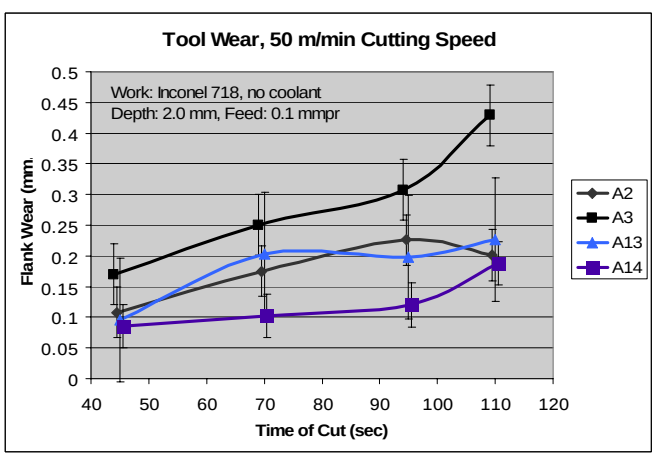

FIGURE 4 INCONEL 718 AT 50 M/MIN (EXPER. #2)

(i.e., A14 vs. A3). As with the first experiment, greater differences are seen at the slower speed (i.e., longer tool life).

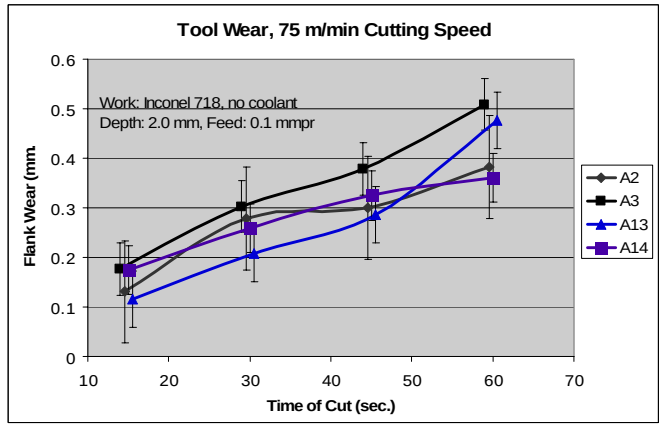

FIGURE 5 INCONEL 718 AT 75M/MIN (EXPER. #2)

The actual effect of binder % (and TiCTaC presence) in the second experiments (Figures 4 and 5) is not shown to be consistent. As expected with a smaller binder % (and higher measured hardness), A2 consistently performs better than A3 for the cobalt only grades. Within the alternative binder tools, however, A13 performs poorer than expected in most cases.

Significant porosity and edge-grinding defects that were observed on the A13 tools may be responsible for the increased wear seen in the tests, but additional experimentation will be needed to confirm that suspicion. Of course it may also be true that with the harder alternative binders, the % of binder has less (or an opposite) effect.

Finally, the best performing tools overall (A5,A6) were run along with A1, A7, and A11 to ultimate failure at 50 m/min in order to estimate the increase in tool life achievable with the alternative binder tools. As shown in Figure 6, the best alternative binder tools achieve approximately 400 seconds tool life prior to reaching VB = 0.3 mm wear, while A1 lasts just 160 seconds. The alternative binder tools increased tool life 150%.

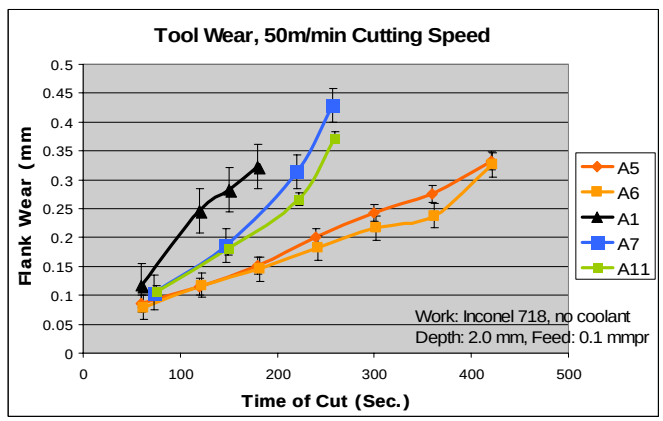

FIGURE 6 TOOLS A1, A5, A6, A7, A11 RUN TO FAILURE

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Based on the data from Figures 3 and 6 for tools A5/A6 at the two cutting speeds, the parameter n for a simple Taylor tool life model comparing speed V to life T,

$$VT^n = \text{Constant} \quad (1)$$

is calculated as

$$n = \frac{\ln(75/50)}{\ln(400/40)} = \underline{.18} \quad (2)$$

for the alternative binder tools. Based on this model, to achieve

a comparable tool life compared to the cobalt only tools (e.g., 160 seconds at 50 m/min) the cutting speed could be increased by 18% if the alternative binder tools were used; i.e., $50(400/160)^{.18} = 59$ m/min.

CONCLUSIONS

A set of cutting tool samples was produced based on a new class of tungsten carbide composite made with alternative binder metals including rhenium and nickel-based superalloy. The new tools were tested for hardness and toughness and subject to turning experiments on Inconel 718. Several grades of tooling, made by varying the amounts of each binder constituent and the overall proportion of binder in the composite, were tested and measured for wear. Based on the results, the following conclusions can be drawn.

- Tungsten carbide tools bound with rhenium, cobalt, and nickel-based superalloy can be used to cut Inconel 718 effectively.
- The tools with alternative binders showed significantly less wear compared to tools bound only with cobalt. The best alternative binder tools lasted 150% longer than cobalt only tools when cutting at 50 m/min.
- The advantage of the alternative binder tools diminished as cutting speeds increased and all the tool lives were shortened.
- The improved performance of alternative binder tools compared to cobalt only tools allows an increase of 18% cutting speed without sacrificing tool life.
- Increasing rhenium content in the binder improved wear resistance roughly proportionately at 50 m/min.
- No clear effect was evident from varying the superalloy-to-cobalt ratio in the alternative binders.
- The typical effect of increased wear resistance from a smaller binder % was not evident in the alternative binder tools.

Additional experimentation is planned to further confirm and clarify the results obtained in this study. Since most sources recommend coated tools for cutting superalloys [27,53], especially with PVD-coated TiAlN, future experimentation will investigate the life-enhancing effects of coatings to further improve performance of alternative binder cutting tools. Ultimately, the performance of the alternative binder tools will also be examined under conditions of interrupted cutting and on a variety of different work materials.

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