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Investigation of boron nitride-based nano composite in cutting tool for enhancing efficiency

Dr. K. Anandan*[1], Mr. D. Saravanan[2], Mr. D. Manivannan[3], Mr. G. Arun kumar[4], K. Saravanasuriya[5]

[1]Professor,
[2, 3,4]Assistant Professor, Department of Mechanical Engineering,
P. S. V. College of Engineering and Technology, Tamil Nadu, India
[5]Student, Department of Mechanical Engineering,
P. S. V. College of Engineering and Technology, Tamil Nadu, India

*Corresponding Author: Dr. K. Anandan
Email: *anandandmeena@gmail.com*

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Abstract:

Many production processes make use of machining tools. The performance characteristics of the tools greatly influence the cost and quality of the final products. The existing machine is improved with superior qualities by the reinforcement of diverse materials with based materials made utilising new manufacturing techniques. Due to its high strength and light weight characteristics, aluminum composites are quickly making their way into commercial use. Steel, cemented carbides, ceramics, and exceptionally hard materials are the primary materials utilized to make machining tools. Creating new Nano composites based on these materials is a promising strategy to enhance their performance properties. Steel, cemented carbides, ceramics, and exceptionally hard materials are the primary materials utilized to make machining tools. Creating new Nano composites based on these materials is a promising strategy to enhance their performance properties. Micromechanical modeling can be used to produce composite materials for machining tools, lowering the cost and time associated with creating new tools with improved performance. In order to improve the performance and properties of machining tools, this article covers recent developments in various nano composites groups.

Keywords:

Wear, Nano Composites, Aluminum 356 Alloy.

1. Introduction:

Machining tools are the most important means of production. They need to be characterized by high productivity, wear-resistance and technological effectiveness. The quality of the tools plays an important role in the machine- building and energy sectors, and many other industries. The BN based Nano composites Machining tools are used in many areas of production. The cost and quality of the finished items are significantly influenced by the tool performance characteristics. The main materials used to build machining tools include steel, cemented carbides, ceramics, and extremely hard materials. Composite materials are created when two materials with different physical and chemical properties are mixed.

When they are mixed, they produce a substance that is specifically designed to perform a given task, such as being stronger, lighter, or electrically resistant. They can also increase strength and stiffness. The main benefit of composite materials is their combination of strength, stiffness, and lightweight.

Advanced materials like hybrid composites are produced by reinforcing a base alloy with two or more potential particles. This approach provides superior properties without compromising on the individual properties of both the materials. Manufacturers can produce properties that exactly fit the requirements for a particular structure for a particular purpose by selecting an appropriate combination of reinforcement and matrix material.

1.1. Nano Composites:

Nano composites are a subclass of nanomaterials that consist of one or more nanoscale phases embedded in a ceramic, metal, or polymer material. These phases can be constructed of inorganic or organic materials at the molecular level to create novel features. Nano composites can be found in nature, such as in the bone and abalone shell structures.

The use of materials with a lot of nanoparticles precedes knowledge of their physical and chemical properties by a long shot. By adding nanoscale fillers with at least one dimensionally consistent length, nanocomposites are created. A new type of hybrid materials called nanocomposite can have much better functional qualities (e.g. electrical conductivity). The electrical conductivity of polymer matrices can be improved by adding suitable nanoscale metallic components.

1.2. Properties:

Materials known as nanocomposites contain nanoscale particles within a matrix of conventional material. Nanocomposites can significantly enhance qualities like: Strength, modulus, and dimensional stability are examples of mechanical qualities.Conductivity of electricity. Decreased permeability of water, gas, and hydrocarbons. Technical characteristics (strength, bulk modules, withstands limit, etc.). Thermal stability inhibits flame and lowers the production of smoke. Solvents, water, and gases are less permeable. Additional appearance an increase in electrical conductivity. Increased resistance to chemicals.

1.3. Application:

Numerous industries are now using nano composites, and new ones are constantly being created. Nano composites are used in applications like: Computer chip thin-film capacitors batteries using solid polymer electrolytes.Fuel tanks and components of automobile engines blades and impellers.

2. Selection of Materials and Methodology:

2.1. Aluminum 356 Alloy:

An aluminium alloy for casting is called A356. There are 1xx.x series in the cast aluminium alloy designation system. The 3xx.x series denotes that boron combined with nitride and/or carbide is the main alloying element. The minimal percentage of aluminium can be seen in the second and third figures. Whether the alloy is a casting or an ingot is indicated by the number that comes after the decimal point. A greater purity version of an alloy's chemical makeup is indicated by the letter A before its designation. The Aluminum Association has given this substance the designation A356.0 (AA). It has the SAE identifier 336 and the UNS standard A13560. The casting and machining performance of A356 aluminium die casting alloy is excellent. Pump housings, impellers, high-velocity blowers, and other structural castings that are appropriate for use in aviation

Table. 1: Properties of Al A356 Alloy

Density	2.6 g/cm³
Yield Tensile strength	83-200 MPa
Elongation at break	3-6%
Melting temperature (Tm)	570°C

Thermal conductivity(k)	150 W/mk
Thermal expansion	21 mm/m-k
Shear Modulus	26 GPa
Fatigue Strength	50-90 MPa
Ultimate Tensile S	160-270 MPa

In applications requiring high strength with little weight, such as structural casting, pump housings, impellers, high velocity blowers, and aviation parts, aluminium A356 alloy is employed. utilised mostly in cylinder heads. A356 aluminium, which offers lightweight, pressure tightness, and excellent mechanical qualities, is frequently utilised to create elaborate and complex aluminium castings. Sometimes. An alternative to 6061 aluminium is A356. The aluminium and its nanometric view as shown in fig. 1and fig. 2.

Figure. 1: Aluminium is A356

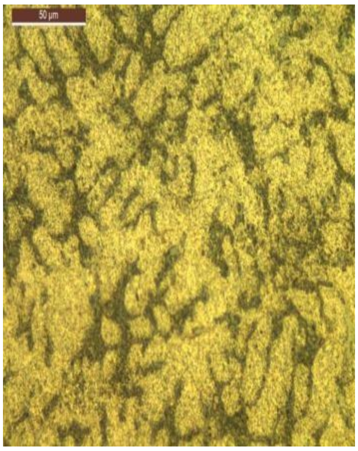


Figure. 2: 100 Nano meter view of aluminum 356 alloys

2.2. Boron Nitride (Reinforcement Material)

The refractory material known as boron nitride, having the chemical formula BN, is thermally and chemically resistant. It can be found in a number of crystalline forms that are isoelectronic to a lattice of carbon with a comparable structure. The most stable and pliable of the BN polymorphs, the hexagonal form corresponding to graphite, is employed as a lubricant and an ingredient in cosmetic products. The c-BN version of the cubic (zinc blende sphalerite structure) variety is softer than diamond but has greater chemical and thermal resilience. The uncommon wurtzite BN alteration is softer than the cubic form but similar to ions dolerite.

Table. 2: Properties of Boron Nitride

Chemical Formula	BN
Molar mass	24.82 g/mol
Density	2.1 g/cm³ (h-BN); 3.45 g/cm³ (c-BN)
Appearance	Colorless crystals
Melting point	2,973 °C (5,383 °F; 3,246 K) sublimates (CBN)
Solubility in water	Insoluble
Electron Mobility	200 cm²/(V.s) (CBN)
Refractive Index (np)	1.8 (h-BN); 2.1 (c-BN)

3. Preparation of Materials:

3.1. Stir Casting Process:

The stir casting technique requires continuously stirring the melt, which exposes the melt surface to the environment and tends to lower the amount of aluminium while leaving the reinforcing particles separate. A mechanical stirrer is used in the stir casting process to create a vortex that mixes the reinforcement with the matrix material. Due to its low cost, suitability for mass production, simplicity, nearly net shaping, and ease of composite structure control, it is an appropriate procedure for producing metal matrix composites.

A furnace, reinforcement feeder, and mechanical stirrer make up a stir casting apparatus. The ingredients are heated and melted in the furnace. The bottom poring furnace is better suited for stir casting because instant poring is needed to prevent the solid particles from settling in the bottom of the crucible after stirring the combined slurry.

In order to create the vortex that facilitates the mixing of the reinforcement materials added to the melt, a mechanical stirrer is used. The impeller blade and the stirring rod make up a stirrer. The geometry and number of blades of the impeller blade might vary. The three-number flat blade is preferred because it creates an axial flow pattern in the crucible while using less power.

The matrix material is retained in the bottom pouring furnace for melting during one of the several processes involved in the stir casting process. In order to remove moisture, contaminants, etc., reinforcements are simultaneously warmed at a specific temperature in a different furnace. After the matrix material has melted at a certain temperature, mechanical stirring is started to create a vortex for a set amount of time, after which the feeder included in the setup is used to feed reinforcement particles at a constant rate into the centre of the vortex. The stirring process is then continued for a set amount of time. As shown in fig. 3(a) and (b).

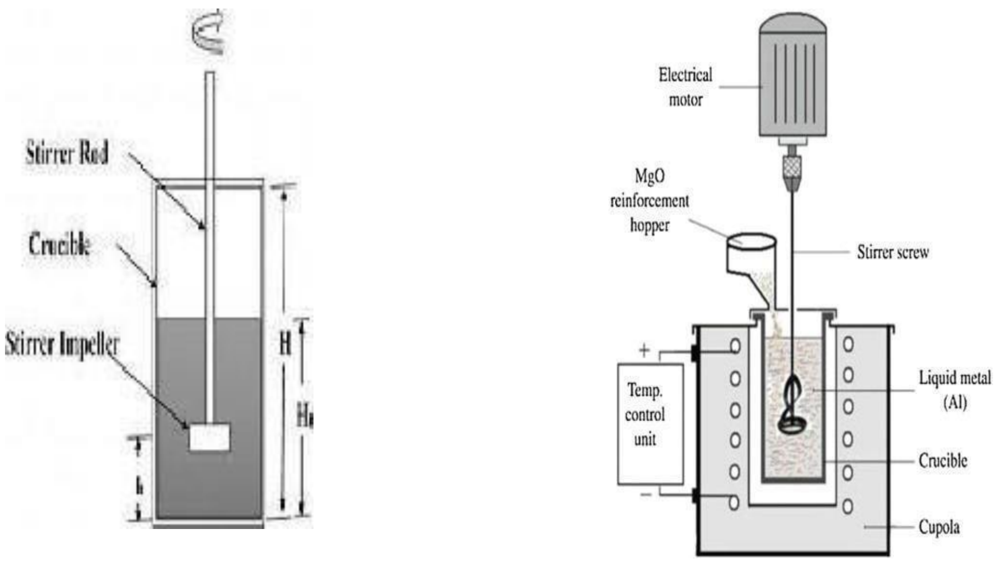


Fig.3. (a) and (b) preparation of materials for stir casting process

3.2. Process Parameter:

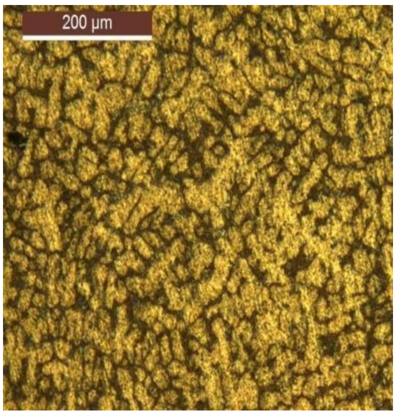
Maintaining certain stable process parameters is necessary whenperforming the stir casting process. These procedure parameters will be determined by the researchers based on the necessary qualities and the reinforcement supplied to the base materials. The stirring speed, temperature, stirring time, feed rate, and other factors are process parameters for the stir casting process. These restrictions are established based on the researchers' review of the literature.

Table. 3: Specification for Preparation

Reinforcement time casting duration	30 min
Pre heating temperature	105°C
Stir speed	350 rpm

Both the matrix base material and the reinforcing material should be at the ideal temperature. The amount of time and pace of stirring affect how well the base material and reinforcing material are combined. The following diagram illustrates the ideal production conditions for an aluminium A356 composite reinforced with silicon nitride.

The reinforcement melts well at 610°C, the melting point of the base material A356, and 350 rpm stirrer speed was maintained for 10 minutes. A composite material with the best foundation and reinforcement material was created by the stirrer. To produce the best combination, the stirrer's impeller should also be kept at a specific distance. To achieve a well-mixed mixture of A356 and boron nitride, the material should be fed into the crucible at a rate of 0.8 to 1.5 g/s. Then the nanometer view of A356 +5% and +15% of BN as shown in fig 4(a) and (b) and also fig. 5(a) and (b).



(a)

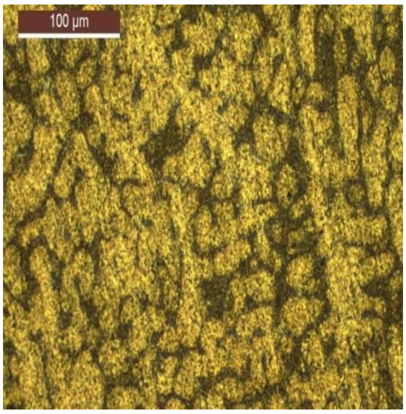
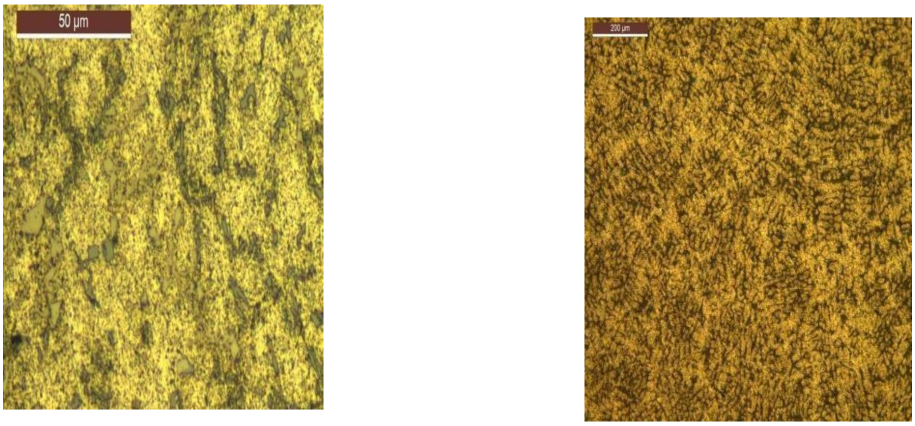


Figure. 4: (a) And (b) Nanometer view of A356 alloy+5% of BN



(a) *(b)*

Figure. 5: (a) and (b) of Nanometer view of A356 alloy+5% of BN

3.3. Micro Hardness Test:

An indentation is made in a metal surface using the non-destructive hardness test method, which includes exerting a consistent load with a rounded or pointed item under controlled circumstances. The material's hardness is then gauged based on this measurement. It provided information on a material's capacity to withstand being indented and, as a result, indicated strength, wear resistance, and toughness.

In order to make an indentation in the material surface, a rounded or pointed indenter must be subjected to a steady load. The hardness is then determined by measuring the depth of penetration. Although it can be performed independently, it is typically combined with other mechanical tests to provide a comprehensive evaluation of the material's qualities. As shown in fig. 6. From the results of the hardness test, it was evident that the hardness value increases along with an increase in the weight percentage of reinforcement material. This describes how boron nitride helped the composite material's hardness increase. The specimen with the lowest weight percentage of boron nitride had a hardness of 77 MPa, whereas the specimen with the highest weight percentage had an 87 MPa hardness. As a result, the hardness value increases from 77 to 87 MPa when the weight percentage of silicon nitride is increased from 5 to 15. As a result, the mixture's hardness was increased by the addition of boro

Table. 4: Hardness Value

Specimens	Material	Load	Result
1	A356 alloy	1Kg	72HV
2	A356 alloy+5% of BN		77HV
3	A356alloy+15% of BN		87HV

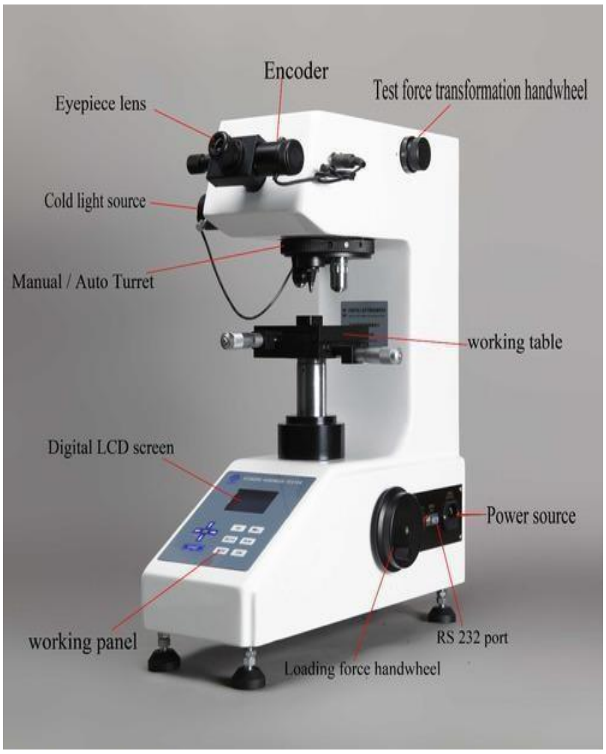


Figure. 6: Hardness test machine

3.4. Wear Test:

Wear refers to the material's deteriorating, sluggish removal or distortion at solid surfaces. Wear can have chemical or mechanical causes. Tribology is the study of wear and associated processes. Wear is caused by the detachment of particles that make up wear debris as well as by the plastic displacement of surface and near-surface material. The range of the particle size is between millimeters and nanometers. As shown in fig. 7.

Figure. 7: Wear Test Machine

Table. 5: Hardness Value

Specimen	**Load (N)**	**Weight Before Sliding(g)**	**Weight After Sliding(g)**	**Wear Rate (g/m)**	**Coefficient of Friction**
A356	20	5.920	5.879	$2.05*10^{-5}$	0.20
	40	5.879	5.790	$4.45*10^{-5}$	0.25
A356+5% of BN	20	5.725	5.690	$1.75*10^{-5}$	0.32
	40	5.690	5.638	$2.6*10^{-5}$	0.38
A356+15 % of BN	20	5.987	5.960	$1.35*10^{-5}$	0.39
	40	5.960	5.928	$1.6*10^{-5}$	0.43

3.5. Pin On Disc Apparatus:

Pin on disc testing is arguably one of the most used tribometers used for characterisation of friction and wear (usually wear rates and wear resistance) in materials. The method's popularity can be attributed to its relative simplicity and abundance of tribological contacts that can be accurately described by a straightforward pin-on-disk motion, ranging from the dry contacts of bolt screws to the lubricated contacts of biological implants. Various motion modes, including unidirectional, fretting, and more recently, any other complex motion patterns, are often tested during the test.

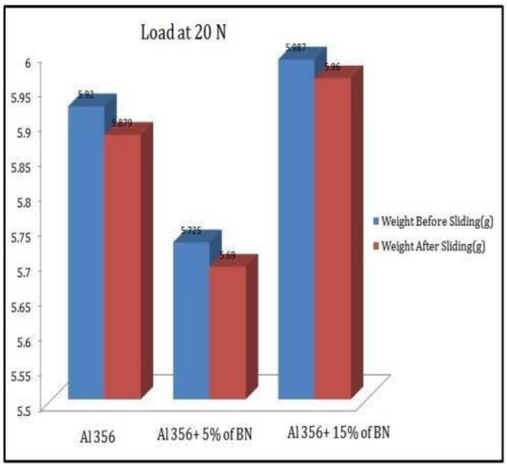
The tests are typically carried out in accordance with ASTM G99, G133, and F732 testing standards. Under the applied stress, the rotating disc is pressed against the stationary pin. The pin can be any shape; however, because of their simplicity of alignment, spherical (ball or lens) and cylindrical shapes are the most common (flat pins are typically subject to certain misalignment which can lead to non-uniform loading and difficulties for theoretical analysis). Temperature, wear, and friction force are continuously measured throughout the test. The size of machine components is being reduced, power is being increased, maintenance is being reduced, and dependability is being improved.

These specifications test the bounds of design and necessitate creative solutions. It would be extremely expensive and time-consuming to test these ideas on an entire computer. As a result, prior to full-scale tests, tribological research is frequently conducted using the universal experimental set-ups. The Coefficient of Friction (CoF) and wear rate are determined using the pin on disc testing procedure.

The ASTM G99 standard is followed for conducting the wear test. The specimen holder is tightly clamped to the sample specimen.

To obtain the desired or correct output, the various process parameters should be set to their optimal values. The parameters for the sliding path, speed, load, and other factors should be specified properly. Based on the literature review, we determined the ideal sliding distance and speed for this project. We varied the applied load for three specimens with varying boron nitride weight percentages from 20 N to 40 N. Similar calculations and tables were made for the other wear rate and coefficient of friction values for other weight percentages of 0, 5, and 15. The values are obtained for 2 types of loads, including 20 and 40N, by maintaining the sliding distance as constant.

To obtain the desired or correct output, the various process parameters should be set to their optimal values. A technique called optical microscopy is used to magnify a sample and view it using visible light. This is a type of microscopy known as addition, which was created in the 18th century and is still in use today. An optical microscope, commonly referred to as a light microscope, makes use of one or more lenses to magnify visible light images of small materials. The lenses are positioned between the sample and the viewer's eye to enlarge the image and enable closer examination. As shown in Fig.8. (a) And (b) Graph: BN wt.% vs Wear rate.A micrograph can be produced by an optical microscope utilising common light-sensitive cameras. In the past, photographic film was used to record because eyepieces are no longer required, using the device is more convenient. The molecular and objective lenses of a compound optical microscope determine its magnification strength. It is equivalent to the sum of these lenses' powers, so a 10x ocular lens combined with a 100x objective lens would result in a 1000x final magnification. As shown in Fig.9. (a) and (b) Graph: BN wt.% vs Wear rate



(a)

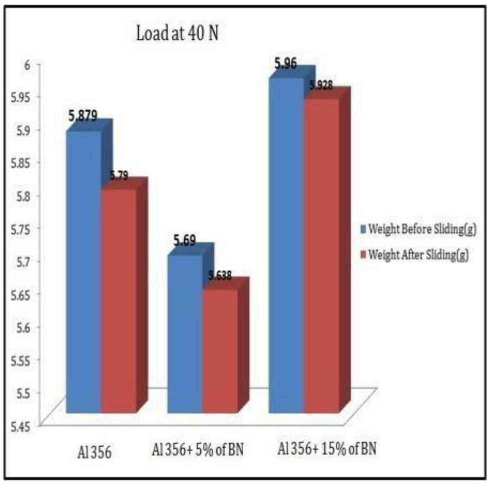
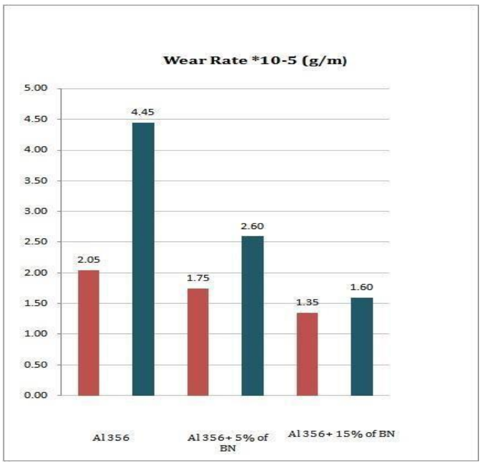


Figure. 8: (a) and (b) Graph: BN wt. % vs Wear rate



(a)

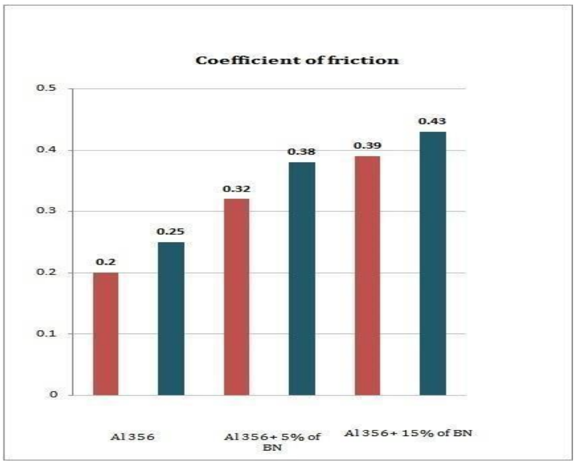


Figure. 9: (a) and (b) Graph: BN wt. % vs Wear rate

4. Conclusion:

Because of their distinctive architectures, superior mechanical capabilities, and resistance to wear, nano composites are receiving a lot of attention in the context of contemporary tool materials. A particular function is played by metallic, ceramic, and cemented carbide binders that have been enhanced with carbon nanotubes and the improvement in material hardness and yield strength, which results in an increase in wear-resistance and tool life, is one of the benefits of BN modification. 2017 materials 10, 1171 of 19.

Despite the fact that the market for machining tools is expanding quickly, producers are still trying to develop new materials that are durable, affordable, and can successfully replace the best benchmark specimens currently available. The goal of all these ican offer the best levels of production.

The mechanical characteristics and performance of materials can be significantly improved by adding nanoparticles of two or more types to metallic and ceramic matrices. In order to further create machining tools with improved qualities, studies of the interaction of the dislocation front with the nanoparticles upon the deformation of such hybrid materials, as well as hybrid modification using carbon nanotubes and hexagonal boron nitride, are also promising.

The development of hybrid nanomaterials with the best possible combination of their mechanical properties will be made easier by mathematical modeling, resulting in improved tool performance. Additionally, major efforts must be undertaken to eliminate the known weaknesses of current top-level tool materials.

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