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A REVIEW OF INPUT PARAMETERS ON SURFACE INTEGRITY FOR QUALITY AND PRODUCTIVITY IMPROVEMENT IN HARD TURNING

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ABSTRACT
Hard turning is the turning of the material at hardened state. It reduces the re-processing of the component; thus, it is an economic alternative to grinding, but its reliability is often unpredictable and challengeable. The reliability of hard turning surfaces mainly depends on their surface integrity. Surface integrity factors, i.e., external and internal factors, play a prominent role in the performance of the machined components. High service integrity delivers the good service performance of the component or vice versa; thus, the control of surface integrity is of uttermost importance in hard turning processes. This paper aims to conduct a thorough analysis of the machining parameters, cutting tools, and work piece material used in hard turning. It also aims to identify the various response parameters that affect the surface integrity of work piece material with a view to enhancing quality and productivity.

Index Terms – Hard Turning; Material Removal Rate; Micro hardness; Microstructures; Surface integrity; Surface roughness; Tool Life; Tool wear.

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1. INTRODUCTION
Productivity is now become watchword for all the manufacturing industries. The manufacturers in the world are continuously identifying the higher productivity solutions to sustain the competitiveness of manufactured products [1]. High productivity means work with minimum investment on inputs and in the optimized possible time without sacrificing quality, and with least wastage of resources i.e. the aim is higher quality, lower cost and less wastage. Therefore, it is required to identify appropriate technological advancements that can help the manufacturing industry to improve the quality of the product and reduce the cost. It is known that 8-10 percent of material generated by machining processes goes to waste. By utilizing better machining conditions and tools, this waste can be reduced to an extent [2].

In manufacturing industries, practical knowledge, experience, and skill of supervisors are considered to assess the cutting conditions, cutting tools and tool geometries but these cannot be accepted all the time. This irrational approach shows lower efficiency because of improper utilization of machine tool capabilities. This can be enhanced by carefully selecting the important evaluation factors to achieve the commanded responses within the constraints of low-cost production [3]. Any incorrect judgment in this area results in increased manufacturing costs and lower product quality.

Although in the production industry continue advancement takes place but turning still leftover as the most significant process used for shaping the different materials because the conditions of operations are varied [4]. Turning focus on the features of the tool, input work material, output quality characteristics (or responses) and the cutting conditions which perform a significant role in the productive use of a machine tool [4]. The materials mostly required in the tooling applications have high wear resistance. Wear resistant materials are difficult to machine [1]. These wear resistance materials used in blanking or forming dies and thread rolling dies, shear blades and planer blades. The hard turning has the potential for improving the output quality characteristics of these wear resistance work piece materials [5].

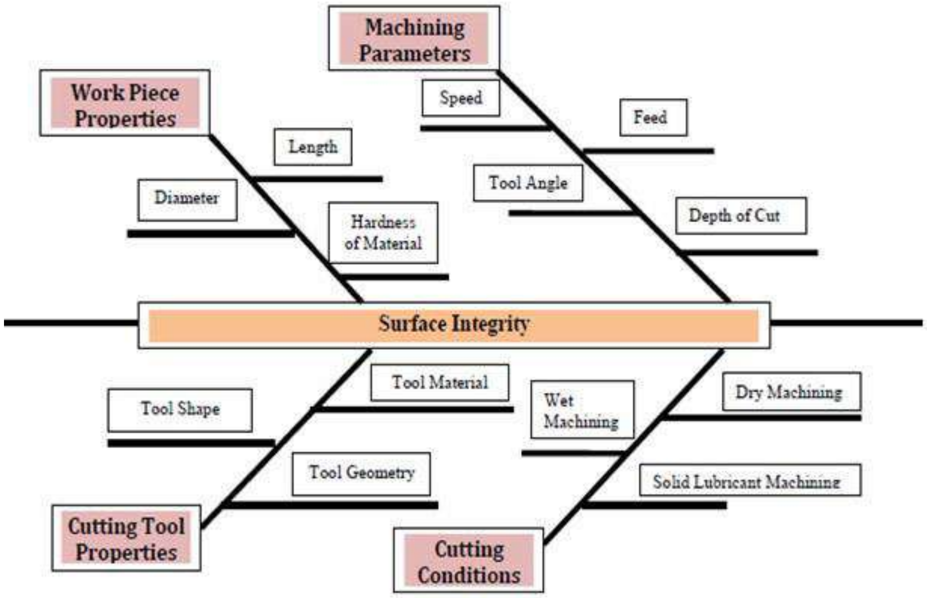

Figure I

INPUT PARAMETERS THAT AFFECTING RESPONSE PARAMETERS

2. HARD TURNING

During the 1970's the work on hard turning was started and primarily gets its reorganization with the development of new advanced cutting tools [6] [7]. These tools phase out the need for annealing and grinding since these are able to produce complex geometrical surfaces with precision[8] [9]. Hard turning enables the manufacturers to machine hardened materials having hardness values typically in between the 50–60 HRC to obtain finished work pieces directly under dry conditions [10], [11], [12], [13], [14], [15], [16].

Even at smaller depth of cut and feed rates, the material removal rate is much greater than in grinding for some applications in hard turning [10] [17]. Thermal distortion takes place on the surface of work piece, due to the rubbing action of the grinding wheel, which allows high temperatures to penetrate deep into the work piece resulting in the formation of a white layer. Hard turning drops the number of operations including rough turning, heat treatment needed to manufacture a component as shown in figure II and thereby utilizing the input resources effectively thus enhancing productivity [18].

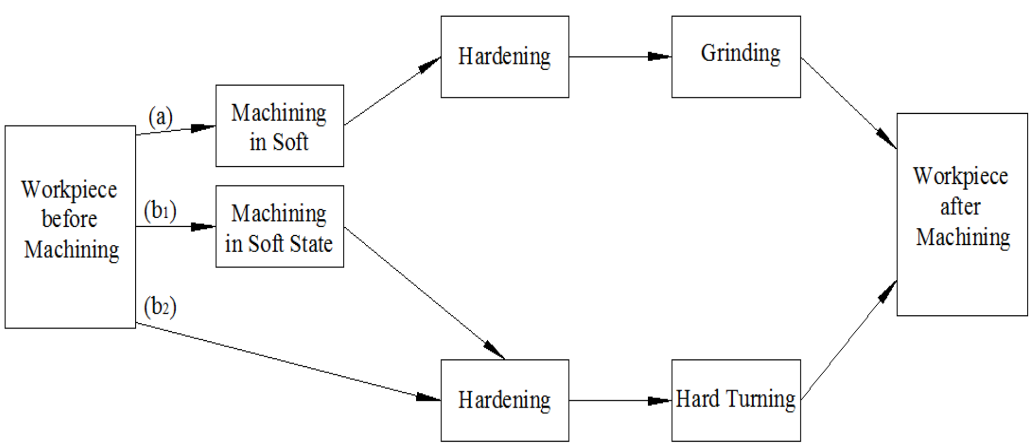

Figure II

(a) CONVENTIONAL TURNING and (b1) & (b2) OPTIMIZED TURNING PROCESS

2.1 Surface Integrity

Surface integrity have the prominent role in the mechanical performance of machined components [19]. Service performance of the component will be proportional to surface integrity. Thus the control of surface integrity is of substantial importance in machining processes and depends upon internal and external factors as shown in figure III,

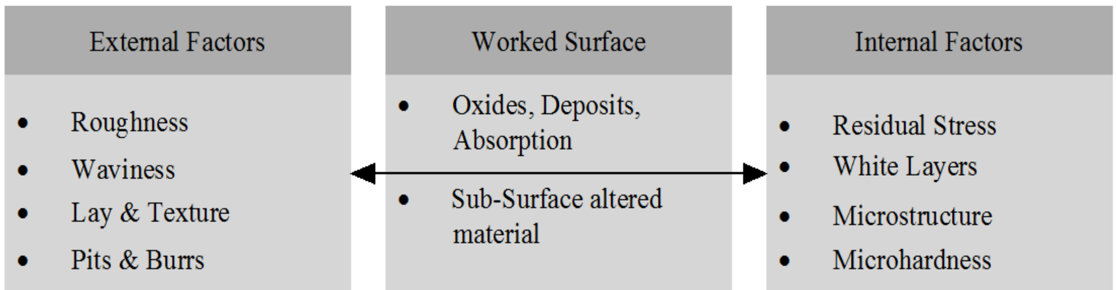

Figure III

SCHEMATIC DIAGRAM OF WORKED (MACHINED) SURFACE

3. LITERATURE REVIEW

Various studies have been performed by the researchers showing the effect of machining parameters such as feed, depth of cut, speed and tool geometry on residual stresses, microstructure, tool wear and surface roughness and their combinations in hard turning by using different workpiece materials. The summary of their work has been listed in table 1.

Table I Machining Parameters, Tool & Workpiece Material And Response Parameters In Hard Turning

Author's Name	**Material**	**Machining Parameters**	**Tool** (Single / Multiple)	**Tool Material**	**Response Parameters**
Meyer R, Köhler J, Denkena B [5]	AISI 5115 (16MnCrS5)	Feed/ Corner radius/ Depth of Cut	Single	WBN560 with a CBN content of 56% with different corner radius	Tool wear and Cutting forces
Hosseini S. et al. [20]	AISI 52100	Speed	Single	CBN insert - grade BNC200	Cutting temperature & its correlation with white layer, microstructure & the residual stresses.
Suha K. Shihab, Zahid A. Khan A [21]	AISI 52100	Feed/ Speed/ Depth of Cut	Single	Multicoated carbide inserts (TiN-TiCN-Al_2O_3-TiN) under cryogenic cooling conditions	Cutting forces
Zhou J, Andersson M, Stahl J	AISI 52100	Feed/ Speed/ Depth of Cut (Fixed	Single	CBN10 with 50% of CBN grit	Flank wear and Cutting forces

[22]		parameter)			
Singh D, Rao P [18]	AISI 52100	Speed/ Feed/ Nose radius/ Rake angle/	Single	Mixed ceramic inserts of different geometry	Surface roughness
Singh D, Rao P [23]	AISI 52100	Speed/ Feed/ Nose radius/ Chamfer angle	Single	Mixed ceramic inserts of different geometry with solid lubricants	Surface roughness
Umbrello D. et. al [10]	AISI 52100	Feed/ Speed/ HRC/ Chamfer-Hone	Single	CBN Tool	Residual stresses
Dahlman P, Gunnberg F, Jacobson M [24]	AISI 52100	Rake angle/ Feed/ Depth of Cut.	Single	CBN100 with different geometry (Rake angle)	Residual stresses
Liu M, Takagi J, Tsukuda A [25]	AISI 52100	Feed/ Speed/ Depth of Cut / Nose radius	Single	CBN tool (TiC & Al_2O_3) with different nose radius	Tool wear, Cutting forces and Residual stresses
Thiele J, Melkote S [26]	AISI 52100	Hardness/Feed/ Chamfer edge / Hone edge	Single	PCBN inserts with three types of edge preparation	Residual stresses and Microstructures
Yallese M. et.al [27]	100 Cr 6	Feed/ Speed/ Depth of Cut	Single	CBN7020	Surface roughness, Tool wear, Cutting force and Chip volume
Xueping Z, Erwei G, Richard Liu C [28]	AISI 52100	Feed/ Speed/ Depth of Cut	Single	CBN	Residual stresses
Zhou J, Hognas S, Stahl J [29]	AISI 52100	Feed/ Speed/ Depth of Cut (Fixed parameter)	Single	PCBN tool with low CBN contents (50%) & ceramic (TiAl) as binder	Surface roughness, Tool wear and Cutting forces
Guddata J. et al. [30]	AISI 52100	Speed	Single	CBN inserts of grade BNX10	Cutting forces, Tool wear, Residual stresses and Microstructure
Shihaba K. et al. [31]	AISI 52100	Feed/ Speed/ Depth of Cut	Single	Coated carbide inserts under cryogenic	Surface roughness and Micro hardness

				cooling conditions	
Shihab S. et al. [32]	AISI 52100	Feed/ Speed/ Depth of Cut	Single	Multilayer coated carbide inserts	Tool - chip interface temperature
Revel P. et al. [33]	AISI 52100	Feed/ Speed/ Depth of Cut	Single	CBN insert	Surface roughness, Micro structural analysis, Residual stresses and Chip morphology
Bapat P. et al. [34]	AISI 52100	Speed	Single	PCBN	Temperature measurement
Bhokse V. et al. [35]	AISI 52100	Feed/ Speed/ Depth of Cut	Single	PVD coated Nano-laminated carbide inserts (TiSiN – TiAlN)	Plowing cutting forces and Chip morphology
Hosseini S. et al. [36]	AISI 52100	Speed	Single	CBN insert	Microstructures of different types of White layers
Dawson T, Kurfess T [37]	AISI 52100	Feed/ Speed/ Depth of Cut/ HRC/ Tool material	Multiple	High CBN & Low CBN	Tool life
Suhail H. A. et al. [15]	AISI 1020	Feed/ Speed/ Depth of Cut	Single	CNMG 432TT5100 Carbide insert	Surface roughness and Temperature
Noordin M. et al. [38]	AISI 1045	Feed/ Speed/ Side cutting edge angle	Single	CVD Coated Carbide Tools with different Side cutting edge angle	Surface roughness and Cutting force
Choi Y, Liu C [39]	AISI 1053	Feed/ Speed/ Depth of Cut/ Rake angle (Fixed parameter for both tools)	Multiple	CBN particle coated tools and solid PCBN tool	Residual stresses, Microstructure and Micro hardness
Rashid W. et al. [9]	AISI 4340	Feed/ Speed/ Depth of Cut	Single	Al_2O_3 insert	Tool life, Residual stresses, Cutting force and Microstructure with simulations.
Sahu S, Choudhury B	AISI 4340	Feed/ Speed	Multiple	Uncoated carbide tool and TiN coated carbide inserts	Surface roughness and Tool wear

[40]					
Maia L. et al. [41]	AISI 4340	Feed/ Speed/ Depth of Cut	Single	Polycrystalline cubic boron nitride (PCBN) tools	Tool wear and Tool life using acoustic emission
Diniz A, de Oliveira A [42]	AISI 4340 (Continuous, Semi-interrupted and Full interrupted surfaces)	Feed/ Speed/ Depth of Cut/ Cutting geometry: Chamfered and Edge rounding. (Fixed parameter for both tools)	Multiple	**CBN** Low CBN 7020 and High CBN 7050	Tool wear and Tool life
De Godoy V, Diniz A [7]	AISI 4340 (Continuous and Interrupted surfaces were taken)	Speed as recommended by the manufacturer for each tool	Multiple	**CBN** Low 7015 and High 7025 **Ceramic** CC670 & CC650	Tool wear and Tool life
Thamizhmanii S. [43]	AISI 440C	Feed/ Speed/ Depth of Cut	Single	CBN	Surface roughness and Tool wear
Grzesik W [17]	AISI 5140	Feed/ Speed/ Depth of Cut	Multiple	Mixed ceramic inserts (71% Al_2O_3, 28% TiC and 1% other) and Wiper insert	Surface roughness and Tool wear
Özel T. et al. [16]	AISI D2	Feed/ Speed/ Cutting time	Single	Wiper mixed alumina ceramic inserts with TiN coating	Surface roughness and Tool wear
Varaprasad B, Srinivasa Rao C, Vinay P [6]	AISI D3	Feed/ Speed/ Depth of Cut	Single	Al_2O_3/TiC mixed ceramic tool	Tool wear
Camargo J. et al. [12]	AISI D6	Feed/ Speed	Single	PCBN tools in the form of inserts (CB7015 of CBN with PVD TiN coating and ceramic binder)	Surface roughness, Cutting force and Tool wear

Rao C, Sreeamulu D, Mathew A [4]	Aluminum	Feed/ Speed/ Depth of Cut	Single	Tungsten carbide	Surface roughness, Cutting force, Tool wear, MRR and Power consumption
Chen J, Zhao Q [44]	Al 7075	Feed/ Speed/ Depth of Cut	Single	Single point diamond tool with different nose radius	3D Micro topography and Tool wear
El-Axir M [45]	S.S. - 304 Steel – 37 Al alloy 2024 Al alloy 7001 Brass	Feed/ Speed/ Tensile strength		Not Mentioned	Residual stresses
Rajasekaran T, Palanikumar K, Arunachalam S [46]	Carbon Fiber Reinforced Polyester Material	Feed/ Speed/ Depth of Cut	Single	CBN	Surface roughness
Natarajan C, Muthu S, Karuppuswamy P [47]	Brass C26000	Feed/ Speed/ Depth of Cut	Single	CNMG 120408 insert	Surface roughness
Bordin A, Bruschi S, Ghiotti A [48]	CoCrMo alloy	Feed/ Speed	Single	Single layer PVD coated TiAlN carbide tools	Surface finish, Microstructure, Micro hardness and Residual stresses
Chen T. et al. [49]	GCr15 steel or SAE52100	Feed/ Speed	Single	PCBN tools (7015)	3D Micro topography and Cutting forces
D Y. [50]	H11	Tool material/ Feed/ HRC/ Speed	Multiple	High CBN, Low CBN, Mixed ceramic	Tool wear
Aramcharoen A, Mativenga P [51]	H13	Speed/ Depth of Cut	Single	CBN	White layer, Tool wear, Temperature measurement and Microstructure

Mamalis A. et al. [8]	H13	Feed/ Speed	Single	CBN	Cutting forces and Temperature measurement
Sharman A, Hughes J, Ridgway K [52]	Inconel 718	Feed/ Nose radius/ Entry angle	Single	Coated tungsten carbide inserts with a multilayer coating	Residual stresses, Cutting forces, Surface roughness, Tool wear and Microstructure analysis
Jafarian F, Amirabadi H Sadri J [53]	Inconel 718	Feed/ Speed/ Depth of Cut	Single	Cemented carbide inserts	Residual stresses
Bushlya V, Zhou J, Ståhl J [54]	Inconel 718	Feed/ Speed	Multipl e	PCBN Tools Uncoated and TiN Coated tools	Cutting forces, Tool life, Tool wear and Surface integrity
Cantero J. et al. [55]	Inconel 718	Speed/ Side cutting edge angle	Multipl e	Carbide substrates (CP500 and TS2000)	Cutting forces, Surface roughness and Tool wear
Lalwani D, Mehta N, Jain P [56]	MDN250	Feed/ Speed/ Depth of Cut	Single	Coated ceramic inserts	Surface roughness and Cutting forces
Rodrigues L, Kantharaj [57]	Mild Steel	Feed/ Speed/ Depth of Cut	Single	High speed steel tool	Tool wear and Surface roughness
Breidenstei n B, Denkena B [58]	Not Defined	Feed/ Speed/ Depth of Cut	Single	PVD-coated carbide cutting tool	Residual stresses
Chen X, Cheng K, Wang C [59]	Not Defined	Feed/ Speed/ Depth of Cut (Fixed parameters)	Single	Smart turning tool embedded piezoelectric film sensors	Cutting forces
Hu H, Huang W [11]	H 13	Feed/ Speed/ Depth of Cut (Fixed parameters)	Multipl e	Ultrafine-grained ceramic and Common ceramic tool	Simulation results were used to explicate the differences of wear mechanism for different tools.
Kalyan Kumar K, Choudhury S [60]	SS202	Feed/ Speed/ Depth of Cut	Single	Carbide insert tool under cryogenic cooling conditions	Tool wear and Cutting forces
Nouari M, Makich H [61]	Ti–6Al–4V and Ti-555	Feed/ Speed/ Rake angle/	Multipl e	Coated carbide inserts made of tungsten carbide	Tool wear, Cutting force, Cutting temperature

		(Flank angle was fixed)		(WC–Co)	Microstructure and Micro-hardness
Gómez-Parra A. et. al [62]	UNS A92024 alloy	Feed/ Speed/ Depth of Cut	Single	Uncoated WC-Co inserts	Surface roughness and Ultimate tensile strength (UTS)
Wojtowicz N. et. al [19]	Elektron-21 wrought Mg-Zn-Zr-RE alloy	Feed/ Speed/ Nose radius (Fixed parameters)	Single	Carbide inserts with different nose radius	Residual stresses, Surface roughness, Microstructure and Micro-hardness
Darshan C, Singh L, Sethi A [14]	EN-31	Feed/ Speed/ Depth of Cut	Single	Mixed ceramic with PVD coated ceramic	Tool wear and Surface roughness
Abhang L, Hameedullah M [63]	EN-31	Feed/ Speed/ Depth of Cut Nose radius	Single	Diamond shape carbide tool with different nose radius	Tool wear and Surface roughness
R. Karimdadashi, M. A. Mohtadi-bonab [64]	AISI D3 Tool steel	Feed/ Speed/ Depth of Cut	Single	Not mentioned	Surface roughness
Oussama Zerti et al. [65]	AISI D3 Tool steel	Speed/ Feed/ Depth of Cut/ Nose Radius/ Major cutting edge angle	Multiple	Mixed ceramic inserts CC650 (Sandvik Coromant) and ISO geometric designations SNGA120408T01020, SNGA120412T01020, SNGA120416T01020.	Surface roughness Tangential force and Cutting Power
Varaprasad Bhemuni et al. [66]	AISI D3 Tool steel	Speed/ Feed/ Depth of Cut	Single	Ceramic Insert of TiC SNGA120408T01020 (CC6050 of Sandvik make)	Experimental and CAE simulations results are Compared for Surface roughness, Temperature and Force
Vikas Sharma, Joy Prakash Misra [67]	AISI D3 Tool steel	Speed/ Feed/ Depth of Cut	Single	Carbide inserts CCMT060208 (Sandvik Coromant)	Surface roughness and MRR

Rath D, Panda S, Pal K [68]	AISI D3 Tool steel	Speed/ Feed/ Depth of Cut	Single	Coated Al2O3 + Ti (C, N) Mixed Ceramic Insert AB2010 (Taegu Tec limited)	Surface roughness Tool wear, Cutting force and Chip Morphology
Srinivas C. et al. [69]	EN 8 Steel	Speed/ Feed/ Depth of Cut	Single	Carbide inserts CNMG 09 03 08-PF 4325 (Sandvik Coromant)	Surface roughness MRR
Norfauzi Tamin et al. [70]	AISI 1045 Carbon Steel	Speed/ Feed/ Depth of Cut (Constant)	Single	Carbide inserts TNMG 160404-MB (Sandvik Coromant)	Surface roughness Tool wear,
Okechukwu Izelu C et al. [71]	41Cr4 Alloy Steel	Speed/ Feed/ Depth of Cut	Single	Carbide insert, F30	Surface roughness machining induced vibration
Jabri A, Barkany A, Khalfi A [72]	EN -19	Speed/ Feed/ Depth of Cut/ Coolant flow rate	Single	Not Mentioned	Surface Finish, Tool – Work piece interface Temperature
Azizi M. et al. [73]	EN -19	Speed/ Feed/ Depth of Cut	Single	Coated carbide insert SNGA 120408T01520 (GC3015) (Sandvik Coromant)	Surface roughness MRR
Mallick R. et al. [74]	AISI D2 Tool Steel	Speed/ Feed/ Depth of Cut	Single	CVD coated carbide TiCN-Al2O3 (KCK05) (KENNAMETAL) CNMG120408FN	Surface roughness, Tool wear, Cutting temperature, Power consumption, Noise emission, and Chip morphology
Thi D. et al. [75]	90CrSi steel	Speed/ Feed/ Depth of Cut	Single	Not Mentioned	Surface roughness

4. DISCUSSION AND CONCLUSION

Most of the literature has revealed that researchers have attempted their study with bearing steel with the single insert of tool material. Very few researchers reported on alloy steel (EN-19) with different input and output parameters so far. Alloy Steel (EN-19) is heat treatable and also known for good strength. With a combination of good ductility and shock resistance, EN-19 is suitable for applications with very high loading such as engine gearboxes. Popular in the automotive sector it is possible to machine the material extremely accurately, in recent years. The material lends itself well to any application where strength is a primary consideration.

Therefore, it is valuable to determine the effect of the machining process parameters on the alloy steel and subsequently, prefer those machining parameters which may enhance the product life and reduce the maching time and ultimately increase the productivity of the organization.

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