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A review on hard machining technology for sustainable development

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Abstract
The review work presented in this paper shows the main features and development trends of hard machining technology in the field of metal cutting. As the demand for productivity and product quality is increasingly demanded while ensuring environmental friendliness, new approaches are needed to replace traditional solutions. Hard machining has been researched, developed and applied as a matter of course. This work aims to focus on the studies on hard turning process and the main cutting parameters having strong influences on the cutting performance. The outstanding works are summarized and discussed in detail in order to show the main results and provide reasonable technological guidelines, thereby orienting for further studies for further improvement and development. Furthermore, the existing problems that need to be fixed are also pointed out and discussed for more investigations needed to focus on.

Keywords: *Hard machining, hard turning, hard material, cutting parameter; cutting force; surface roughness*

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I. Introduction

In recent years, the problem of environmental pollution is becoming an issue with more and more increasing concern. The issue of climate change has posed unprecedented new challenges such as global warming, ice free, sea level rise, El nino phenomenon, storms and floods that are causing greater and greater damage to humanity. Therefore, more and more strict laws to protect the environment such as ISO 14000 and Green Round were introduced, so manufacturing industries need to have fundamental changes in the approach and processing technology [1]. Traditional technologies and old processing lines are gradually being phased out, which is not suitable for the trend of sustainable production. The machining industry is no exception to this trend, especially in the field of metal cutting [2]. The use of cutting fluids to lubricate and cool the cutting area is the traditional solution and widely used in machining practice [3]. However, the disposal of used cutting oil is very expensive and its discharge into the environment without treatment is becoming a complex issue. Therefore, the need for new, environmentally friendly lubrication and cooling technologies needs to be researched and developed. The traditional finishing solution for materials after heat treatment is grinding [4]. The use of the grinding process shows advantages such as high precision and surface quality. Besides, some inherent disadvantages of this process are low productivity and the use of industrial coolants due to high heat generated during grinding process. These two factors are issues that need to be investigated and solved. Among the technologies that are studied and developed, hard machining technology is showing the attractive advantages and is widely applied in industrial production. The use of tools with defined geometric cutting edge for directly machining heat-treated materials with high hardness has been proven to significantly improve the productivity and exhibit the great flexibility in production, suitable for machining parts with complex shapes [5]. Hard turning is a hard machining process that was first used in industrial production to machine transmission shafts in automobile industry. Productivity is significantly improved while ensuring accuracy and surface quality are noted. Moreover, the machining in the dry state, which completely eliminates the use of cutting oil, thus reducing the use and treatment costs, so dry hard turning is considered environmentally friendly [6].

One issue to consider is that the high heat and cutting forces generated accelerates tool wear and adversely affects the quality of the machined surface, so the choice of cutting tool material and cutting parameters should be considered very strict [7]. In hard turning, it is often necessary to use high-quality cutting tool materials such as coated carbide, ceramic, CBN, and so on. Another technology that also needs attention is hard milling, which is a technology that has attracted great attention from mold manufacturers. The use of hard milling for finishing the cavity as an alternative to grinding and Electrical discharge machining (EDM) has brought a significant effect on productivity, contributing to reduce machining costs. However, the intermittent cutting process combined with high cutting force and cutting temperature is the major problems for the efficiency of the cutting process. The use of cutting oil under wet condition is not suitable because it easily causes thermal shock, leading to tool breakage [8]. Therefore, dry hard milling is also classified as an environmentally friendly machining method. Besides, there are some hard machining methods such as hard drilling, hard broaching, and so on [9]. But this content is not discussed in the review content. In this paper, the author focuses on summarizing the main research results on hard turning technology in dry condition to meet the needs of sustainable development. In addition, discussions of research topics will be presented to point out technology trends and guidelines, as well as research gaps for future research.

II. Machining of hard materials

In the last few decades, there have been many experimental studies on the hard turning process and have proposed important technological guidelines and important conclusions about the cutting mechanism during hard cutting. Some prominent research works on hard turning are summarized in Table 1. Khaider Bouacha et al. (2010) [2] studied the effect of cutting mode on cutting force and machined surface roughness when turning AISI 52100 steel with CBN inserts. Research results show that when machining materials with hardness above 46 HRC, hardness has a greater influence on cutting force than cutting speed. As the feedrate and depth of cut increase, the cutting force increases due to the increase of the cutting area. The depth of cut has a great influence on the cutting force. Thrust force is the force component with the largest value and has a close relationship with the hardness of the workpiece and the flank wear. T. Tamizharasan et al. (2008) [5] conducted an experimental study on the hard turning process with three levels of cutting speed, feed rate and depth of cut. Research results show that hard turning can completely replace grinding operation, but the productivity is superior. Besides, the author also pointed out that the CBN tool is suitable for hard turning. X. Wang et al. (2008) [6] proposed the artificial neural network (ANN) model to estimate the flank wear for hard turning process of AISI 52100 (62 HRC) by using CBN tool. By using the proposed model, the estimation of flank wear was determined by the faster, more accurate, and more robust way. L. Tang et al. (2019) [10] made a study on the hard turning of AISI D2 with different hardness values (40, 45, 50, 55, 60 HRC) using PCBN tools. The crater wear is the main flank wear mechanism with the hardness of 55-60 HRC. The increase in cutting forces went with the rise of workpiece hardness. M.S. Karthik et al. (2020) [11] investigate the effects of cutting parameters on surface roughness in dry hard turning of EN 31 bearing steel using CBN inserts. The authors found out that the higher feed rate, the higher surface roughness values. The feed rate is the most influencing on surface roughness. Also, the optimal set of cutting parameters was determined as V = 100 m/min, f = 0.04 mm/rev and a_p = 0.2 mm by using Taguchi L9 Orthogonal array. G. Hussain et al. (2022) [12] newly made an investigation on hard turning of GCr15 hardened steel using PCBN inserts with different chamfer width and chamfer angle. The authors found that the cutting temperature and cutting force were increased with the increase of chamfer angle. Also, the high cutting temperature of over 800°C was recorded, which caused negative influence on the machined surface quality.

No.	Authors, publication year	Workpiece material; Cutting tool material	Feed rate (mm/rev)	Depth of cut (mm)	Cutting speed (m/min)	Findings
1	Khaider Bouacha et al. (2010) [2]	AISI 52100; CBN tool	0.08; 0.12; 0.16	0.15; 0.30; 0.45	125; 176; 246	The machined material hardness has stronger impact on the cutting forces than cutting speeds. Also, the higher the feed rate and cutting depth, the higher the cutting force, whereas the higher the cutting speed, the lower the cutting force.
2	T. Tamizharasan et al. (2006) [5]	*; PCBN tool	0.06; 0.010; 0.14	0.2; 0.3; 0.4	100; 150; 200	Hard turning can be an alternative solution for grinding process. The surface finish was equivalent to that of grinding. CBN cutting tools are well suited for hard turning.
3	X. Wang et al. (2008) [6]	AISI 52100; CBN tool	0.05; 0.10	0.203	200; 250	The artificial neural network (ANN) model was built and proposed to estimate the flank wear for hard turning process. The faster, more accurate, and more Robust process could be achieved by using ANN estimator.

No.	Authors, publication year	Workpiece material; Cutting tool material	Feed rate (mm/rev)	Depth of cut (mm)	Cutting speed (m/min)	Findings
4	L. Tang et al. (2019) [10]	AISI D2; PCBN tool	0.10	0.20	250	The crater wear is the main flank wear mechanism with the hardness of 55-60 HRC. The higher hardness, the higher cutting forces.
5	M.S. Karthik et al. (2020) [11]	EN 31 bearing steel; CBN tool	0.04; 0.08; 0.12	0.1; 0.2; 0.3	100; 200; 300	The higher feed rate, the higher surface roughness values. The feed rate is the most influencing on surface roughness.
6	G. Hussain et al. (2022) [12]	GCr15 hardened steel; PCBN tool	0.1	1.0	150	Cutting temperature increased with the growth of chamfer width and chamfer angle. The high cutting temperature of 808°C was recorded, which caused the negative effect on the machined surface quality.

III. Discussion

Through the overview of outstanding works on hard turning technology, it was noticeable that the use of the CBN cutting tool material is suitable. Most studies were focusing on the influence of cutting parameters or geometrical parameters of cutting tools on the hard turning performance. The main factors affecting machined surface quality and cutting forces are specified to reveal that feed rate and nose radius have the greatest influence on machined surface roughness. The depth of cut, the hardness of the workpiece and the amount of feed have the great influences on the cutting forces. Besides, some studies also pointed out that the heat generated from cutting zone is very high, which will accelerate the tool wear and adversely affect the quality of the machined surface. Therefore, new lubricating technologies are required to assist in lubricating and cooling in the cutting zone, which will contribute to improve the efficiency of the hard turning process as well as the machinability of the CBN tools. Besides, reducing cutting force and cutting temperature will reduce cutting force and tool wear rate, thereby increasing tool life and machined surface quality.

IV. Conclusion

In the work content, the main research results on hard turning technology are summarized and discussed in detail. This will be an important basis for further studies to inherit and develop hard turning technology. Dry hard turning is an environmentally friendly processing technology, so it will be an important technological solution in line with today's sustainable production trend. Technological guidelines on cutting condition, cutting tool materials, and machining materials are summarized, evaluated and discussed, contributing to the identification of research trends and research gaps for more investigations to complete the hard turning process. Besides, more research is needed to develop environmentally friendly lubricating and cooling technology for improving the hard turning efficiency.

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