Carbide Cutting Tools Are Superior to High-Speed Steel (HSS) for Manufacturing: A Review

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Abstract— Manufacturing processes are greatly reliant upon machinery. Effective tools can improve performance and lower costs for production processes. Cutting tools are particularly crucial for manufacturing processes, and the present paper seeks to draw a comparison between the two abundant constituent materials used for cutting tools: carbide and HSS. Where carbide is known to exhibit impressive longevity, strength, thermal resistance and strength, HSS is known to be more cost-effective and resilient. Carbide tools are known to produce cleaner cuts with high-speed cutting, whereas HSS tools generally exhibit slower speeds. Considering specific performance parameters for both materials, it was determined that carbide cutting tools are far superior to HSS in terms of their usefulness for manufacturing processes, though a trade-off is present when considering specific properties of each.

Keywords— The carbide is better than HSS in terms of exhibit impressive longevity, strength, thermal resistance, and cheaper cost.

Introduction

As technology has advanced, there has been an increasing amount of research dedicated towards researching new materials to make manufacturing processes more efficient. Cutting tools, which may be considered as the backbone of manufacturing processes, have also evolved and there are currently various alternatives available to address extreme conditions under which cutting tools are employed, such as high stress, temperature, and corrosion. For processes such as drilling and milling turning, it is crucial that appropriate cutting tools are selected. Carbide and high-speed steel (HSS) are two of the most common materials used for cutting tools.

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It is recognized that manufacturing processes often include operating conditions that impose serious strain on cutting tools, and the required necessary characteristics must be ensured for cutting tools to be able to operate within such conditions. In recent times, various newly emerging hybrid material compositions can offer performance enhancement and longevity for tool life, through processes such as surface coatings and cryogenic incorporation (Rizzo et al., 2020; Akincioglu et al., 2015). Several hard coatings for cutting tools have been successfully employed in the industry for several decades, and these are adjusted with tool design. In this vein, the present research is centred around drawing a comparison between carbide and HSS cutting tools as viable tools for manufacturing processes.

There is research to suggest that cemented carbide constitutes a majority of the cutting materials used for tools, with a 53% prevalence of use in industry. This is followed by HSS, which shares 20% of the market. Other materials, such as ceramics, diamond and others account for the remaining 27% of the market share (Bobzin, 2017), as shown in figure 1. Given the clear abundance of use of carbide cutting tools, it may be considered that this material may boast certain desirable characteristics that enable their widespread use in the industry.

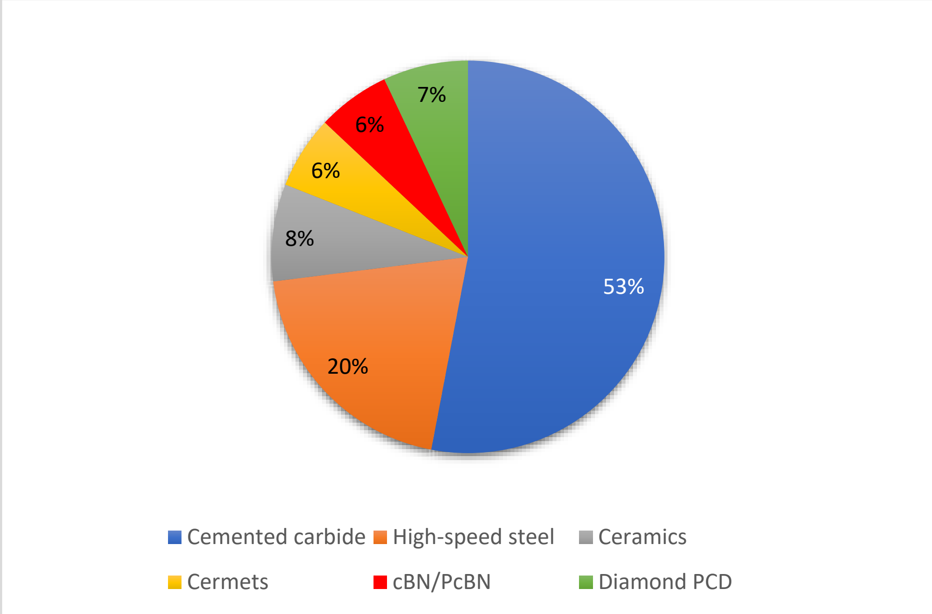

Figure 1: Market share of materials using for cutting tools (Bobzin, 2017)

The present paper seeks to address the perceived superior performance of carbide as a cutting tool material as compared with HSS. To achieve this, it is first necessary to consider a high-level overview of basic properties of each type of material, followed by a more thorough consideration of necessary performance parameters. Each material is evaluated and compared to arrive at a careful analysis of which material may be best suited for most industrial manufacturing applications.

Carbide Cutting Tools

Carbide cutting tools are made up of a binary composition of carbon together with another element, commonly tungsten or titanium. Table 1 demonstrates a commonly used composition for uncoated carbide cutting tools. The specific composition of a carbide cutting tools determines its properties, and these can also be understood by considering the specific manufacturing process that yields carbide tools. To begin with, carbon powder is mixed with the powder of another element, such as tungsten powder. Then, this granulated mixture is pressed in a die, so that it is slightly hardened. At this point, the material is similar to chalk in terms of hardness. These compacts are placed in a furnace and heated to temperatures above 1000℃, which yields the desired hardened carbide.

Table 1: Common composition of carbide cutting tools (Khairussaleh & Syed, 2017)

Element	**Weight %**
Tungsten Carbide, WC	88.4 – 90.0
Cobalt, Co	9.5 – 10.5
VC+Cr3C2	0.5 – 1.1

Several authors have studied properties of carbide cutting tools. Hausner (2012) considered basic concepts for the development of cemented titanium carbide cutting tools and suggested that it is essential to consider the chemical interactions between the binder and the carbide phases during the sintering process. The microstructure of cemented carbides is related to grain growth and dispersion. For both tungsten and titanium-based carbide tools, fractures are obtained in the fine-grained materials and these penetrate into the carbide phase when grain size exceeds 2-4 µm (Hausner, 2012).

Most carbide cutting tools employed in the present day are coated with hard materials in order to improve desirable attributes, such as tool life and machining performance. Coating processes, such as chemical vapour deposition, are widely employed techniques that layer crystal structures on to the carbide material, in order to achieve certain desirable properties for specific applications (Prengel et al., 1998). The advent of such techniques is crucial to present-day manufacturing processes, which are heavily reliant on cutting tools.

High-Speed Steel Cutting Tools

Alongside carbide cutting tools, HSS remains popular for manufacturing processes and is used primarily for the production of complex thin blade and impact-resistant metal cutting tools. HSS is essentially a class of tools steels, and it is termed as such due to its high carbon content (between 0.8 wt% to above 3 wt %). HSS also contains chromium and certain carbide forming elements, such as vanadium, tungsten and molybdenum. Often, HSS may also contain cobalt, which enhances the material's secondary hardening response (Garrison, 2001). Table 2 demonstrates common HSS types and their compositions, as explored by Dobrzanski et al. (2003).

Table 2: Common HSS compositions (Dobrzanski et al., 2013)

<table>
<tr><th rowspan="2">Steel type</th><th rowspan="2">Designation</th><th colspan="8">Average composition. wt%</th></tr>
<tr><th>C</th><th>Mn</th><th>Si</th><th>Cr</th><th>W</th><th>Mo</th><th>V</th><th>Co</th></tr>
<tr><td>9-2-2-5</td><td>SW9M2K5S</td><td>0.95</td><td rowspan="6">0.4</td><td rowspan="6">0.7</td><td rowspan="6">4.5</td><td>9.0</td><td rowspan="2">2.0</td><td rowspan="6">1.8</td><td rowspan="3">5.0</td></tr>
<tr><td>11-2-2-5</td><td>SW11M2K5S</td><td>1.05</td><td rowspan="2">11.0</td></tr>
<tr><td>11-0-2-5</td><td>SW11K5S</td><td>0.95</td><td>0.0</td></tr>
<tr><td>9-2-2</td><td>SW9M2S</td><td></td><td>9.0</td><td rowspan="2">2.0</td><td rowspan="3">0.0</td></tr>
<tr><td>11-2-2</td><td>SW11M2S</td><td>1.05</td><td rowspan="2">11.0</td></tr>
<tr><td>11-0-2</td><td>SW11S</td><td></td><td>0.0</td></tr>
<tr><td colspan="10"><0.02% P, <0.02% S</td></tr>
</table>

The addition of chromium improves the material's hardenability and reduces the likelihood of scaling. Vanadium improves overall wear resistance for the material, be it temperature-induced wear or abrasive wear. Tungsten is also beneficial in that it improves the material's cutting efficiency, makes it resistant to tempering, while also enhancing hardness and high-temperature strength. Molybdenum also improves the material's hardness and temper resistance. The presence of these, as well as other elements, serves to enhance desirable properties of HSS, and modifications of compositions can be performed to optimize the material's utility for a specific application. A distinguishing characteristic of HSS tools is the ability to obtain extremely sharp cutting edges, which are often difficult to obtain for cutting tools.

Further coatings and substrates for HSS have also been developed since its advent. Hedenqvist et al. (1990) explored the improved performance of HSS cutting tools when coated with tin using the method of physical vapour deposition. Tin coatings are able to improve desired properties of HSS cutting tools by providing a unique combination of substrate adhesion, high hot hardness and wear resistance, as well as an ability to improve the cutting-edge contact (Hedenqvist et al., 1990).

Performance Parameters & Comparison

When selecting cutting tools for specific manufacturing processes, it is essential to consider specific performance parameters, for which material properties can be evaluated. High-heat tolerance is one such crucial parameter to consider when selecting cutting tools, given the issue of overheated tools during production processes. It is known that carbide cutting tools exhibit superior thermal resistance as compared with HSS cutting tools. Steel tools are prone to deformation under extreme temperatures, and the binary carbon-tungsten or carbon-titanium composition of carbide tools provides the appropriate hot strength for carbide tools to be used for high-temperature applications.

It is also known that carbide cutting tools have a longer tool life as compared with HSS, particularly those carbide inserts that are coated with wear-resistant materials. Astrand et al. (2004) conducted a study to investigate characteristics of alumina-coated carbide cutting tools. Their research demonstrated that the lifetime of TiN-enhanced alumina carbide materials with multiple layers was twice as long as that of single-layered materials. This is best explained by the coating thickness, which improves resistance attributes. It was generally observed that the tool life was extended owing to surface properties of the tool to a large degree, not just due to the thickness of the coating (Astrand et al., 2004). Although carbide tools boast a greater lifetime, it is known that HSS is more resilient and less brittle; this is because HSS is not built to last as long as carbide, so it is not crucial to make these tools wear resistant, but rather resilience is emphasized.

Carbide cutting tools are known to exhibit cleaner cuts and finishes as compared with HSS cutting tools. This is owed to steel's relatively greater tendency to wear as compared with carbide; the latter causes little to no grain damage, with reduced incidents of kickback. These also remain sharper for a longer period of time as compared with HSS, whose cutting tools tend to dull faster. For manufacturing processes, carbide blades are ideal to cut at high speeds without binding, so the machine is not over-burdened. Sharp tips of carbide tools are thus far more efficient and need less sharpening than steel cutting tools. However, surface roughness is higher when carbide tools are used, as compared with HSS tools. This is demonstrated in table 3 below.

Table 3: Surface roughness values when using HSS (represented by H) and tungsten-carbide (represented by T) (Lawal et al., 2016)

S/N	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Surface Roughness (µm) H	Surface Roughness (µm) T
1	300	0.2	1.0	1.20	2.81
2	350	0.2	1.0	0.99	2.57
3	400	0.2	1.0	1.02	2.35
4	450	0.2	1.0	0.93	2.44
5	500	0.2	1.0	0.87	2.23
6	550	0.2	1.0	0.72	2.03
7	600	0.2	1.0	0.61	1.98

Considering longevity, carbide tips are replaceable once they wear out, and new tips can be welded on to the tools. While it is costly to replace a carbide tool tip, the fact that the tips can be replaced serves to make the tool affordable in the long run. HSS tools do not comprise of replaceable tips, so once they wear out, the tool must be replaced altogether. This is correlated with the overall cost-effectiveness of both types of tools. While carbide tools are costlier to begin with, they are considered to be an investment given the high heat resistance and

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strength of these materials, which allows them to offer superior mileage and cutting power when compared with HSS.

It is also essential to consider toughness of both materials. Carbide cutting tools are extremely tough, more so than are HSS tools. Astacio et al. (2019) considered the fracture toughness of cemented carbides made of WC-Co. It is known that these materials boast a unique combination of hardness, toughness and wear resistance. High fracture toughness values for such carbides are owed to the ductile ligament bridging and crack deflection. Through this study, the optimal parameters (cobalt volume fraction, sintering, porosity, cobalt volume fraction, carbide grain size, binder thickness, Vickers hardness) were determined for obtaining WC-Co carbide pellets having desired homogeneous microstructures as well as mechanical behaviours (Astacio et al., 2019).

Several other performance parameters can also be compared for both types of cutting tool materials. It is known that carbide tools typically exhibit higher cutting speeds as compared with HSS – carbide tools are up to 4-7 times faster than HSS tools, but HSS tools are cheaper to invest in. On the whole, it is then evident that carbide tools dominate the market owing to several superior characteristics when compared with HSS. Carbide cutting tools are sharper and can cut at faster rates without binding, while HSS tools tend to dull and require more frequent sharpening. Carbide tools also operate cleaner and straighter, with joints that fit better and hold together more firmly. They offer greater longevity to manufacturers than do HSS cutting tools.

On the other hand, HSS tools are resistant to vibrations. This means that, regardless of workplace conditions and potential loss of rigidity, HSS tools can prevent mechanical shocks which may cause temperature changes, and then are able to adapt to differing lubricant concentrations. The fact that HSS tools are manufactured using cut metals, instead of torn metals, ensures that a relatively lower cutting force is required to perform the operation. Lower cutting forces translate to lesser energy consumption for HSS tools, even though this means that a lower cutting speed range is allowable for HSS tools when compared with carbide tools.

On the whole, it is recognized that each type of material possesses its own unique set of attributes and drawbacks. In the present age of rapidly evolving technology and processes, it is unquestionably essential for such materials to evolve in terms of desirable properties. Such advancements are apparent; for example, the continual development of superior hard coatings demonstrates how existing cutting tool materials can be further improved. The aforementioned comprehensive analysis suggests that carbide cutting tools may be best suited for utility in a majority of industrial applications, even though it may initially be costlier than HSS tools. This disadvantage is offset by the excellent longevity offered by carbide cutting tools, for which HSS falls short. Ultimately, it is recognized that a majority of the market is dominated by carbide cutting tools as compared with other materials because these offer the perfect blend of thermal resistance, wear resistance, strength, sharpness, cleaner operation and longer lifetimes when compared with other materials.

Conclusion

The present paper was aimed at drawing a comparison between the properties of carbide and HSS as constituent materials of cutting tools to be used in manufacturing processes. To begin with, it was recognized that there are a number of materials used to develop cutting tools, but data suggests that carbide dominates the market, followed by HSS. This widespread use of carbide cutting tools was thought to be indicative of their potential superiority when compared with HSS, and a relevant analysis was conducted to compare specific performance parameters for both carbide and HSS cutting tools. It was determined that carbide cutting tools present better longevity, sharper tools, superior thermal resistance and strength required for a vast majority of manufacturing processes, even though HSS cutting tools may be more cost-effective. Ultimately, the choice of material may be greatly guided by the exact manufacturing operation under consideration.

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