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A Comprehensive Review on Cutting Tool Material in Hard Turning Performance

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ABSTRACT : The work presents a comprehensive review on the influences of cutting tool material on the efficiency of hard turning process. Major trends in tool use and coating innovations are specified. The results of the hard turning process are evaluated through a number of main parameters such as surface roughness, cutting force, cutting heat, and wear mechanism. These results show that high cutting forces and cutting temperatures are still the huge challenges in choosing cutting tool materials in hard turning. This also limits the applicability of these materials and increases tooling costs due to the need to move towards using cutting tools with higher grades and hardness. The analysis results also point out the necessity of using appropriate cooling lubrication technology to support the hard turning process, helping to improve tool usage efficiency and the effectiveness of the hard turning process.

KEYWORDS: hard turning; cutting tool material; surface quality; surface roughness; cutting force

1. INTRODUCTION

Metal cutting field has a long history of development and still plays an important role in the industrial economy of any country in the world. This technology possesses characteristics that are difficult to replace with any other method such as high dimensional accuracy and surface quality, capability for from simple to complex profiles, and so on. In this field, the finishing of heat treated materials is still mainly used by grinding, but to meet the increasing demand for productivity, flexibility and environmental pollution problems from using coolants, hard machining technology was proposed and developed. Unlike traditional machining methods, cutting tools with geometrically defined cutting edges are used to directly cut materials with high hardness (usually 45 HRC or more) hard machining technology [1]. High dimensional accuracy, surface quality, productivity and flexibility are the outstanding characteristics of this technology [2]. Hard turning is the process first applied in industrial production and has shown positive results. During the hard turning process, the cutting tool is often subjected to high cutting forces and enormous cutting heat, which accelerate the tool wear rate and reduce the tool life, so the cutting tool material and the cutting tool quality often are highly required [3]. Besides, the tool parameters as well as the cutting mode are the factors that have the main influences on the results of the machining process as well as the economic and technical aspects. Some types of cutting tool materials commonly used in hard turning include coated carbide, ceramics, CBN, (P)CBN, PCD, and so on [4]. There have been many studies on the application of these cutting tool materials to the hard turning process and have proven their effectiveness. However, the studies on the effects of tool materials and cutting tool parameters on the hard machining outputs are still very limited. Therefore, in this article, the main purpose is to study the influence of cutting tool material on the efficiency of the hard turning process.

2. APPLICATION OF COATED CARBIDE TOOLS IN HARD TURNING

In the first stage, uncoated carbide tools opened up low-cost technological solutions for hard turning in industrial production. With low tool costs, the application in industrial production of this type of tool shows economic feasibility. However, machining with materials with higher hardness and higher strength has shown the disadvantages of this tool type when the wear rate is high and the tool life is low. Thanks to advances in materials technology, coated carbide tools are an outstanding achievement to overcome the disadvantages of uncoated carbide inserts. Ramanuj Kumar and his co-authors [5] did an experimental study comparing the effectiveness of uncoated carbide and coated carbide tools in hard turning of AISI D2 (55HRC) with dry condition. The study results showed that better wear resistance was observed in Al_2O_3 coated carbide inserts compared to uncoated carbide ones. Besides, coated carbide inserts outperformed the uncoated carbide tools in terms of surface quality, flank wear, temperature at chip-tool interface and chip morphology. Furthermore, rapid wear, severe chipping, and low tool life make uncoated carbide cutting tools unsuitable for processing high-hardness steel. P.V. Badiger et al. [6] studied the influence of cutting parameters on cutting forces, tool wear and surface roughness in hard turning using coated carbide tools. The obtained results indicated that AlCN/AlC coatings exhibited lower cutting force and better surface quality than

FeCrN coated carbide tools. Also, the improvement of wear resistance was reported in coated tools when compared to uncoated tools. Saswat Khatai et al. [7] investigated the tool wear and chip morphology in hard turning of EN 31 steel using AlTiN-PVD coated carbide tools. The authors pointed out that AlTiN-PVD coated carbide inserts exhibited the good machining performance under wet condition with proper tool wear rate. The AlTiN-PVD coated material for carbide tools is suitable for hard machining. R. Suresh et al. [8] made an extensive study on the performance of multilayer coated carbide tool in hard turning of AISI 4340 hardened steel (48 HRC). The experimental findings indicated that the tool wear rate increased with the rise of cutting speed, feed rate and depth of cut. The tool wear increased with the higher cutting speed. The main wear mechanism is abrasive wear. For higher cutting conditions, the abrasion and diffusion will occur.

Reference and year	Cutting tool material	Findings
Ramanuj Kumar et al. [5] (2018)	($TiN-TiCN-Al_2O_3$) CVD-applied coated carbide	The greater wear resistance of Al_2O_3 coated carbide tool compared to uncoated carbide. In addition, the lower cutting forces and cutting temperature were reported in case of using coated carbide tool.
Pradeep V Badiger et al. [6] (2018)	AlCN/AlC and FeCrN coated carbide	AlCN/AlC and FeCrN coated inserts reduced the values of surface roughness and cutting forces compared to uncoated cutting tool
Saswat Khatai et al. [7] (2022)	AlTiN-PVD coated carbide	AlTiN-PVD coated carbide inserts showed the excellent performance in flood cooling. The generated chip turned blue color at cutting speed of 240 m/min due to higher cutting temperature.
R. Suresh et al. [8] (2015)	TiN/MT TiC,N/Al_2O_3 coated carbide	The tool wear increased with the higher cutting speed. The main wear mechanism is abrasive wear. For higher cutting conditions, the abrasion and diffusion will occur.

3. APPLICATION OF CERAMICS TOOLS IN HARD TURNING

Recently, the coated ceramic tools have been developed and proven to have more advantages than traditional uncoated ceramic tools. S. R. Das et al. [9] used TiN coated ceramic tool for machining AISI 4140 hardened steel (52 HRC). The obtained results exhibited that the increase of cutting speed to 170 m/min led to the negative effects on surface roughness and tool life. Also, the built-up-edge (BUE) deteriorate the surface quality due to vibration cause. K. Aslantas et al. [10] investigated the tool life and wear mechanism of coated and uncoated ceramics inserts in hard turning of AISI 52100 alloy steel (63 HRC). The findings indicated that the fracture and chipping are more dominant in uncoated ceramic tools than in coated ones. On the other hand, the crater wear was more common in TiN coated tools. The temperature at the tool-chip interface was lower in coated ceramic tools, which contributed to bring out the better surface quality and tool life. B. Karpuschewski et al. [11] made a study on the application of Al_2O_3–TiCN coated and uncoated ceramic inserts in hard turning of X153CrMoV12 – 1.12379 (56 – 60 HRC). The authors concluded that the small feed rate is more favorable for ceramic tool to ensure the machined surface quality and tool life. Sanjeev Saini et al. [12] studied the influence of cutting parameters on tool wear and surface roughness in hard turning of AISI H11 tool steel (48-50 HRC) using ceramic inserts. The results showed that the depth of cut has less impact on tool wear and surface roughness, while the cutting speed and nose radius had strong influences on tool wear. Even so, the tool life of ceramic tools was about a third of that of CBN inserts, but the price was lower. Accordingly, the cost investigation should be made to evaluate these factors to give the most suitable technical guides for further studies.

Reference and year	Cutting tool material	Findings
Sudhansu Ranjan Das et al. [9] (2014)	TiN coated ceramics	The increase of cutting speed to 170 m/min led to the negative effects on surface roughness and tool life. Also, the built-up-edge (BUE) deteriorate the surface quality due to vibration cause.
K. Aslantas et al. [10] (2012)	Al_2O_3–TiCN coated and uncoated ceramics	The fracture and chipping are more dominant in uncoated ceramic tools than in coated ones. On the other hand, the crater wear was more common in TiN coated tools. The temperature at the tool-chip interface was lower in coated ceramic tools, which contributed to bring out the better surface quality and tool life
B. Karpuschewski et al. [11] (2013)	Uncoated and coated mixed ceramics Al_2O_3–TiCN	The small feed rate is more favorable for ceramic tool to ensure the machined surface quality and tool life. Even so, the tool life of ceramic tools was about a third of that of CBN inserts, but the price was lower
Sanjeev Saini et al. [12] (2012)	Ceramics	The depth of cut has less impact on tool wear and surface roughness, while the cutting speed and nose radius had strong influences on tool wear.

4. APPLICATION OF CBN TOOLS IN HARD TURNING

The CBN tools are preferred in hard turning process but are more expensive, since they provide the better performance ratio than other tool materials used in hard turning. Hamdi Aouici et al. [13] investigated the surface roughness and cutting forces in hard turning of AISI H11 hardened steel (40; 45 and 50 HRC) using CBN tool. They pointed out that the cutting forces were strongly affected by the cutting depth and material hardness. Feed rate and material hardness had significant influences on surface quality. K. Bouacha et al. [14] (2010) studied surface roughness and cutting forces in hard turning of AISI 52100 alloy steel (64 HRC) using CBN tool. The authors stated that feed rate and cutting speed had the strongest influences on surface roughness. The thrust force was the highest among cutting force components, and the cutting depth presented the strongest impact on cutting force when compared to feed rate and cutting speed. Manoj Nayak et al. [15] investigated the CBN tool machinability of AISI D6 tool steel during hard turning. The results obtained from this study exhibited that the surface finish improved with lower feed rate, and the properties and features of cutting tool materials affected the thrust force and cutting heat. The crater wear, micro-chipping, and breakages are the main causes of tool failure. S.A. Bagaber et al. [16] compared the turning performance of CBN inserts under dry and flood conditions. The study results indicated that the dry conditions can be accepted in terms of power consumption, machined surface quality, environment impacts, and coolant cost. The low cutting speed combined with high feed rate and depth of cut contributed to reduce energy consumption. The feed rate was the most significant impact on surface roughness.

Reference and year	Cutting tool material	Findings
Hamdi Aouici et al. [13] (2012)	Cubic Boron Nitride (CBN)	The cutting forces were strongly affected by the cutting depth and material hardness. Feed rate and material hardness had significant influences on surface quality.
K. Bouacha et al. [14] (2010)	Cubic Boron Nitride (CBN)	The feed rate and cutting speed had the strongest influences on surface roughness. The thrust force was the highest among cutting force components, and the cutting depth presented the strongest impact on cutting force when compared to feed rate and cutting speed.
Manoj Nayak et al. [15] (2021)	Cubic Boron Nitride (CBN)	The surface finish improved with lower feed rate, and the properties and features of cutting tool materials affected the thrust force and cutting heat. The crater wear, micro-chipping, and breakages are the main causes of tool failure.
S.A. Bagaber et al. [16] (2017)	Cubic Boron Nitride (CBN)	The dry conditions can be accepted in terms of power consumption, machined surface quality, environment impacts, and coolant cost. The low cutting speed combined with high feed rate and depth of cut contributed to reduce energy consumption. The feed rate was the most significant impact on surface roughness.

5. DISCUSSION

In hard turning, the selection of cutting tool material, cutting tool parameters, and cutting mode are key factors to achieve an economically and technically effective hard turning process. In addition, high cutting force and cutting heat generated from the cutting zone are still the main causes of wear and short tool life, which greatly affect the cost of using cutting tools. Therefore, using cutting tools with high costs but unreasonable cutting modes still leads to ineffectiveness. More technological solutions are needed to reduce cutting forces and high cutting temperatures in the cutting zone to improve tool usage efficiency as well as the efficiency of the hard turning process. The results of the experimental studies presented in this article were all performed in dry condition, so this is also one of the limitations that need to be improved.

6. CONCLUSION

In this paper, a comprehensive study is presented to investigate the influence of cutting tool material on the efficiency of hard turning. Factors such as surface quality, cutting force, cutting heat, cutting mode, wear mechanism, and tool life are all studied and discussed in detail. Besides, the influences of these parameters were also pointed out in the overview study. The development trends of cutting tool materials and coating materials are the main research directions in improving the efficiency of using cutting tools in hard turning. Furthermore, tool cost factors need to be investigated in detail and the use of cooling lubrication needs to be supported to expand the technological capabilities of hard turning and the cutting capabilities of tools, thereby helping hard turning to be more widely applied in production practice.

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