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Review Paper on Development of Nano Inserts for Machining HRSA Materials for Aerospace Applications

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Abstract

In the current scenario, cutting tool industries use the powder material tungsten carbide of 60-80 microns grain size to produce cutting inserts. There are a lot of scopes to improve the properties of cutting tool materials to enhance their ability to machine challenging materials like heat resistant super alloys (HRSA). Reducing the grain size of cutting tool material powder to nano level may help to increase the strength, substrate hardness, Fracture toughness, and thermal conductivity of the cutting insert. This review studies different strategies used to develop nano powders for the cutting tool application. We observed that most of the studies focused on the latest powders used in cutting tool industries like tungsten carbide, boron carbide powders which are reduced as nano powders, pressed, and sintered with different techniques like hot isostatic pressing (HIP), Spark plasma sintering. Finally, the current research gaps and the future challenges in understanding the development of nano powders for cutting tool applications are critically discussed, providing an interpretation of the possible directions for scientific development in this field.

Keywords: *HRSA, Cutting tools, Nano powders, Tungsten carbide, Grain growth inhibitors, Spark Plasma sintering.*

1.0 Introduction

Metal cutting is a traditional manufacturing process to produce the required components. In the manufacturing process, specifically in metal cutting processes, it is very important to increase the tool life while machining challenging materials like heat resistant super alloys used in aerospace applications. The temperature plays a crucial role in machining: it increases the tool wear and reduces the tool life; it causes the thermal deformation of the component, machine, and cutting tool, which affects the machining accuracy; it induces the residual stresses and activates the thermal defects. There is a wide variety of cutting tool materials used for metal cutting applications. But among them, tungsten carbide is dominating because of its unique mechanical and electrochemical properties. The performance of tungsten carbide especially in cutting tool applications can be improved by reducing its grain size. Due to their smaller sizes, it attains higher surface area, which provides additional active sites for reactants. Thus, it will be an interesting study to develop tungsten carbide nano powders.

Initial literature work started with collecting more information about HRSA material which was chosen as a potential challenge to machine material in the aerospace industry. In many studies tool life of cutting inserts was analyzed while machining Inconel 718 with different focuses like turning, milling, cutting parameters, and machining process. However, no researchers worked on the base material of the cutting tool. So, this research focuses on powder

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material used to produce cutting inserts. In the era of nanotechnology, typically, particles not exceeding 100 nm in dimension on an atomic and molecular scale will be considered nanoparticles. If we observe the research going on in material science, we can observe the significant contributions of nanotechnology in recent days. There are several breakthrough technologies developed using nanotechnology [15]. There are different approaches through which we can synthesize nanomaterials some of the processing techniques are top-down and bottom-up techniques. In the top-down technique, bulk-shaped materials will be broken into smaller sizes until the microstructure exhibits nanostructure. While the bottom-up approach involves synthesizing crystalline materials from nanocrystalline particles, atoms, ions, or molecules are orderly put together as an assembly structure.

2.0 Background of research

In the aerospace industry, three major sets of component categories require machining. First one is structural parts, where CFRP (carbon fiber reinforced polymers) material dominates. The second one is engine parts, where heat combustion takes place, so nickel-based HRSA (heat resistant super alloy) materials are used widely to produce these components. The last one is landing gears here high chromium materials will be used. Before starting this project, I did one survey asking some questions to aerospace industry experts in 12 different industries. One of the crucial questions in that survey was related to the material they use in their industry. We found the answers as shown in Fig.1.

In this survey, we understood that even though there are different materials used in aerospace components, For the combustion engines, HRSA materials, mainly Inconel 718, are the best-suited material, and there are a lot of scopes to help in the machining of the same. In this study, we will be focusing more on HRSA materials because those are the only promising materials in combustion and turbine sections of aerospace engines. However, machining HRSA is comparatively difficult from normal steel or stainless steel, because of its properties like hardness, toughness, and strength. But some properties like corrosion resistance, retention of strength and hardness at high temperatures, etc. make these materials more attractive for usage in aerospace engines, medical equipment's, gas turbines, oil, and gas industries. HRSA materials classified into three groups as shown in Table 1.

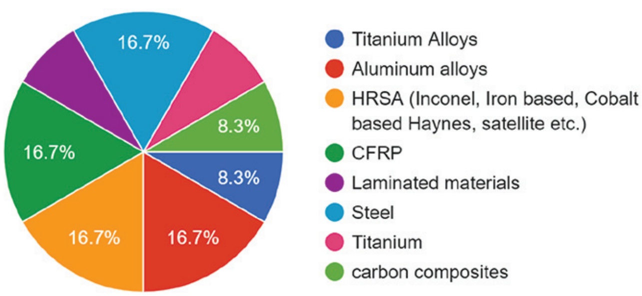


Fig. 1: Results of survey related to material used in Aerospace industries

Nowadays aerospace and energy industries are emerging, and it created more requirements for heat-resistant metals, such as nickel-based alloys. Among all HRSA materials, Inconel 718 is the one that constitutes 35% of all heat-resistant metal production [1]. The HRSA materials, mainly Inconel 718, are used widely for the combustor and turbine parts of the aero engine. Those components of engines work in high temperatures, thus materials of those components demand high strength, excellent oxidation, corrosion resistance, and creep. Components of jet/rocket engines, turbine engines, and turbine blades, must have good efficiency because of higher operating temperatures. Superalloys are used in super-critical steam-generating electricity plants as operating temperatures move bey [3]. Inconel 718 is having good heat resistance, but it has several issues in machining, generally while machining Inconel cutting tool failure happens because of adhesion, notch wear, built-up edge, and chipping of cutting edge.

Currently, in the industries, Inconel 718 will be machined using the below-mentioned strategy, rough machining will use tungsten carbide cutting tools with suitable grades and coatings. For semi finishing ceramic and for finishing operations will use CBN cutting tools.

But in both cases, tool life is the central issue. While using tungsten carbide, generally, cutting edges wear out within 20 minutes while machining of the workpiece. The machine operator must frequently index or replace the cutting edge while machining Inconel 718. It leads to an increase in the cost of production due to the waste of man and machine time. Earlier the research was conducted to increase the tool life while machining Inconel material, but still, there are limitations. So, through this study, we want to contribute

Table 1

Nickle based HRSA	Inconel 718, 706, 625.
	Hastelloy
	Nimonic
	Waspaloy
Iron based HRSA	Greek Ascoloy
	Incoloy 909
Cobalt based HRSA	Hayness
	Stellite

towards improving the tool life while machining Inconel 718 by conducting our study in terms of developing cutting inserts through nano material. If we prioritize roughing operations of Inconel 718, tungsten carbide powders of a grain size of 50-60 microns are significant materials used to make cutting inserts. This study examines recent studies on the different techniques to reduce the grain size to nano level, and press it to the required shape of an insert. And also different sintering methods, like HIP and SPS (spark plasma sintering), can be tested. The positive effect of nanoparticles may help to improve the properties like hardness and yield strength. Through this, we can make sure that the wear resistance of cutting tool material is good enough to provide increased tool life. Along with new powder, coating layers also plays crucial role in cutting inserts. By providing different alternate coating techniques. We can get the best advantages of nanostructures so that we can achieve improved wear resistance chemical stability higher hardness, better fracture toughness for the cutting insert. Thus it may help us to improve the Tool life [2].

3.0 Machining HRSA Materials

Initial literature work started with collecting more information about HRSA material which was chosen as a potential challenge to machine material in the aerospace industry. In many studies tool life of cutting inserts was analyzed while machining Inconel 718 with different focuses like turning, milling, cutting parameters, and machining process. However, no researchers worked on the base material of the cutting tool. So, this research focuses on powder material used to produce cutting inserts.

Nils Potthoff et al. [1] investigated the wear evolution of cutting insert while machining nickel based alloys like Inconel 718. Here the influence of cutting parameters which results in tool wear is studied. They investigated the tool wear while machining with different path strategies and also while using coolant and without coolant. Through design of experiments they identified suitable process parameter values and identified flank wear. The affect of lubricant coolant on the process forces and tool wear progression were studied. And finally it was concluded that the trochoidal path strategy with coolant could improve the tool life in comparison with other machining path strategy and without coolant. Damir Grguras et al. [3] investigated the suitability of the solid round ceramic end mills for high-speed machining Inconel 718 which is one of the nickel-based alloys. In this paper, the machining process using a solid round ceramic end mill was compared to the milling process using carbide tools while machining Inconel 718. The results show ceramic tools offer an increase in productivity, however, overall efficiency is still questioned concerning cost. The results show that the material removal rate (MRR) was more while machining with ceramic end milling tools regardless of their shorter lifetime. Carbide tools can be used for machining Inconel 718, but its tool life will be very less. However, ceramic end milling tools offer higher MRR. But due to the high brittleness of ceramic end mills and also the huge cost difference between ceramic tools and carbide tools, it is difficult for medium-scale industries to use ceramic end mills in regular machining operations. Thus it is very much necessary to have a different set of cutting tool materials that should possess good hardness, toughness, and fracture strength. This thought process resulted in studying nanopowders from tungsten carbide materials.

4.0 Tungsten Carbide Nano Powders

In the era of nanotechnology, typically, particles not exceeding 100 nm in dimensions on an atomic and molecular scale will be considered nanoparticles. If we observe the research going on in material science, we can observe the significant contributions of nanotechnology in recent days. There are several breakthrough technologies developed using nanotechnology [15]. There are different approaches through which we can synthesize nanomaterials some of the processing techniques are top-down and bottom-up techniques. In the top-down technique, bulk-shaped materials will be broken into smaller sizes until the microstructure exhibits nanostructure. While the bottom-up approach involves synthesizing crystalline materials from nanocrystalline particles, atoms, ions, or molecules are orderly put together as an assembly structure. Similarly, WC nano powders also can be developed through different techniques, many researchers tried to produce WC nanopowder but no one tried it for industrial applications. There are several challenges to doing the same as, the properties of the powder, and its processability [15]. Gourav Singla et al. [15] worked on his thesis and he gave some conclusions on the different synthesis techniques for the development of tungsten carbide nano powder. Through this initial study we can learn that decrease in the grain size helps to improve the substrate hardness of tungsten carbide.

Figure 2 shows finer grainsize in tungsten carbide increases the substrate hardness and strength but decreases the toughness. With proper addition of inhibitors and nanoparticles we should be able to get the cutting insert with good strength, substrate hardness, Fracture toughness and thermal conductivity. Through this we are planning to conduct similar exercise even with boron carbide powder. In the case of currently used tungsten carbide material, literatures say that lower the cobalt percentage is and smaller

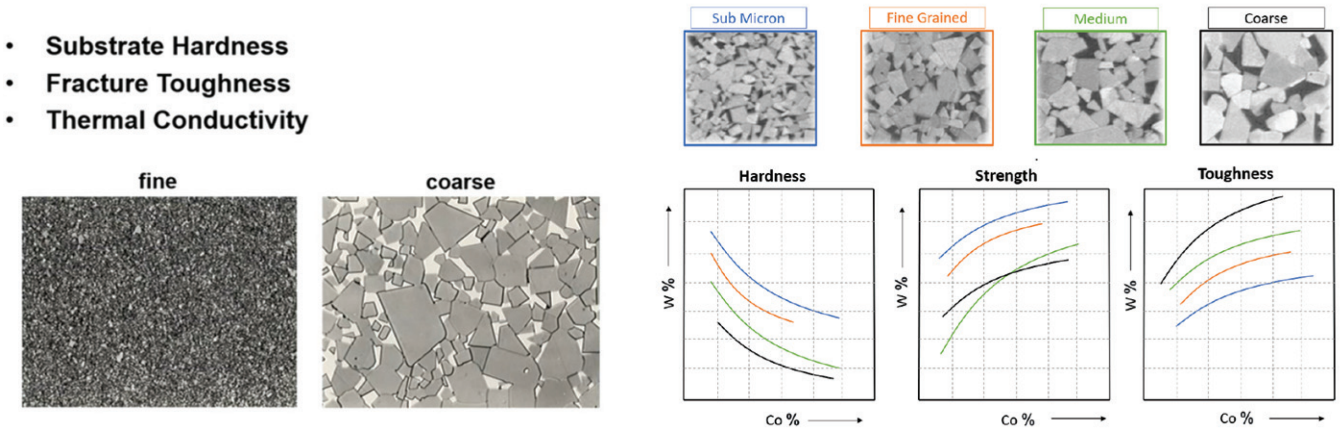
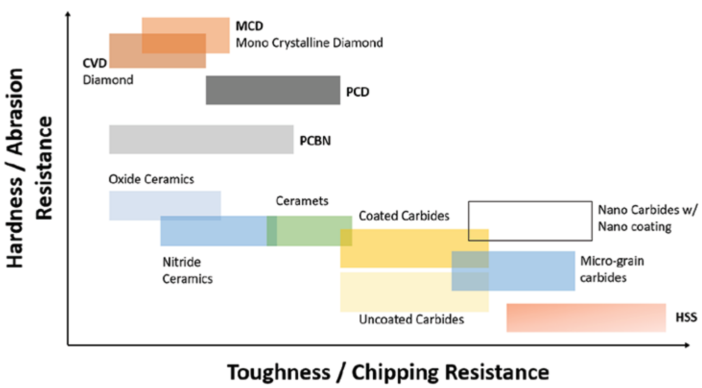


Fig. 2: Effect of grain size on the properties of WC



Properties of tungsten carbide

Youngs modulus	600 MPA
Density	15.63 g/cm3
Thermal Conductivity	110 W/(m·K)
Boiling Point	6000 °C
Poisson's Ratio	0.21
Melting Point	2,785–2,830 °C

Fig 3: Cutting tool materials based on its properties

the grain size will be the harder carbide. The higher the cobalt percentage is and larger will be the grain size tougher on the carbide.

Fig.3 shows nano carbide cutting inserts has large scope in machining of complex materials due to its combined properties of abrasion resistance and chipping resistance.

M. Mahmoodan et.al [13] worked on the grain growth of tungsten carbide nano powders during the sintering process. They added tantalum carbide and vanadium carbide as grain growth inhibitors, and they were successful in increasing the fracture toughness along with reduced grain size up to 380nm.

F. M. Kustasz, L. L. Fehrehnbacherz, R. Kornanduri et. al [6] proved that multilayered nano coatings reduce tool wear while drilling titanium alloy. Effect of multilayer nanocoating's on tungsten carbide cutting tools and HSS tools were compared through this study. Here they used balanced magnetron sputtering process to deposit multilayer nanocoating's (100 bilayers of 13A B4C/18AW) on cemented WC-Co tools and HSS drills. Comparison of tool life was done for coated and uncoated inserts while machining the material AlSl 4140 steel (302 BHN) at 105 m/min in dry condition. New coated insert is shown better results. While drilling titanium materials with HSS drills generally there will be seizure of drill with component. This new coating helped to reduce torque by 33% as well as there was no seizure while dry drilling the material Ti-6AI-4V alloy with multilayer-coated HSS drills. H. Hegab et.al [7] focused on effect of lubricants with nanoparticles like MWCNT, during machining Inconel 718. Through this study, we can observe that the addition of 4% of MWCNT nanoparticles in the existing lubricant of MQL will be helpful in the reduction of flank wear of the cutting insert. When comparing other nanoparticles like Al_2O_3, carbon nanotubes showed better results in terms of tool wear and surface quality. This study helped us to understand how the nanofluids helped to reduce tool wear while machining Inconel 718. Here multi-walled carbon nanotubes (MWCNT) are used as nanoparticles in coolant fluid. Xiaoyong Ren, Zhijian Peng et. al [9] in their research explored, binder less WC with diffrent amounts of ZrC nano-powder (0–9 wt.%) was used and they used spark plasma

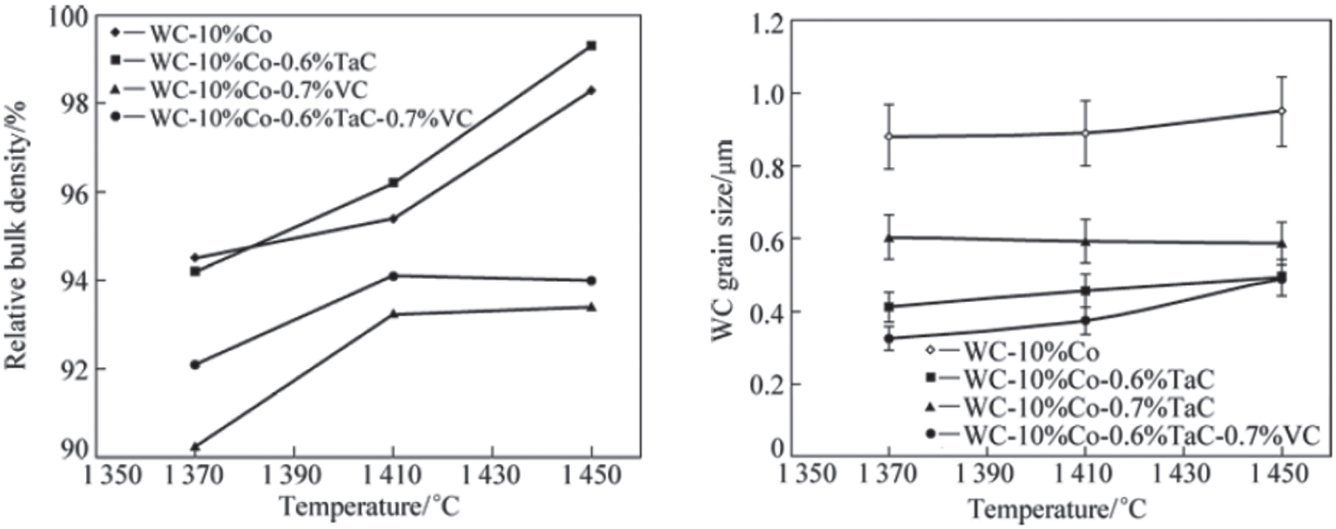


Fig 4: Relative bulk densities of sample v/s sintering temp and WC grain size in sinetred samples at various temperature [13]

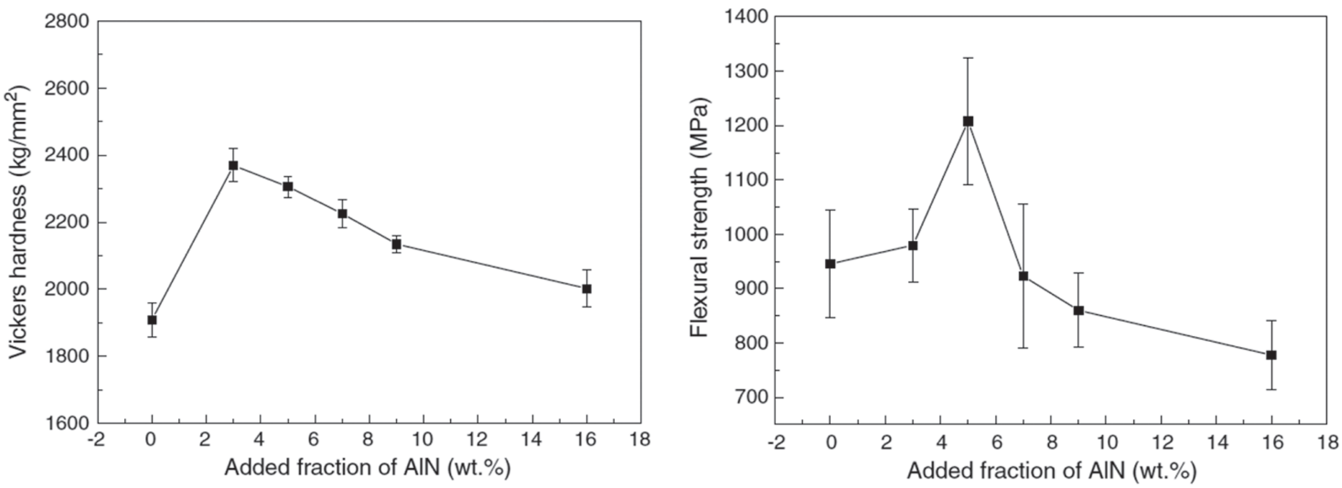


Fig 5: Hardness and Flexural strength of the WC–nano-AlN samples as a function of the added fraction of AlN nano-powder [18]

sintering technique. Shrinkage was observed at different temperature, and it was observed that relative density of the sample was good when the mixture of 1–3 wt.% ZrC nano-powder was added into the tungsten carbide. It was concluded that addition of 1% nano particles like ZrC into the tungsten carbide powder and processing the mixture through spark plasma sintering may help us to improve the hardness and fracture toughness of the sample.

Guangbiao Dong et. al [10] utilized conventional powder metallurgy techniques used to develop samples by adding tungsten carbide to the Ti(C,N) based nano Cermet's. This study concluded that the abnormal grain growth can be decreased in nano Ti(C, N)-based cermet's, by addition of WC. It will help to improve the mechanical properties of Cermet's. Research of Xianhua Tian, Jun Zhaon et. al [11] was focused on fabrication of Si_3N_4/(W, Ti)C/Co nano-composite ceramic tool materials with better mechanical properties. This study concludes that addition of cobalt to Si_3N_4 ceramics can improve the flexural strength and fracture toughness, but it may decrease the hardness.

S. Faraga, I. Konyashina, b, et. al [12] reviewed in detail about effect of grain growth inhabitors (GGI). Through this study we can understand the influence of grain growth inhibitors on fine nano hard metal powders like WC. This review discusses about different GGI nano particles doped into hard metal powders like WC also its effect on microstructures and properties. Xiaoyong Ren et al [18] experimented on ultrafine binderless tungsten carbide with

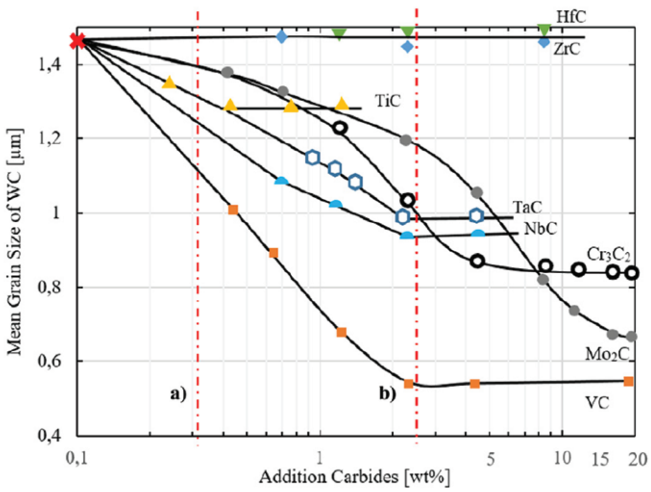


Fig 6: Dependence of the mean grain size of a WC-20wt%Co carbide additions at (a) low doping content and (b) high doping content [14]

varied amount of aluminum nitride nano powders fabricated through spark plasma sintering technique. Here ultrafine tungsten carbide powder was mixed with varied amount of AlN nano powders, ranging from 0-16 wt% and this powder was sintered through spark plasma sintering technique. Then different mechanical properties along with phase composition, densification behaviour and microsturure of prepared samples were investigated. It was observed that hardness and flexural strength increased along with addition of AlN nanopowder up to 3 wt% and then started decreasing.

Through this study it was evident that ultrafine binderless WC-nano-AlN powders with gransize of 0.7 microns can be fabricated through spark plasma sintering technique with the addition of grain growth inhibitors like vanadium carbide and tantulum carbide. S. Farag et. al [14] reviewed on the influence of grain growth inhibitors (GGI) on the microstructure of tungsten carbide with different grain size. Here different techniques of controlling the growth of grain size in sintering process was illustrated. Here different techniques like, “passive grain growth inhibition”, “active grain growth inhibition”, and “unconventional GGIs and grain growth inhibition techniques” were discussed.

According to Hayashi et al. the different additives are ranked in order of decreasing grain inhibition potential as follows: VC > NbC > TaC/TiC>Mo2C/Cr3C2 > ZrC/HfC (valid at low doping amounts).

5.0 Summary/Conclusions

In this review, we identified that the significant research gap is that, no one explored different cutting tool materials on HRSA materials. Most of the researchers worked on either process or cutting parameters. So, we can conduct research from the material powder until the testing of Inconel 718 material to optimize tool life. If we achieve a better tool life, it will significantly benefit the aerospace and energy industries where Inconel material is used to a large extent. To achieve this we have to develop a novel powder material that should possess the combination of the best mechanical properties like hardness and toughness. As we observed in several kinds of research, tungsten carbide nanomaterial must have such properties. The major challenge is the industrial development of WC nanopowders and also pressing and sintering techniques. From the overall observation of this study, we can conclude that there are possibilities to develop WC nanopowders with help of grain growth inhibitors and we can produce cutting inserts through spark plasma sintering techniques.

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