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Research Paper

A review of cutting tool material and optimized parameters in the hard turning process of Cold tool steels (SKD11)

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ABSTRACT: *SKD11 (AISI D2) cold tool steel is a high-carbon and high-chromium alloy tool steel that is used to make cold work or hot work dressing dies, sides of rollers, screw lines, lines dies, transformer core stamping dies, rolled knives, steel tube forming rollers, special molding rollers, screw heading molds. The hardened SKD11 steel has the high hardness 58-62HRC good wear resistance and good toughness. Hard turning is the turning process using a single point cutting of part pieces that have hardness values over 45 HRC. Typically, however, hard turned part pieces will be found to lie within the range of 58-68 HRC. Hard turning is an important process because all manufacturers are continually seeking ways to manufacture their parts with lower cost, higher quality, rapid setups, lower investment, and smaller tooling inventory while eliminating non-value added activities. The migration of processing from grinders to lathes can satisfy each and every one of these goals. We'll explore what hard turning is, its advantages and limitations, the best machine for the job, and how to be successful when implementing hard turning into your operation. This paper synthesizes the recent studies of SKD 11 hard-turning steel turning processes of various cutting materials such as PCBN, cubic boron nitride, Ceramics, Carbide. The common cutting materials of the hard turning of hardened SKD11 steel and the influence of the cutting conditions in the hard turning process of cutting force, cutting temperature, surface roughness and tool wear have been mentioned in the highlight of the previous studies.*

KEYWORDS: *Hard turning, SKD11, CBN, Ceramic, carbide*

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I. INTRODUCTION

With many outstanding advantages, hard turning is a finishing method applied more and more widely, hard turning is a finishing method applied more and more widely in industries. In the hard turning process, the most important thing is the selection of cutting tool material and grade. A basic knowledge of each cutting tool material and its performance is important when making the correct selection. Considerations include the workpiece material to be machined, the component type and shape, machining conditions and the level of surface quality required for each operation. In the recent years, the hard turning of hardened alloy steel has been widely applied as an efficient and cost effective alternative to grinding process. There are many studies related to the turning processes of hardened SKD 11 steel that have been published. Most of reseachers have chosen the properties of cutting tool material, workpiece materials, cutting tool geometry, machining conditions and the properties of technological systems as the input parameters for the study. Parameters such as cutting force, cutting temperature, surface quality and tool life are considered as process efficiency standards or output parameters. Therefore, the recent developments in turning hardened SKD11 steels are reviewed in this paper, the areas of research done, scope for further research are discussed.

II. CUTTING TOOL MATERIALS

In the hard turning process, the choice of cutting tool material greatly affects the productivity, quality and cost of the cutting process. Furthermore, the hard turning process has high shear force and high shear force, so the cutting tool material should be have high cohesion, high durability, not react with machining material, has a stable chemical composition, is resistant to oxidation, diffusion and has great thermal endurance. With the development of cutting tool material technology, there are many types of cutting tool materials that can be used in SKD11 hard turning process such as carbide insert, ceramic and CBN. The studies of hard turning processes using different cutting material materials will be summarized in this section.

2.1. Carbide insert

Carbide is made by mixing TiC with Cobalt and then being heated in high temperature and pressure environments. Tic has a high hardness (about 3200 Kg / mm2) and is resistant to high temperatures (about 3000 degrees Celsius) so that the conventional bits are used for hard and high-speed machining [1]. Anthony Xavior (2014) studied the tool wear, the surface roughness, temperature, machining time and metal removal rate in the hard turning of different workpiece materials such as AISI 304, AISI 52100 and AISI D2 steel process using carbide, cermet and alumina inserts [2]. The results of his investigations indicated that variations in work material considerably affect all the output parameters except for surface roughness and tool material variations exhibit reasonable influence on flank wear only. The temperature in the machining of AISI 52100 and AISI D2 process is almost the same and higher than the temperature in the machining of AISI 304. Futher, the machining time decreases when feed rate, cutting speed and depth of cut are increased, while the machining remove rate increases as the cutting parameters are increased. A. Srithar and et al. (2014) anlysed the surface quality in the hard turning SKD11 tool steel having 66 HRC hardness using the coated carbide insert with variations of the cutting speed, feed rate and cutting depth [3]. The research results considered that the surface roughness decreases, while increasing the cutting speed and decreasing the feed rate and cutting depth. In 2015, Anthony analysed the cutting force and chip morphology during turning of hardened AISI D2 steel with multicoated carbide, cermet and ceramic inserts [4]. Junaid and wani (2017) studied the performance evalution of PCBN, coated carbide and mixed ceramic inserts in the hard turning of AISI D2 steel having 45 HRC hardness [5]. This research indicated that the main wear mechanism of the coated carbide tools are abrasive wear, adhesive wear and cratering at lowest cutting speed. And abrasion, adhesion along with chipping was the cause of failure at moderate and highest cutting speeds during the hard turning of AISI D2 steel. Pay Jun Liew and et al (2017) investigated that the effect of cutting conditions on the surface roughness and tool wear in the turning AISI D2 steel process using nanofluid with coated carbide inserts [6]. In 2018, The investigation of Flank wear, Surface roughness and Cutting Temperature in the Hard Turning AISI D2 process using CVD coated carbide inserts was studied by [7] and et.al. Abrasion and diffusion are major mechanisms responsible for flank wear and cutting speed is the most sensitive term for flank wear. López-Luiz and et al (2018) analyzed the flank wear and surface roughness when turning a hardened steel AISI D2 with PVD coated carbide using the Taguchi method [8].

2.2. Ceramics

All ceramic cutting tools have excellent wear resistance at high cutting speeds. There are a range of ceramic grades available for a variety of applications. Oxide ceramics are aluminium oxide based (Al_2O_3), with added zirconia (ZrO_2) for crack inhibition. This generates a material that is chemically very stable, but which lacks thermal shock resistance [1]. Ceramic grades can be applied in a broad range of applications and materials, most often in high speed turning operations but also in grooving and milling operations. The specific properties of each ceramic grade enable high productivity when applied correctly. Knowledge of when and how to use ceramic grades is important for success.

Ceramics are very hard and refractory materials, withstanding more than 1500°C without chemical decomposition. These features recommend them to be used for the machining of metals at high cutting speeds and in dry machining conditions. Ceramic tools are based primarily on alumina (Al_2O_3), silicon nitride (Si_3N_4), and sialon (a combination of Si, Al, O, and N). Alumina tools can contain titanium, magnesium, chromium, or zirconium oxides distributed homogeneously into the alumina matrix to improve toughness (Davim, 2011). Several researches have been done to study the effect of hard turning on different types of ceramics tools.

Junfeng Yuan and et al (2018) in their research provided a novel strategy to enhancing the efficiency of machining processes which operate under extreme tribological conditions of the hard turning of AISI D2 hardened tool steels using uncoated ceramic (mixed alumia and TiCN) inserts [9]. Sarmad Ali Khan and et al (2018) analyzed the effects of the cutting parameters, workpiece hardness and the tool edge geometry on machinability aspects such as material removed, surface roughness, and tool wear during turning of high chromium AISI D2 cold work tool steel with TiN PVD coated mixed alumina inserts [10]. From their analysis, it was revealed that the Wiper configuration is seen to be overriding the effect of tool edge preparation as no difference in terms of tool wear and surface roughness is noticed between chamfered wiper insert and chamfer plus hone wiper insert. Gaitond and et al (2009) analyze the effects of depth of cut and machining time on machinability aspects such as machining force, power, specific cutting force, surface roughness and tool wear using second order mathematical models during turning of high chromium AISI D2 cold work tool steel with ceramic inserts [11]. Tugrul and et al (2007) stated the effect of cutting parameters on the cutting force, surface roughness and flank wear in the hard turning of AISI D2 steel with ceramic wiper inserts [12]. Muhammad Aftab Ahmad and et al (2018) explored the effect of the nose radius and feed rate on the surface roughness in the hard turning of AISI D2 steel using mixed alumina TiN coated ceramic inserts [13]. Ramon and et al (2008) investigated two models were adjusted to predict tool wear of the hard turning D2 steel using the ceramic inserts for different values of cutting speed, feed and time, one of them based on statistical regression, and the other based on a multilayer perceptron neural network [14]. Gaitonde and et al (2009) used the response surface methodology-based mathematical model to analyze the effects of the cutting parameters on machinability during turning of high chromium AISI D2 cold work tool steel using wiper ceramic inserts [15]. Sarmad Ali Khan and et al (2016) analyzed the tool wear/life, material removed and workpiece surface roughness during the hard turning D2 steel with the multi radii mixed alumina TiN coated tool inserts [16].

2.3. Cubic boron nitride

Polycrystalline cubic boron nitride, CBN, is a cutting tool material with excellent hot hardness that can be used at very high cutting speeds [17]. It also exhibits good toughness and thermal shock resistance. Modern CBN grades are ceramic composites with a CBN content of 40-65%. The ceramic binder adds wear resistance to the CBN, which is otherwise prone to chemical wear. Another group of grades are the high content CBN grades, with 85% to almost 100% CBN. These grades may have a metallic binder to improve their toughness. CBN is brazed onto a cemented carbide carrier to form an insert. CBN grades are largely used for finish turning of hardened steels, with a hardness over 45 HRC. Above 55 HRC, CBN is the only cutting tool which can replace traditionally used grinding methods. The steels, below 45 HRC, contain a higher amount of ferrite, which has a negative effect on the wear resistance of CBN. CBN can also be used for high speed roughing of grey cast irons in both turning and milling operations.

Linhu Tang and et al (2018) investigated that the principle wear mechanisms in the flank wear of the PCBN inserts are the abrasive wear in the case of 40-55 HRC and abrasive and delamination wear in a case of 60 HRC due to an abrupt increase of friction at tool – workpiece interfaces, while the crater is the principle wear in the rake face of PCBN inserts [18]. Sarnoba (2018) studied attempts to investigate the effect of the different tool edge geometries and the process parameters in CBN hard turning of AISI D2 steel on the tri-axial surface residual stresses, surface roughness and work hardening in the machining affected region [19]. Dosbaeva and et al (2014) investigated that these tribo-films become ineffective, when increasing the cutting speed to 175 m/min, and consequently the cutting temperature to over 1100^0C in the hard turning of AISI D2 steel using PCBN inserts [20]. Their results led to the conclusion that adhesive and chemical wear can be considered the main wear mechanisms in the used PCBN cutting tool. Sarnobat and et al (2018) analyzed the effect of the cutting conditions on the cutting tool vibration and proposed the model of the predicting surface roughness in hard turning of AISI D2 steel using the conventional and wiper CBN inserts [19]. Sande (2018) also optimized the surface roughness in the hard turning of AISI D2 steel using CBN inserts. Author analyzed the cutting forces and surface roughness in the hard turning AISI D2 steel . The results indicated that the increase of feed rate and depth of cut increases the cutting forces in machining of AISI D2 steel by PCBN tool.

III. EFFECT OF PROCESS PARAMETERS IN HARD TURNING

In the machining process, the cutting parameters such as cutting speed, feed rate, and depth of cut strongly affect on the production costs and product quality. So the determining cutting parameters to reduce the production costs and to achieve the desired product quality is very important and is studied by many technicans. The cost of machining is strongly related to the material removal rate. The material removal rate for a turning operation is given by the product of cutting parameters (cutting speed (Vc), feed rate (f), and depth of cut (d)). Therefore, if an increase in productivity is desired then an increase in these three cutting parameters is required. But, there are limits to these cutting parameters since they also have an effect on the tool life, tool wear, surface quality, cutting forces, cutting temperature, etc. Keeping this in view, many researchers have investigated effect of these parameters pertaining to the hard turning. The following sections present the findings of some of the research studies involving these parameters with reference to hard turning.

3.1. Cutting force

Cutting force is an important parameter in the machining process in general and the hard turning process in particular. Knowledge of cutting forces is needed to estimate power requirements, parameters for the design of machine tools, auxiliary tools and machining jigs. Many force gauges have been developed that are capable of measuring the force generated during machining with increasing accuracy. The energy consumed during metalworking is largely converted to heat in the vicinity of the tool's cutting edge, and many of the economic and technical problems of the machining process are caused directly or indirectly by cutting temperature and cutting force [21]. By measuring the cutting force components, researchers can understand the cutting mechanism such as the influence of technological parameters in the cutting process on cutting force, workpiece machinability, chip formation, wear mechanism and amount of tool wear. The shear force under unstable state conditions is even affected by many parameters and the variation of shear force with time has a typical characteristic. The shear force can be resolved into three components, i.e. radial thrust (Fx), axial force (Fy) and tangential shear force (Fz). Usually, the tangential shear is the largest of the three components, although in the end, the radial thrust is usually greater, while the intake force is minimal. The findings of several studies regarding the influence of shear parameters on shear forces are presented below. The shear force components increase sharply when machining materials with hardness higher than about 45 HRC (Davim, 2011).

Linhu Tang and et al (2018) used the Kistler dynamometer to measure the cutting force and determined the friction force in the hard turning AISI D2 process [22]. The result indicated that the notch and delamination wear does occur due to an abrupt increase of the friction at tool workpiece interfaces compared to other cases (4). Arsecularatne and et al (2006) investigated the variations of the average flank wear land width VBB and, the cutting (Fc), feed (Ff) and radial (Fr) force components in the turning process of hardened AISI D2 steel with PCBN tools [23]. This research analyzed the effects of the cutting parameters on the cutting forces and the tool life in the hard turning process. Gaitonde (2009) developed the mathematical model for the cutting force, powed and specific cutting force in the hard turning AISI D2 steel with the different cutting material [11]. This research investigated the influence of cutting depth, cutting geometry and machining time on the cutting force, power and specific cutting force of the machining process. A.Srithar (2015) considered the influence of the cutting speed, feed rate and depth of cut on the cutting force in the hard turning process of AISI D2 steel using PCBN inserts [24]. Davim (2007) studied the influence of the wiper inserts when compared with conventional inserts on the machinability parameters (cutting forces, surface roughness, and tool wear) obtained in hard turning of AISI D2 hardened steel [12].

3.2. Cutting temperature

The heat generated in the cutting zone is produced by plastic deformation and friction at the contact area between the chip - the cutting tool and the cutting tool - the work piece. Heat generation during machining increases the temperature during cutting which affects strength, hardness, wear resistance and tool life and makes it difficult to control dimensional accuracy. and surface integrity. Cutting heat also affects the properties and durability of the work piece. The temperature in the cutting zone is influenced mainly by the basic parameters of the cutting process. In addition, it also depends on the properties of the workpiece material, as well as the physical properties of the tool. Therefore, researchers mainly focus on measuring and predicting the temperature at the contact zone between tool, chip and work piece [12]. Cutting tools used for hard working shall have adequate hot hardness to withstand the high temperatures generated at high cutting speed conditions. Under these conditions, most tool materials in general lose their stiffness resulting in a weakening of the intergranular bonding and, as a result, accelerated tool wear as reported by Ezugwu, Bonney and Yamane [25].

Ramanuj Kumar (2018) performed machining of AISI D2 steel at various cutting speed, feed rate and depth of cut using CVD coated carbide inserts. Chip-insert interface temperature (T) was measured during machining with use of infrared Fluke Ti-32 thermal imager [26]. The results indicated that the cutting temperature (chip-tool interface) rises with speed and it is highly influenced by speed in hard turning AISI D2 steel. Puneet Sharma (2015) studied effects of Nanofluids on turning of AISI D2 Steel using Minimum Quantity Lubrication [27]. The results from experimental tests are summarized here. It can thus be concluded that the cutting zone temperature can be decreased with the help of inclusion of multiwall carbon nanotubes in cutting fluid because due to inclusion of multiwall carbon nanotubes in cutting fluid the thermal conductivity of cutting fluid improves and its heat carrying capacity increases which helps to reduce the cutting zone temperature. Dosbaeva and et al analyzed the effect of the cutting temperature on PCBN and CVD coated carbide inserts in hard turning of AISI D2 tool steel. The cutting temperature was determined by using the tool workpiece thermocouple technique.

3.3. The surface integrity

The surface integrity of a machined surface is defined in terms of residual stresses, surface roughness, microhardness, etc. Surface roughness and dimensional accuracy play an important role in the performance of a machined component. High cutting forces and high localized temperatures may dramatically affect the surface integrity, often resulting in the development of high tensile residual stresses in the machined surfaces. Residual stress on the machined surface and the subsurface is known to influence the service quality of a component, such as fatigue life, tribological properties, and distortion. Therefore, it is essential to predict and control it for enhanced performance as suggested by many researchers. Vallabh (2019) analyzed the effects of the cutting speed, feed rate and nose radius on the surface roughness in hard turning of AISI D2 steel [28]. Also, Vallabh developed a mathematical model showing the functional relationship of feed, cutting speed, nose radius and surface roughness. Prediction of surface roughness found very close to the experimental values of surface roughness. Srithar (2014) investigated the effects of the cutting parameters on the surface roughness in the hard turning of AISI D2 steel using coated carbide insert [24]. The results showed that the surface roughness decreases when increasing the cutting speed and increases when increasing the feed rate and depth of cut in hard turning of AISI D2 by coated carbide insert. Muhammad (2018) studied the influences of the tool geometry and cutting parameters on the surface roughness in the hard turning of AISI D2 steel using conventional and wiper inserts [29]. The result revealed that increase in the feed rate value resulted the decrease in surface finish but surface finish for conventional inserts was better than that with wiper inserts. Sarnoba (2018) predicted the surface roughness from cutting tool vibrations in hard turning of AISI D2 steel of different hardness with conventional and wiper geometry CBN inserts [19]. Sande (2018) used Plackett – Burman designs to optimize the surface roughness in turning of hardened AISI D2 steel. Krish (2017) used the Taugchi technique and ANOVA to obtain optimal Turning parameters in the Turning of D2 under wet conditions [30]. Tugrul and et al (2007) investigated the model of surface roughness in the hard turning of AISI D2 steel with ceramic wiper inserts using the Neural network algorithm [12]. This research showed that this model is able to predict the surface roughness of hard turning process with a range of cutting parameters. Junaid Mir and Wani (2017) analyzed the surface roughness in the hard turning of AISI D2 steel with three cutting material (PCBN, Coated carbide and mixed ceramic inserts) [5]. This research indicated that Better surface roughness Ra was produced by PCBN inserts for all the speeds used when compared to the surface produced by the mixed ceramic and carbide cutting tool. López-Luiz and et al (2018) investigated the optimum levels of the cutting conditions of the hard turning of AISI D2 steel using carbide inserts for minimizing the surface roughness using the Taguchi method [8].

3.4. Tool wear

Wear is a common criterion used to evaluate the performance of cutting tools, the ability to process materials and is one of the most important and most interested criteria when studying the selection of cutting tools and machining conditions. There have been some researchers interested in cutting tool wear during intermittent hard turning. In 2009, Oliveira et al. analyzed and compared the cutting tool wear during hard turning and intermittent hard turning using PCBN and ceramic pieces with the change of cutting speed (150-195 m/min) [31]. Research results also show that PCBN flakes are more efficient than ceramic flakes in the process of intermittent hard turning. In 2010, Vitor augusto studied intermittent hard turning using CBN and ceramic flakes [32]. Suresh et al also analyzed wear and shear forces during intermittent hard turning using coated carbide flakes [33]. The study has shown the wear mechanism in intermittent hard turning with carbide flakes. In 2019 Manoj Nayak built an experimental model to study tool wear during hard turning and surface hard turning of AISI D6 steel using low CBN pieces [34]. The study analyzed the wear mechanism and built a mathematical model to predict the durability of the tool in hard turning and intermittent hard turning.

Yuan and et al (2018) focused on the investigation of nano-scale tribological effects formed during the turning of hardened AISI D2 steel (58HRC). This research showed that the generation of tribofilms formed at the friction surface due to workpiece material mass transfer within the running-in stage was strongly affected by the cutting conditions [9]. Linhu Tang and et al (2018) analyzed the wear performance and mechanisms of PCBN inserts in the hard turning of AISI D2 hardened steel with the different hardess of workpieces [22]. The results indicated that the workpiece hardness has a marked impact on the flank wear. Arsecularatne and et al (2006) studied the effect of cutting speed and feed rate on the flank wear and tool life in the hard turning of difficult to cut material AISI D2 steel of hardness 62 HRC with PCBN inserts [23]. Gaitonde and et al (2009) made comparison between the surface roughness and tool wear of conventional ceramic inserts with wiper ceramic insert during finish hard turning of AISI cold tool steel [15]. The wiper ceramic insert performs better with reference to surface roughness and tool wear, while the conventional ceramic insert is useful in minimizing the machining force, power and specific cutting force. Tugrul Ozel and et al (2007) investigated the model of flank wear in the hard turning of AISI D2 steel 60 HRC with ceramic wiper inserts using the Neural network algorith [12]. The flank wear model was used to determine optimization cutting parameters. Paulo Davim and Luı´s Figueira (2007) used the Taguchi method to analysis the effect of the cutting parameters on the tool wear of the ceramic tool in the hard turning of AISI D2 steel [12]. Junaid Mir and Wani (2017) investigated that the tool life for PCBN cutting tools is higher than coated carbide and mixed ceramic tools at all the cutting speeds used [5]. López-Luiz and et al (2018) determined the optimum levels of the cutting conditions of the hard turning of AISI D2 steel for minimizing the flank wear of carbide inserts using the Taguchi method [8]. Jinpeng Song and et al (2014) analyzed the cutting performance and failure mechanisms of the Ceramic inserts in the hard turning of Cr12MoV mold steel [35]. The results indicated that the main wear mechanisms were adhesive wear and abrasive wear. Ramon Quiza and et al (2008) compared the statistical models and the artificial neural netwworks on predicting the flank wear in the hard turning D2 steel using ceramic inserts [14]. The results indicated that the neural network model has shown better capability to make accurate predictions of tool wear under the conditions studied.

IV. SUMMARY

Hard turning is commonly applied by several manufacturing industries, since it offers numerous advantages when compared with traditional methodology based on finish grinding operation after heat treatment of workpieces. This technology possesses immense potential to machine very hard materials to produce near net shape components and also to contribute to a great extent to the sustainable manufacturing. In the recent past, this technology has created interest among researchers and attracted their attention, and consequently, many research studies have been conducted and the results have been reported which are available in the literature. This paper has presented an overview focusing mainly on turning of hardened steels that are used by ball bearings, automotive, gear, and die-making industries. On the basis of the research findings reported in the available literature reviewed and presented in this paper, following conclusions can be drawn: Hard turning offers a number of potential benefits over traditional form grinding, including lower equipment costs, shorter setup time, fewer process steps, greater part geometry flexibility, and elimination of the use of cutting fluid. During hard turning, the cutting tool is subjected to heavy mechanical loads and also it is exposed to very high temperature due to excessive heat generation, and therefore, cutting tools made of superhard materials such as coated cemented carbide, ceramic, PCD, CBN, etc. must be used as they perform well under severe machining conditions. The cutting tool geometry, workpiece hardness, and cutting parameters significantly affect the cutting forces, surface residual stress, surface roughness, surface integrity, tool wear, and tool life. The information gained through study and prediction of the tool wear during machining can be used as a basis for the effective design of cutting tools and determination of cutting conditions that will lead to the formulation of the tool change strategies.

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