Chapter

Graphene Composite Cutting Tool for Conventional Machining

Gaurav Saini, Sarabjeet Singh Sidhu and Simranpreet Singh Gill

Abstract

Cutting is an important process in the manufacturing industry and cutting tool is an important element in machining. It is essential to use good quality cutting tools in arrange to maintain the quality of a product. To retain the performance of cutting tool, various techniques have been utilized like cutting fluid, cutting under MQL, coating, multilayer coating, cryoprocessing, different types of surface texturing, different types of solid lubricants, etc. All these processes have a great impact to enhance the mechanical, thermal, and tribological properties in case of conventional machining process. Nowadays composite engineered materials are very successful in metal cutting industry due to its wear-related application and excellent mechanical and thermal properties. A very few research has been carried out on graphene mixed composite tool material, which has very high demand in manufacturing industries, due to its application as a cutting tool material for machining of Al, copper, or high strength carbon steel. In the end, challenges in the processing of tungsten carbide graphene mixed self-lubricated tool have been identified from the literature. In parallel, the latest improvements to enhance the properties of tungsten carbide-cobalt cutting tool with graphene mixed are reviewed.

Keywords: tungsten carbide, tool life, powder metallurgy, spark plasma sintering, graphene nano-powder

1. Introduction

Today, almost every manufacturing industry is focused on improving productivity and reducing operational cost associated with machining operation [1]. In the current machining scenario, this can be achieved by implementing several changes such as providing required training to skilled workers, procuring better material, and using better quality cutting tools. Cutting tools being the heart of a machining system requires attention while selection of its material and other specifications such as tool life due to its high cost. The quality of the tools plays an important role in the machine-building and energy sectors, and many other industries. They need to be characterized by high productivity, wear resistance, and technological effectiveness.

Cutting tools are made of different types of materials such as carbon tool steel, high-speed steel, cemented carbide, boron nitride, and diamond tools [2]. All these materials have different mechanical and tribological properties, but particularly for steel cutting applications, cemented tungsten carbide is a commonly used material in the manufacturing industry. Various studies have been made over the generation for further improvement of cemented carbide properties to meet the severe cutting conditions. Various studies have also reviewed different ways to improve tool life by various types of coatings on tungsten carbide–based cutting tools [3]. However, the results of these studies vary due to different process parameters and manufacturing technology. In general, materials for cutting tools must possess high hardness, sufficient toughness, as well as hot strength in order to withstand high working temperature during the machining process. Also, hardness is one of the important factors that determine the life of tool at extreme temperature conditions. Therefore, high-speed steel and cast-cobalt alloys are no longer preferable as cutting tools [4].

Cemented carbides were initially introduced in the 1930s to overcome the challenge of high cutting speed that was impossible with the high-speed steel tool material. Cemented carbide shows high hardness (which is adequately stable over a wide range of temperature), high elastic modulus, high thermal conductivity and low thermal expansion. It is most widely used in machining, drilling and other related applications [5]. The use of tungsten carbide cutting tool is growing faster in metal cutting industry. Tungsten cemented carbide typically comprises tungsten carbide (WC) particles bonded together in cobalt (Co) matrix. WC-Co properties depend upon hard and brittle carbide, while cobalt as a metal binder provides ductility and toughness to the composite. Today, hard metal industry is focusing on the advancement of all cutting tools like high-speed steel, cemented carbide, and ceramic to obtain better grained composite to maximize hardness while maintaining reasonable toughness in order to meet the extreme cutting conditions. As compared to speed steel and ceramic, cemented carbide tool has high hardness, high wear resistance, good strength, and toughness and retains hardness at high temperature [6].

There are various types of techniques that have been utilized to improve the performance of cutting tool like cutting fluid, coating, multilayer coating, cryoprocessing, different types of surface texturing, and applied solid lubricants as shown in **Figure 1**. There are many studies that concern the enhancement of properties of various cutting tool, but there is no dedicated summarization of composite cutting tool works. Hence, the current study summarizes the different work done to improve the properties of WC-Co composite utilizing different consolidation and sintering techniques.

2. WC-Co-based cutting tool materials

WC-CO has become one of the most common materials for many applications requiring high temperature and high wear resistance like cutting tool in manufacturing industry [7]. It also includes machining of cast iron, various non-ferrous metals, etc. WC-based composite tool materials normally possess higher hardness, strength, thermal conductivity, chipping resistance, and plastic deformation resistance and have been universally used in high-speed cutting. These attractive properties gave it great potential to be used as high-speed cutting tool materials. But the application of WC as cutting tools is severely limited due to low fracture toughness. Cemented

1.
Cutting fluid

2.
Coating and Multilayer coating

3.
Cryogenic Processing

4.
Surface Texturing

5.
Soild lubricants

6.
Composite cutting tool

Figure 1.
Various techniques to improve the performance of cutting tool.

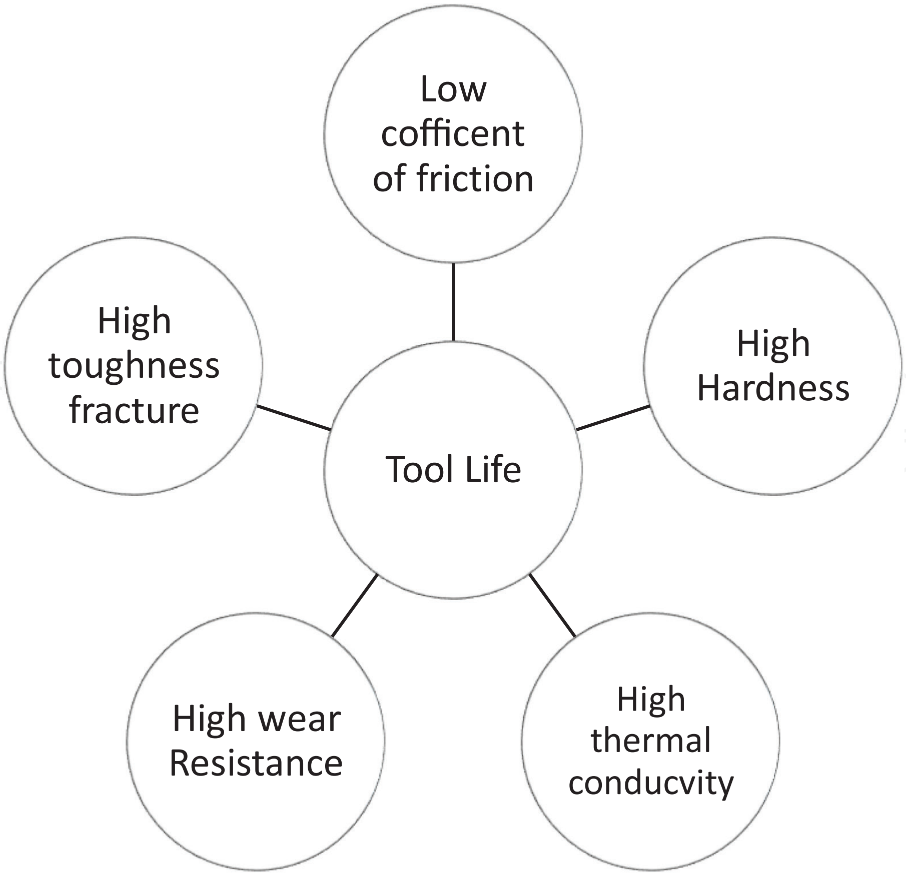


Figure 2.
Tool life depends upon various factors.

carbides belong to the most common and the longest-used tool materials produced by powder metallurgy methods [8, 9]. Sintered carbides are characterized by their high strength and abrasion resistance and include one or more high-melting metal carbides constituting the basic component together with the metallic binding phase. The basic component of cemented carbides is WC, which, depending on the manufacturer and group of material applications, can constitute from 50% to 90% by weight of the sintered content. Cemented carbides have replaced high-speed steels in metalworking and mining. Cemented carbides are metal-ceramic composites that consist of hard tungsten, titanium, and tantalum carbide grains located in a ductile matrix (binder) based on cobalt or nickel and have a unique combination of high hardness, wear-resistance, and toughness [10]. By now, a large number of cemented carbide grades have been developed, with diverse combinations of components both in the carbide phase and in the binder. Nowadays market distribution of cutting tool material has shown that cemented carbide has a dispersion of 53%, high-speed steel has a dispersion of 20% [11]. As we know, tool life of cutting tool depends upon various factors as shown in **Figure 2**.

3. Classification of composite cutting tool

Composite is the combination of two main constitutions namely matrix and reinforcement with the specific end goal to enhance the properties [12]. In recent years, cutting tool industry move from metal cutting tool to composite cutting tool. The function of the matrix is to hold the reinforcement particles in position by surrounding and supporting them. The reinforcements generally have an impact on mechanical and physical properties or any other tailored property enhanced from the matrix material [13]. The combination of a wide variety of reinforcement materials for specific effect on matrix allows the researchers to choose an optimum combination of materials to make a product and also classification of composite material as shown in **Figure 3**.

3.1 Classification of composites based on matrix material

3.1.1 Metal matrix composite (MMC)

A metal matrix composite is a combination of two or more constituents, of which at least one should be a metal, and the other may be a metal, ceramic or organic

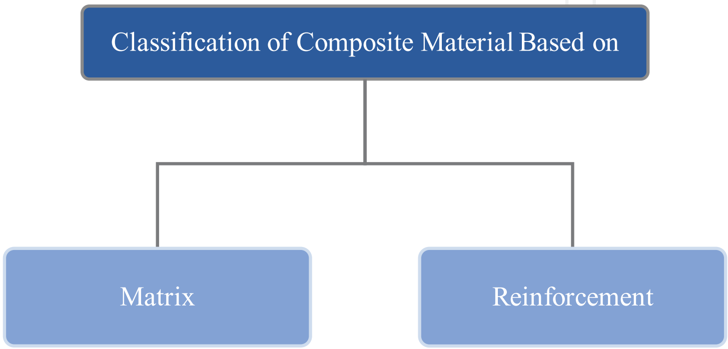


Figure 3.
Classifications of composite materials.

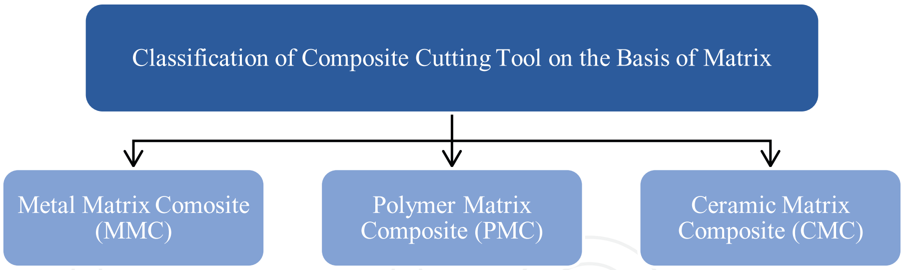


Figure 4.
Classification of composite cutting tool.

compound [14]. Various matrix used in MMC are aluminum, copper, magnesium, and iron. Oxides, carbides, and solid lubricants such as graphite and MoS2 are the common reinforcements used in MMCs.

3.1.2 Polymer matrix composites (PMC)

Polymer matrix composites are composed of thermoplastic or thermosetting plastic as matrix with one or more reinforcements such as glass, steel, carbon and natural fibers.

3.1.3 Ceramic matrix composites (CMC)

Ceramic matrix composites uses ceramic material as matrix and fibers embedded on the matrix made of other ceramic material **Figure 4**.

3.2 Advantages of MMC over metals

1. Lighter density and better mechanical properties with an increase in strength per unit weight
2. Better dimensional stability during sintering
3. Better creep resistance with higher-temperature withstanding capabilities

3.3 Advantages of MMC over PMC

1. Can service better at high-temperature environments.
2. Electrical and thermal conductivity is higher compared to PMC.
3. It can transfer the load better in transverse direction, by which better properties in transverse direction are achievable and have better joining characteristics.
4. Survives better when subjected to radiation such as nuclear, laser, and UV.
5. Improved fatigue resistance.

4. Graphene as a reinforcement

Since 2004, graphene is treated as one of the most wonderful achievements in the field of science and technology Graphene is an attractive alternative to other carbon nanofillers (CNT, CNF, etc.). From the mechanical point of view surface engineering is also meant to be considered an attractive instrument for tribological challenges, several solutions involving chemical, structural and morphological modification by means of adding graphene on surface topography, can be adopted with the aim of improving performances, reducing friction and wear, and/or increasing hardness and toughness [15]. Latest trend has shown that texturing the surfaces of cutting tools can have a beneficial influence on the tribological properties when cutting different types of materials [16]. Moreover, surface textures can act as reservoirs for cutting fluid and increase the fluid's retention on the tool surface leading to enhanced lubrication and cooling. Surface texturing includes modifications of exterior geography, making a uniform smaller scale help with consistently formed severities or depressions. Latest research has considered an advancement of small-scale dimples for automobile portions including bearing and cylinder rings. This examination highlighted the significance of different examples and its impact on decreasing the friction coefficient [17].

Graphene is a novel material in today's scientific world and possesses some excellent properties, such as large specific area, two-dimensional high aspect ratio sheet geometry, and outstanding mechanical, electrical, and thermal properties [18]. The hexagonal crystalline single layer of graphite (the simplest form and one of the most important crystalline allotropes of carbon atoms having a C—C bond distance of 0.142 nm) has received massive attention in the field of sensors, bio-medicals, composite materials and microelectronics. Thus, graphene is the strongest and best conductive material [19]. Graphene platelets or multi-layer graphene has been used as toughening additives to enhance the mechanical properties of various cutting tool materials [20]. Graphene and carbon nanotubes have attracted much attention in recent years due to their extremely high thermal conductivity, strength and exceptional tribological behavior. Graphene possesses similar mechanical properties as CNTs but has superior electrical and thermal properties, and a larger surface area (2620 m^2/g) [21] because of its 2-dimensional crystal structure. High strength, high thermal properties, and tribological behavior make graphene a good candidate as a reinforcement material for MMCs. Still, study of WC-Co-based cutting tool material made by graphene powder is quite a few **Table 1**.

Density	Melting point	Young's modulus	Coefficient of friction	Thermal conductivity
2.0 g/cm^3	4237 °C	1034 GPa	0.03	More than 3000 W/mK

Table 1.
The properties of multilayer graphene used as reinforcement.

5. Fabrications methods

The development of fabrication processes for the production of high-performance composites has been reported in many research studies [22]. **Figure 5** illustrates various fabrication techniques that were in use for the last few years. The following methods are most common for fabrication of the MMCs at large-scale industrial level.

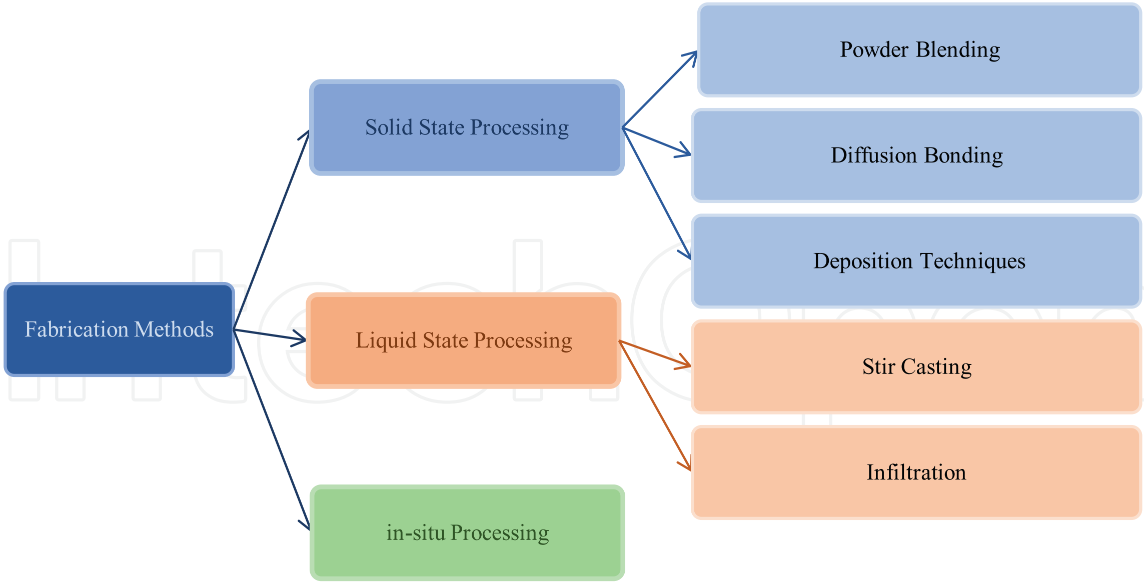


Figure 5.
Different fabrication method of composite cutting tool.

In the past decade, there has been a research done on the fabrication of MMCs with the different proportions of reinforcement for obtaining the required properties.

Liquid-state processing is defined as the incorporation of reinforcement in the matrix in molten form to prepare metal matrix composite. The various advantages of liquid-state processing are:

- Faster processing rate, especially when dealing with low melting point alloys of aluminum and magnesium. It can also produce near net shape of the final component in a single step.

Liquid-state processing of metal matrix composites involves incorporating or combining a liquid metal matrix with the reinforcement. The most common liquid-phase processing techniques can be subdivided into four major categories:

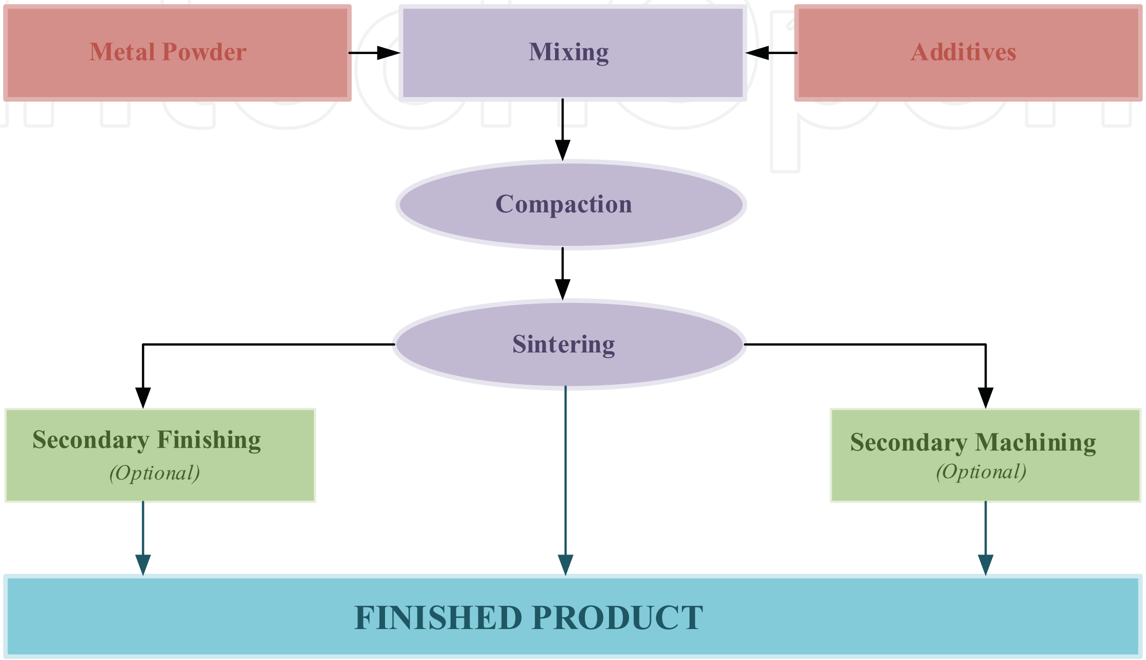
- Casting or liquid infiltration
- Squeeze casting or pressure infiltration
- Spray co-deposition
- Infiltration

Solid-state processing is preferred because of the following drawbacks in the liquid-state processing:

- Distribution of reinforcement is difficult to control.
- Achievement of uniform microstructure is difficult.

The most common solid-phase processes are based on powder metallurgy techniques, which generally use discontinuous reinforcements such as flakes/particulates/

short fibers, since it is easy to do the mixing and blend with it and much more effective to reduce the porosity [23]. During the process, the ceramic and metal powders are mixed, are statically cold compacted, sintered, and hot pressed to get higher densification or it may be mixed and blended followed by direct hot isostatic pressing to achieve the full density. Further secondary processing such as extrusion, forging etc., might be required to achieve the final shape of the component.



In-situ processing involves chemical reactions that result in the creation of a reinforcing phase within a metal matrix. The reinforcements can be formed from the precipitation in liquid or solid. This method provides thermodynamic compatibility at the matrix reinforcement interface. The reinforcement surfaces are also likely to be free of contamination and, therefore, a stronger matrix-dispersion bond can be achieved. Different researchers reported the benefits of using these techniques such as lower processing time, temperature as well as the capabilities of producing near net shape, high densification rate and less energy required.

6. Previous work on fabrication of tungsten carbide-cobalt-based composite

In the literature, various methods have been introduced such as coating, MQL, cryogenics, microwave heating, and high-pressure coolant cutting to improve the performance of various cutting tools.

Arshi [24] have studied to improve surface roughness, tool life and production rate of materials by using a protective covering of titanium nitride (TiN) over steel tools. They have obtained satisfactory results. Huang et al. [25] manufactured WC powder was prepared by the SPS process at 1873K, 8 min, 60 MPa pressure without the addition of any binder phase. Results obtained that binderless WC sintered at 1773 K for 4 min showed almost full densification with a relative density of 99.6% and higher Vickers hardness up to 2600 HV, compare to conventional WC-Co cemented carbides. Yuchi et al. [26] investigated fully dense GNS/Al_2O_3 composites fabricated from ball-milled and then expanded in a graphite die by using SPS. The result showed that conductivity increased when composite has 15% GNSs volume which was 170% higher than CNT/Al_2O_3 composites. Virendra et al. [27] studied graphene-based materials' impact on electronic devices, chemical sensors, nano-composites and energy storage. Various synthesis processes of single-layer graphene, graphene nano-ribbons, chemically derived graphene, and graphene-based polymer and nano-particle composites are reviewed. Prashantha et al. [28] have shown that graphene has noble mechanical properties, which makes it good alternative reinforcement in metal matrix composite. He has also focused on various dispersion methods, mechanisms of strengthening, composites synthesized using graphene, and their applications.

Meanwhile Bashirvand and Montazeri [29] made metal-based composite supported with carbon nanofiller such as graphene sheets and carbon nanotubes (CNTs) were proposed to join the properties of metals. These nanofillers have prompted novel materials for different applications. The outcomes showed that under the same conditions, graphene sheets performed altogether better compared to CNTs to improve thermo-mechanical. Dongguo et al. [30] manufactured a cutting tool by powder injection molding (PIM) technology using 90WC-10Co alloy. The cutting tool obtained after this technology achieved a density of 95% of theoretical density and dimension accuracy achieved was 98%. T. Wejrzanowski et al. [31] introduced the advantages and limitations of applications of single-layer graphene (SLG) and multi-layer (MLG) graphene for thermal conductivity enhancement (TCE) of copper and showed that the volume fraction of multi-layer graphene, their size, distribution and orientation may significantly affect the thermal conductivity of metal matrix composites. Das et al. [32] studied that graphene attracts particular interest due to its novel properties like high thermal conductivity, high mechanical strength and self-lubricating properties etc. Ali Nasser et al. [7] used another methodology for stabilizing a predesigned Co gradient in the microstructure of nano-WC-Co thinning structure via graphene additions is presented. For this purpose, laminated specimens of green WC-Co functionally graded material, having three layers structured, with and without graphene additions in the intermediate layer were sintered at solid and liquid sintering temperatures of 1290 and 1400°C, respectively, using the hot isostatic pressing technique (HIP).

Grasso et al. [33] demonstrated the densification of high-purity nano-structured tungsten carbide by High-Pressure Spark Plasma Sintering (HPSPS) in the unusually low-temperature range of 1200–1400°C. The high-pressure sintering up to 300 MPa produced dense material at a temperature as low as 1400°C. In comparison with more conventional sintering techniques, such as SPS (80 MPa) or hot isostatic pressing, HPSPS lowered the temperature required for full densification by 400–500°C. Bódis et al. [34] prepared silicon carbide (SiC) ceramics that have superior properties in terms of wear, corrosion, oxidation, thermal shock resistance, and high-temperature mechanical behavior, as well. In this work, SiC-based ceramics mixed with 1 wt% and 3 wt% multilayer graphene (MLG), were fabricated by solid-state spark plasma sintering (SPS) at different temperatures. It was found that MLG improved the mechanical properties of SiC-based composites due to the formation of a special microstructure. In other addition of 3 wt% MLG to SiC matrix increased the Vickers hardness and Young's modulus of composite, even at a sintering temperature of 1700°C. Suna et al. [35] investigated mechanical and tribological properties of functionally graded multilayer graphene (MLG)-reinforced WC-TiC-Al_2O_3 ceramics prepared to employ two-step sintering (TSS) are determined in this paper. Results showed that MLG can act as not only an outstanding reinforcement phase but also act as self-lubricant phase. As result demonstrated that 0.1wt% of MLG/WC-TiC-Al_2O_3 ceramics exhibit 53.3% enhancement in fracture toughness, 73.8% decrement in friction coefficient, 82.65% improvement in wear resistance in comparison with monolithic ceramics. The study of Gorti et al. [36] revealed that graphene as reinforcement could be applied in cemented carbides. WC powder with 6% cobalt (Co) and graphene (0.2%) in the form of graphene nanoplatelets (GPLs) was set up by high energy rate ball milling and ultra-sonification. After that mixture was sintered by utilizing spark plasma sintering at 1250°C for 10 min. Results found that spark plasma sintering of graphene reinforced WC-Co composite resulted in a significant increase in toughness. It gave higher hardness (400 Hv) and it makes the grain size conveyance smaller. From different studies, it is clear that the reaction of graphene is limited in spark plasma sintering (SPS) as compared to Hot isostatic processing (HIP) and Graphene goes about protective coating against oxidation.

Karthikeyan et al. [37] studied the effect of laser surface textured tungsten carbide (WC-Co) insert and filled with graphite, which helps in reducing chip adhesion during machining of aluminum AA2025 studied and the following conclusions were carried out. A tribological test was carried out to investigate the frictional behavior of untextured, textured and textured inserts filled with graphite powder. The outcome clearly showed that the coefficient of friction between work material and textured graphite filled inserts reduced approximately by 12% and 90%, respectively, when compared with untextured and textured inserts. Singh [38] proposed the near rake face cutting edge of carbide turning insert were polished and used graphene as a potential solid lubricant was applied. It was found that cutting forces and coefficient of friction at tool-chip interface diminished significantly while turning with inserts applied with graphene. It was also clear that the effect of graphene on tool-chip interface significantly decreased to almost negligible when main cutting force increased beyond 60N. Hence more sincere research and development efforts are required to make its use sustainable in machining as a solid lubricant.

Durwesh et al. [39] aimed to move toward good product quality and better productivity. We know that adverse machining conditions result in fast tool wear, a decrease in surface finish, and an increase in cutting forces. Results demonstrate that microwave-irradiated tool inserts perform better during machining of AISI 1040 steel when contrasted with uncoated inserts. The result indicated that 30.2% increase in tool hardness was observed in 30-min microwave-treated insert and tool wear was reduced by 25–35%. Chen et al. [40] presented the effect graphene and carbon nanotubes were blended with WC-Co powder and sintered by spark plasma sintering technique (SPS). The outcomes showed that adding a small amount of graphene or carbon nanotubes helped to increase the bending strength of the cemented carbide by approximately 50% while keeping the hardness of the cemented carbide constant & thermal conductivity of the cemented carbide has also increased by 10% with the addition of 0.12 wt% graphene [41]. Virendra Singh et al. [42] described that higher mechanical properties (elastic modulus and tensile strength) of graphene sheets have attracted the attention of researchers. Vandana et al. [43] investigated and talked about the addition of graphene to Al_2O_3 ceramic matrix and its effect on different mechanical properties of resulting alumina-graphene (Al-G) composite tool material. The wt% of graphene varied from 0.15 to 0.65 with an interval of 0.1%. The result showed that composite with 0.45 wt% of graphene yielded the maximum hardness and fracture toughness. Lagos et al. [44] introduced the changes in densification behavior and mechanical properties of Ti_3SiC_2 composites containing 0–40 volume % of short carbon fibers densified by Spark Plasma Sintering Technique (SPS). It was feasible to obtain fully densified composites up to 20 volume % of carbon fibers and more than 90% of the theoretical density with the 40 volume % of fibers.

Zhenhua et al. [45] examined ultrafine-grained WC-12Co-0.2VC cemented carbides prepared by using two-step spark plasma sintering (SPS) technique. Thus, the first-step (T1) and the second-step (T2) temperatures in the two-step SPS are 1300°C and 1200°C, respectively. He has talked about the effect of the holding time during the first and second steps on the mechanical properties of the specimen. The results showed that the UYG12V cemented carbide sintered at 1300°C for 3 min and then at 1200°C for 5 min has the best extensive mechanical properties, Vickers hardness, fracture toughness, relative density, and bending strength of 218.06 GPa, 12.25 MPa $m^{1/2}$, 99.49%, and 1960 MPa, respectively. Xuchao et al. [46] chose graphene as reinforcement in Al_2O_3-WC-TiC composite ceramic tool materials by hot pressing technique. The optimal flexural strength, Vickers hardness, and indentation fracture toughness were 646.31 ± 20.78 MPa, 24.64 ± 0.42 GPa, 9.42 ± 0.40 MPa $m^{1/2}$, respectively, at 0.5 volume % of graphene content, which was significantly improved compared to ceramic tool material without graphene. Yuchi et al. [47] studied to obtain fully dense GNS/Al_2O_3 composites have been fabricated from ball-milled graphite and Al_2O_3 by spark plasma sintering (SPS). The GNSs after ball processing are 2.5–20 nm in thickness and homogeneously dispersed in the ceramic matrix. The conductivity achieves 5709 S/m when composite has 15% volume GNS, which was 170% higher contrasted with the best outcome recently announced in CNT/Al_2O_3 composites. Yanju et al. [48] created ultrafine cemented carbides were set up by microwave sintering technique using WC-V8C7-Cr_3C_2-Co nano-composites as a raw material. The outcomes showed that the ultrafine solidified carbides arranged at 1300°C for 60 min have better mechanical properties. The relative density, Vickers hardness, and fracture toughness of the composite reach the maximum values of 99.79%, 1842 kg/mm^2 and 12.6 MPa $m^{1/2}$ respectively.

After studied the above literature it has observed that cutting tool made with different type of reinforcements at different manufacturing condition play a very important role on the performance of composite cutting tool. Different composite like GNS/Al_2O_3, CNT/Al_2O_3, SiC-MLG, WC-TiC-Al_2O_3, WC-CO-GPLs, Al-Gr, and Al_2O_3-WC-TiC have prepared by different consolidation techniques and they reported a beneficial influence of all these reinforcement in mechanical, densification, and thermal properties. Further, more research investigation will also be carried in future to enhance the properties, promoting the application and commercialization of improved cutting tool bit for conventional machining.

7. Processing challenges

There are different parameters that have their roles in determining the final properties of composites, e.g., starting powder size selection, morphology of starting powders, choosing the appropriate volume fractions, various processing techniques, consolidation techniques, and sintering. All the above-mentioned properties play very important roles in fabricating cutting tool, but temperature, holding time, and pressure have major roles in spark plasma sintering technique to fabricate composite cutting tool. **Table 2** showed the study of various composite cutting tool with different percentage of graphene at different temperature, holding time, and pressure, and their effect on microstructure, densification, physical, mechanical properties, and thermal conductivity have been reviewed.

Sr. no	Matrix & reinforcement	Graphene	Temperature	Consolidation process	Pressure	Holding time	Result	Year & ref no.
1	WC	—	1573–1873 K	SPS	60MPa	8 min	Vickers hardness 2600 Hv Fracture toughness 9–15 MPa $m^{1/2}$	2005 &B. Haung et al. [25]
2	Al_2O_3	GNS	1300 °C	SPS	60 MPa	3 min	Conductivity achieves 5709S/m	2010 & Fan et al. [26]
3	WC	—	1400°C	HPSPS	300 MPa	10 min	(2721 HV10) 7.2 MPa $m^{1/2}$	2013 & Grasso et al. [33]
4	WC-Co		50°C	Powder injection molding	37 MPa,	0.6 s	Final density of 14.21 g/cm^3	2015 & Lin et al. [30]
5	Mullite ($3Al_2O_3.2SiO_2$)	WC (5-20)%	1700°C	SPS	30 MPa	3 min	Maximum Strength 298 MPa and Vickers hardness 1589 HV	2016 & H. Rajaei et al. [49]
6	Steel	TiB_2	(1000°C & 1100°C)	SPS	35 MPa	5 min & 30 min	Both compression strength & hardness increased	2015 & Sulima et al. [35]
7	WC	GNP (0.5–6 wt.%)	1850°C	HP	25 MPa	60 min	Relative density 98%	2016 & Kornaus et al. [10]
8	WC-TiC-Al_2O_3	0.1 wt% MLG	1800°C	TSS	—	—	Toughness 14.5 MPa $m^{1/2}$	2017 & Sun et al. [50]
9	Silicon carbide (SiC)	3 wt% MLG	1700 °C	SPS	50 MPa	5 min	Fracture toughness increase by 20% & hardness also increase	2017 & Bodies et al. [34]
10	TiB2/TiC	0.5 wt.% GNP	1750°C	SPS	30 MPa	5 min	Fracture toughness 8.3 ± 0.43 MPa Hardness 19.3 ± 0.52 GPa	2018 & Yin et al. [51]
11	Al_2O_3-WC-TiC	0.25%	1700°C	HP	35 MPa	10 min	Vickers hardness, 646.31 ± 20.78 MPa, 24.64 ± 0.42 GPa fracture toughness, 9.42 ± 0.40 MPa $m^{1/2}$	2019 & Wang et al. [26]
12	WC-Co	MLG	1400°C	TSS		5 min	Relative density 99.8% fracture toughness 15.9 ± 1.2 $m^{1/2}$	2018 & Sun et al. [42]
13	WC-CO	(0.2%)GPL	1250 °C	SPS	50 MPa	10 min	Hardness 2000 fracture Toughness 11.8	2018 & Kiran et al. [36]
14	Al_2O_3	0.15–0.65	1500°C	Microwave furnace		30 min	Fracture toughness2.68 MPa $m^{1/2}$	2019 & Vandana et al. [43]

Sr. no	Matrix & reinforcement	Graphene	Temperature	Consolidation process	Pressure	Holding time	Result	Year & ref no.
15	WC–Co	0.12 wt%	1200°C	SPS	80 MPa	10 min	Thermal conductivity 9.86%	2019 & Chen et al. [40]
16	WC-12Co-0.2VC	—	1100°C	SPS	30 MPa	5 min	Vickers hardness, 18.06 GPa, fracture toughness12.25 MPa $m^{1/2}$	2019 & Wang et al. [45]
17	TiC	0.45 wt% MLG	1850°C	TSS	40 MPa	60min	Hardness 24.36 GPa, flexural strength 708.9 MPa fracture toughness of 7.28 MPa $mm^{1/2}$	2020 & Jialin Sun et al. [52]

Table 2.
Consolidation of different composite materials by various techniques.

Graphene, due to its unique combination of electrical, mechanical and thermal properties can greatly improve simultaneously properties of obtained composites. Addition of graphene seems a new idea is to obtain self-lubricating carbide cutting tool materials with the addition of various graphene reinforcements.

8. Conclusions

This paper gives a state of art and recent development toward various techniques to extend the lifetime of cutting tool and to improve the mechanical and tribological properties of the material. Various study revealed that graphene attracts particular interests in latest for cutting tool development due to its unique properties like high temperature operations, high mechanical strength, high thermal conductivity, and its self-lubricating properties. Previous studied has also showed that properties and microstructure of the composite depend upon strongly SPS conditions. Mostly, graphite is used as solid lubricant to improve the efficiency of various carbide tool materials; however, the study of multilayer graphene to make carbide tools as self-lubricant was relatively few. Results showed that MLG can act as not only an exceptional reinforcement phase but also act as superior self-lubricant phase. Very few Investigations have done on Graphite as reinforcement. Since not much research was done on machining and tribological analysis of fabricate cutting tool insert so far, there are lot of aspects which require improvement. More work should be done to obtain composites with higher homogeneity, which will result in fabricating samples with even better mechanical properties and higher density. Spark Plasma Sintering process seems good method for sintering powders where no degradation to graphene is required. It is strongly recommended that more in-depth studies will be carried out with regard to the preparation of composite, which leads to better mechanical parameters for obtained composites, comparable with commercial insert.

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