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Research Article

Tool Life Performances on Turning Austenised and Quenched AISI 52100 Bearing Steel with Ceramics and CBN/TiC Cutting Tools

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Abstract

Among the metal cutting methods, turning is one of the widely used manufacturing processes in industry. In addition to tool and workpiece material, cutting speed (V), feed rate (f), depth of cut (d) are the most important cutting parameters which highly affect the performance characteristics. It is necessary to select the most appropriate cutting parameters and cutting tools in order to improve cutting efficiency, process at low-cost, and produce high-quality products. Of the present available cutting tools materials, ceramic and cubic boron nitride (CBN) cutting tools are the best candidates and are widely used in turning the hardened steels owing to their high hardness and high melting point. The turning of hardened steels by selecting the right cutting tools and cutting parameters produces surface finishes with grinding quality. The effect of parameters cutting speed, feed rate and depth of cut while turning of AISI 52100 steels are formulated mathematically. A parametric model of cutting tool and workpiece is designed using ProE. Analytical investigations are made on the model by applying the forces by taking different values of cutting speed, feed rate and depth of cut. Analysis is done using Solidworks. Tool life performances of various cutting tools such as mixed alumina ceramic (KY1615 and cubic boron nitride (CBN/TiC) are investigated analytically under different cutting conditions in turning austenised and quenched AISI 52100 steels.

Keywords: *Alumina ceramic, cubic boron nitrite, structural analysis, fatigue analysis, stress, strain.*

1. Introduction

Industries around the world constantly strive for lower cost solutions with reduced lead time and better surface quality in order to maintain their competitiveness. In addition to it, tool life is very important parameter while cutting the materials during turning operation. There are many studies where they explained about the turning operation, the most effectible parameters, and parameters effect on tool life. The experimental validations with numerical suimulations are also observed from the literature. In that few of them are described as Aggarwal, Singh, (2005) reviewed the literature on optimizing machining parameters in turning processes. Various conventional techniques employed for machining optimization include geometric programming, geometric plus linear programming, goal programming, sequential unconstrained minimization technique, dynamic programming etc. The latest techniques for optimization include fuzzy logic, scatter search technique, genetic algorithm, Taguchi technique and response surface methodology. Yahya Isik (2007) conducted a series of test to determine the machinability of tool steels. In these test the effects of tool material, type of coating on the insert (for coated tools) and the cutting parameters that affect the machinability were taken into considerations. The cutting force data used in the analyses were gathered by a tool breakage detection system that detects the variations of the cutting forces measured by a three-dimensional force dynamometer. The workpiece materials used in the experiments are cold work tool steel, AISI O2 (90 MnCrV8); hot work tool steel, AISI H10 (X32CrMo33) and mould steel, AISI improved 420 (X42Cr13). The cutting tools used are HSS tools, uncoated WC and coated TiAlN and TiC + TiCN + TiN inserts (ISO P25). During the experiments cutting forces, flank wear and surface roughness values were measured throughout the tool life and the machining performance of tool steels were compared.

Numerical simulations of high-speed orthogonal machining were performed to study the finish hard-turning process as a function of cutting speed, feed, cutter geometry, and workpiece hardness. In the simulations, properties representative of AISI 52100 bearing steel, AISI H13 hot work tool steel, AISI D2 cold work steel, and AISI 4340 low alloy steel were assumed for the workpiece. Cubic boron nitride (CBN) or polycrystalline (PCBN) inserts are widely used as cutting tool material in such high-speed machining of hardened tool steels—due to high hardness, high abrasive wear resistance, and chemical stability at high temperature. Cutting forces and feed forces were determined in the numerical simulations. Among process parameters, cutter geometry and

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workpiece hardness, the feed has the most significant effect on cutting and feed forces.With same cutting conditions, turning AISI 4340 gets the highest cutting force while turning AISIS 52100 has the highest feed force and turning AISI D2 gets the lowest cutting force and feed force. The feed force appears to be a larger force component than the cutting force in the hard turning. Cutting force and feed force increase with increasing feed, tool edge radius, negative rake angle, and workpiece hardness (Qian, and Hossan, (2007)). Lalwani *et al.* (2008) investigated the effect of cutting parameters (cutting speed, feed rate and depth of cut) on cutting forces (feed force, thrust force and cutting force) and surface roughness in finish hard turning of MDN250 steel (equivalent to 18Ni(250) maraging steel) using coated ceramic tool. The machining experiments were conducted based on response surface methodology (RSM) and sequential approach using face centered central composite design. The results showed that cutting forces and surface roughness do not vary much with experimental cutting speed in the range of 55–93 m/min. A linear model best fits the variation of cutting forces with feed rate and depth of cut. Depth of cut is the dominant contributor to the feed force, accounting for 89.05% of the feed force whereas feed rate accounts for 6.61% of the feed force. In the thrust force, feed rate and depth of cut contribute 46.71% and 49.59%, respectively. In the cutting force, feed rate and depth of cut contribute 52.60% and 41.63% respectively, plus interaction effect between feed rate and depth of cut provides secondary contribution of 3.85%. A non-linear quadratic model best describes the variation of surface roughness with major contribution of feed rate and secondary contributions of interaction effect between feed rate and depth of cut, second order (quadratic) effect of feed rate and interaction effect between speed and depth of cut. The suggested models of cutting forces and surface roughness adequately map within the limits of the cutting parameters considered.

Yellese (2009) investigated the behaviour of a CBN tool during hard turning of 100Cr6-tempered steel. A series of long-duration wear tests is planned to elucidate the cutting speed effects on the various tool wear forms. Then, a second set of experiments is devoted to the study of surface roughness, cutting forces and temperature changes in both the chip and the workpiece. The results showed that CBN tool offers a good wear resistance despite the aggressiveness of the 100Cr6 at 60HRC. The major part of the heat generated during machining is mainly dissipated through the chip.

Selvaraj, Chandramohan, (2010) presented the influence of cutting parameters like cutting speed, feed rate and depth of cut on the surface roughness of austenitic stainless steel during dry turning.They concentrated with the dry turning of AISI 304 Austenitic Stainless Steel (ASS). A plan of experiments based on Taguchi's technique has used to acquire the data. An orthogonal array, the signal to noise (S/N) ratio and the analysis of variance are employed to investigate the cutting characteristics of AISI 304 austenitic stainless steel bars using TiC and TiCN coated tungsten carbide cutting tool. Finally the confirmation tests that have carried out to compare the predicted values with the experimental values confirm its effectiveness in the analysis of surface roughness. Mahdavinejad, Saeedy (2011) aimed to optimize turning parameters of AISI 304 stainless steel. Turning tests were performed in three different feed rates (0.2, 0.3, 0.4 mm/rev) at the cutting speeds of 100, 125, 150, 175 and 200 m/min with and without cutting fluid. A design of experiments and an analysis of variance have been made to determine the effects of each parameter on the tool wear and the surface roughness. It is being inferred that cutting speed has the main influence on the flank wear and as it increases to 175 m/min, the flank wear decreases. The feed rate has the most important influence on the surface roughness and as it decreases, the surface roughness also decreases.

From all the above studies the present work aim is defined as the effect of parameters cutting speed, feed rate and depth of cut while turning of AISI 52100 steels. They are formulated mathematically and modeled with a parametric model of cutting tool and workpiece and then analyzed.

2. Methodology

The purpose of this project is to determine the optimal cutting conditions for surface roughness in a turning process. This process is performed in the final assembly department at a manufacturing company that supplies fluid dynamic bearing (FDB) spindle motors for hard disk drives (HDDs). The workpieces used were the sleeves of FDB motors made of ferritic stainless steel, grade AISI 12L14. The optimized settings of key machining factors, depth of cut, spindle speed, and feed rate on the surface roughness of the sleeve were determined using the response surface methodology (RSM). The results indicate that the surface roughness is minimized when the depth of cut is set to the lowest level, while the spindle speed and feed rate are set to the highest levels. Even though the results from this paper are process specific, the methodology deployed can be readily applied to different turning processes. Figure 1 shows the modeling of cutting tool and workpiece which was modeled using ProE modeling software.

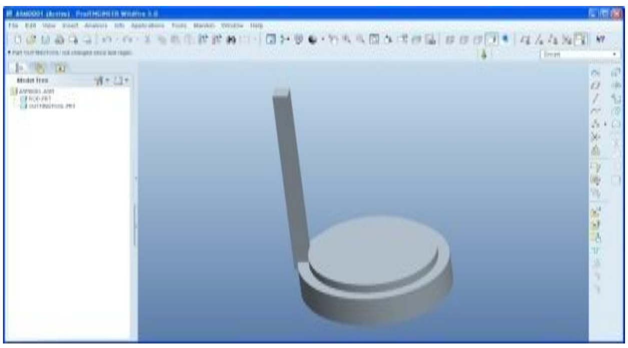


Fig.1 Modeling of cutting tool and Workpiece

4. Results and Discussion

Assembly of modeled work piece and cutting tool is

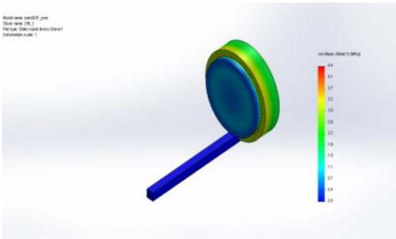
imported from the pro-Engineer and evaluated the structural analysis such as displacement, stress, and strain; Fatigue analysis such damage plot, life plot, load factor.
The effect of parameters cutting speed, feed rate and depth of cut while turning of AISI 52100 steels are formulated mathematically using two different cutting tools Alumina Ceramic KY1615 and Cubic Boron Nitride. A parametric model of cutting tool and work piece is designed using 3D modeling software Pro/Engineer.

Analytical investigations are made on the model by applying the forces by taking different values of cutting speed, feed rate and depth of cut. The parameters considered are: Spindle Speed – 2000rpm,; Feed Rate – 250mm/min, ; Depth of Cut – 0.9mm. Structural and Fatigue Analysis is done in Solidworks.

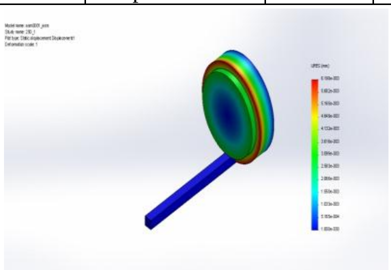
4.1 Cutting Tool-Alumina Ceramic

Feed – 250mm/min, cutting speed – 2000rpm
(i)Structural Analysis

Name	Type	Min	Max
Stress1	Von- Mises Stress	0 Node: 82331	4.43537 (MPa) Node: 14945



Name	Type	Min	Max
Displace--ment1	URES: Resultant Displacement	0 at Node:1	0.00619806 mm at Node: 11170



Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	Element: 57111	0.000183318 Element: 8039

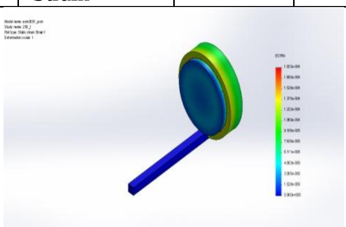


Fig. 2 Structural Analysis

(ii) Fatigue Analysis

Name	Type	Min	Max
Results1	Damage plot	0.05 Node: 1	0.05 Node: 1

Name	Type	Min	Max
Results2	Life plot	1e+006 cycle Node:1	1e+006 cycle Node: 1

Name	Type	Min	Max
Results3	Load factor	32.5088 Node: 14945	1.83039e+028 Node: 82331

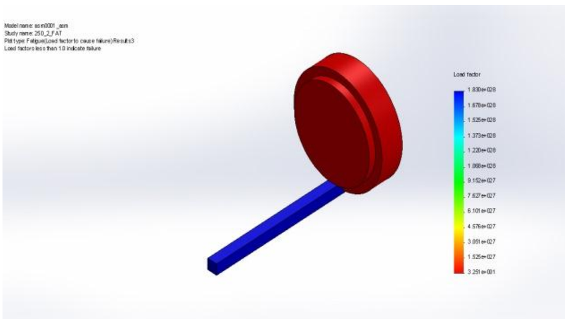
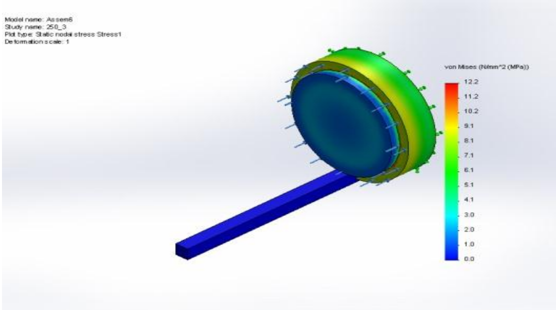


Fig.3 Fatigue Analysis

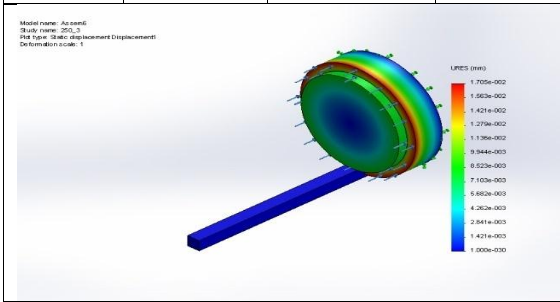
4.2 Feed – 250mm/min, cutting speed – 5500rpm

(i) Structural Analysis

Name	Type	Min	Max
Stress1	von Mises Stress	0 at Node: 82331	12.1989 (MPa) Node: 14945



Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1	0.017047 mm Node: 11170



Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	0 Element: 57111	0.000504193 Element: 8039

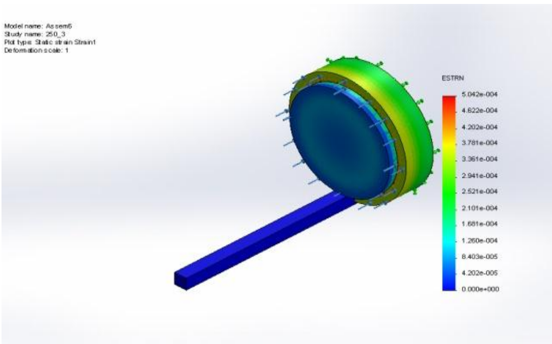


Fig. 4 Structural Analysis

(ii) Fatigue Analysis

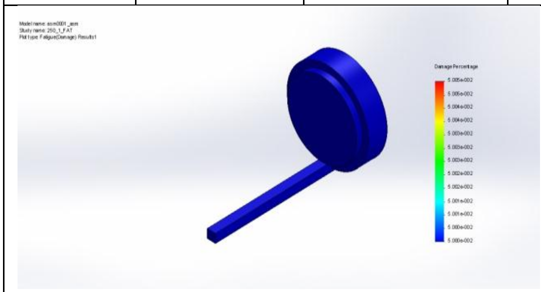
Table 1 Results obtained for Alumina Ceramic KY1615

SS – Spindle Speed, FR – Feed Rate

Parameter	SS – 2000rpm FR –250 mm/min	SS – 5500rpm FR – 250mm/min
Stress (N/mm^2)	4.43537	12.1989
Displacement (mm)	0.006198	0.017047
Strain	0.000183	0.000504
Damage	0.05	0.1
Life	1.00E+06	1.00E+06
Load Factor	1.83E+28	1.47173 e^{28}

In the similar manner, analysis has been done for cutting tool – cubic boron nitride and workpiece – AISI 52100 steel. All the obtained results were shown in the Table 1 and 2.

Name	Type	Min	Max
Results1	Damage plot	0.05 at Node: 1	0.05 at Node: 1



Name	Type	Min	Max
Results2	Life plot	1e+006 cycle Node: 1	1e+006 cycle Node: 1

Name	Type	Min	Max
Results3	Load factor	21.5296 Node: 25208	5.38657e+027 Node: 1

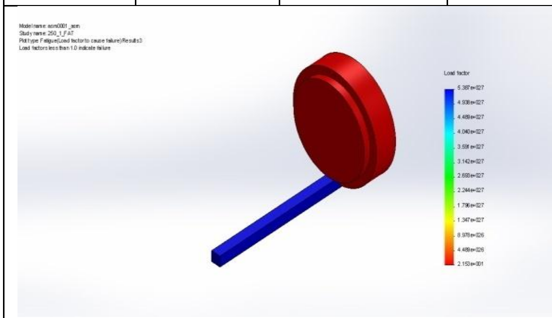


Fig.5 Fatigue Analysis

Table 2 Results obtained for Cubic Boron Nitride

Parameter	SS – 2000rpm FR – 250mm/min	SS – 5500rpm FR – 250mm/min
Stress (N/mm^2)	4.435	12.1985
Displacement (mm)	0.00619	0.0170467
Strain	0.0001833	0.000504
Damage	0.05	0.2
Life	$1e^{6}$	$1e^{6}$
Load Factor	$5.386e^{27}$	3.53 ^{27}

4. Conclusion

The analyzed stress values are less than the yield stress values of the respective materials for all speeds and feed rates selected in the study and the following conclusions are drawn

- The displacements are also very less. By observing the fatigue analysis results, for all the speeds and feed rates, For Alumina Ceramic KY1615 cutting tool, the damage is very less; life of the tool is $1e^{6}$ cycles.
- It is also observed that when the loads applied in the analysis are increased by almost $1.83e^{28}$, then the cutting tool gets damaged.
- By taking Cubic Boron Nitride cutting tool, the damage is very less, life of the tool is $1e^{6}$ cycles. When the loads applied in the analysis are increased by almost $5.386e^{27}$, then the cutting tool gets damaged. Cutting tool Alumina Ceramic KY1615 is better than Cubic Boron Nitride.
- At spindle speed of 2000rpm and feed rate of 250mm/min, the stress values are less compared with other parameters. So spindle speed of 2000rpm and feed rate of 250mm/min are the better values for turning of AISI 52100 steels.

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