Chapter 1

Introduction


1.1 Introduction

Hard turning is a cost-effective, high productivity and flexible machining process for ferrous metal work pieces that are often hardened above 45 HRc and upto 68 HRc. Hard machining is performed by using ceramics and polycrystalline cubic boron nitride (PCBN, commonly CBN) cutting tools due to the required tool material hardness. Hard turning is a lathe machining process where most of the cutting is done with the nose of the inserts. It is a single-point machining process carried out on hard materials which have hardness greater than 45 HRc upto70 HRc. Most hard turning applications involve turning of hardened steels [67].

To implement hard turning successfully, differences between the cutting process physics for machining soft steels (defined as having hardness value below 45 HRc) and hardened steels need to be clarified. The hard turning research discussed in the literature, can be generally divided into five major areas: a) mechanics of chip formation in turning of hardened steels b) effects of tool edge preparation and tool wear c) effects of machining parameters d) dynamic requirements of machine tool and e) surface quality and integrity of the hard turned functional surface. Hard turning has some unique process characteristics e.g.,segmented chip formation and microstructure alterations at the machined surfaces, fundamentally different from conventional turning.

The hard turning process differs from conventional turning because of the work piece hardness, the cutting tool required, and the chip formation mechanism involved. Hardened steel is one such that has been used extensively, particularly in the automotive industry for components such as bearings,gears,shafts and cams, forgings, dies and molds etc.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 [66,67,117].Hard turning is, therefore, of a great interest to both the manufacturing industry and research community.

1.2 Hard Turning: A Brief Introduction

Hard turning is defined as the process of single point cutting of part pieces that have hardness values over 45 HRc but more typically are in the 58-68 HRc range [53]. Basically hard turning which is the dominant machining operation performed on
hardened materials. The world-leading manufacturer of cutting tools, Sandvik coromant defines hard materials as those with hardness of above 42 HRc up to 65 HRc [127,96]. Commonly, hard-machined materials include white/chilled cast irons, high-speed steels, tool steels, bearing steels, heat-treatable steels and case-hardened steels. Sometimes, Inconel, Hastelloy, Stellite and other exotic materials are classified hard-turned materials. From Figure 1.1, values of 1 μm Rz in CBN high-precision machining and correspondingly IT3 dimensional tolerance are possible.

Figure 1.1 Achievable surface roughness and ISO tolerance in hard turning [17]

However, for extremely tightly tolerance parts, hard turning can also serve as an effective pre-finishing operation, followed by finishing grinding. Hard turning is usually performed on steel workpiece harder than 60 HRc with both mixed ceramic and PCBN cutting tools. It can be extended to rough, precision and high precision operation when the Rz parameter is less than 1 μm [17].

1.2.1 Differentiate with Grinding Operations

Hard turning is increasingly a profitable alternative to finish grinding. The objective is to remove work piece material in a single cut rather than a lengthy grinding operation, thus reducing processing time and production costs. Many studies have been carried out in the hard turning of continuous surfaces and the success of this method has encouraged in the recent years studies in the interrupted hard turning area. In addition, improved quality/work piece space surface integrity (SI) leading to
longer component life is also reported [25]. Traditionally, the finishing operations on machine parts in a highly tempered or hardened state with hardness value in excess of 60 HRc are grinding processes, but recently hard cutting operations using tools with geometrically defined cutting edges have become increasingly capable of replacing them and comparable surface finish. Grinding and turning are machining operations so opposite that their full substitution is not always easy or possible. Some of the inherent differences between these machining processes are given as follows [39]:

- Hard turning is a much faster operation because it can be done in one setup and pass under dry conditions.
- Lathes offer more production flexibility.
- Rough and finish operations can be performed with one clamping using a CNC lathe.
- Multiple turning operations are easier to automate through tool changes on turning center or turning cell.
- Since hard turning is done dry, there are no costs for coolant, its maintenance or disposal.

In particular, the hard cutting process performed with ceramic or CBN tools can often cut manufacturing costs, decrease production time (lead time), improve overall product quality, offer greater flexibility and allow dry machining by eliminating coolants these are shown in Figure 1.2.

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Figure 1.2 Criteria used in comparison between grinding and hard cutting Operations [17,62]
There are many opportunities for substituting grinding by turning operations when finish-machining of hardened ferrous materials. In general, hard turning reduces both equipment cost and personal expenses because it can be performed in one pass using one setup. On the other hand, as shown in Figure 1.3, the tool cost for finish-turning a gear blank of approximately 62 HRc hardness with CBN cutting material is almost 50% of the overall cost.

![Figure 1.3 Cost comparison of turning versus grinding [40]](image)

To replace conventional grinding of hardened steel components, precision finishing with super hard cutting tools can be offered to manufacturers as an attractive alternative. This is because it can allow cutting manufacturing costs, decreasing production time, and improving overall product quality [62].

### 1.2.2 Technological processes including Hard Machining

Technology has played an enormous role in advancing the metalworking industry and creating opportunities to reduce costs and improve quality. With the development of super-hard cutting materials, the technology of high speed machining of hardened steels has created considerable interest for die and mould manufacturing. More specifically, hard turning does not eliminate the need for grinding but can reduce the production burden on the more expensive grinders for the properly chosen application.

The advantages of hard machining specified in Section 1.2.1 lead to substantial shortening of the traditional technological chain with heat treatment and finish grinding after rough operation, as illustrated in Figure 1.4 (a) and (b).
1.3 Motivation

It seems obvious that hard turning is an attractive replacement for many grinding operations, but implementation in industry remains relatively low, particularly for critical surfaces. This is because hard turning is a relatively new processing technique, and several questions remain unanswered. It is seen from the available literature on the machining of EN31, Hard Steel that, the researcher employed orthogonal as well as oblique turning to understand the machinability of this material. The results of their studies showed very little promise in improvement of machinability of this material. Some have found increase in machining productivity in terms of material removal rate but at the loss of significant tool wear as well as existence of surface damages.

Therefore few attempts have been made by some researcher to improve the machinability by employing PCBN cutting tool. The above attempts to improve the machinability produce better results in terms of reduction in tool wear, cutting forces, and better surface integrity. This prompted us to undertake one of the above techniques and to investigate the machinability of this difficult-to-machine material by selecting the different process parameters. Hard turning differs from conventional turning in tool/work piece material properties cutting tool geometry, chip formation mechanism, and cutting conditions applied.
In general, significant prior research is available in the area of force modeling in turning operation. However, a comprehensive analysis of hard turning forces has not been well established in view of the unique process conditions involved. In addition to the workpiece and cutting tool material property aspects, hard turning process conditions are defined based on several key characteristics: negative tool rake angle, low feed rate, small depth of cut, relatively large tool nose radius, and rapid tool wear rate. These characteristics provide a set of cutting configuration, chip formation mechanism, and force generation process distinctive to the commonly encountered turning conditions.

The surface integrity is mainly determined by the following conditions: machining parameters, tool materials and conditions, cutting edge geometry, properties of the machine tools, and the geometric shape of the work piece. Without a better understanding of the behavior of CBN tools and the effects of worn tools on workpiece surface quality, implementation of hard turning will remain limited.

1.4 Research objectives

The overall goal of the proposed research is to develop methodologies using Taguchi modeling for predicting the effects of the machining parameters on the cutting force, surface roughness and chip dimensions. Thus the specific objectives of this research are to:

- Study in detail the various current theories of saw tooth chip formation.
- Study in detail the existing hypothesis and further experimentation based on developing new hypothesis, cost estimation of hard turning and grinding processes and hard turning applications.
- Investigation on effect of the cutting parameters on cutting performance such as cutting forces, surface roughness, cutting ratio, material removal rate, cutting power and material removal rate per cutting power.
- Finding out the significance of cracking frequency during hard turning with various cutting speed, feed and depth of cut.
The purpose of this research is to study the effects of cutting parameters on the cutting performance of hard turned parts, in completely dry cutting. The study helps to provide an understanding of the behavior of the tool and the workpiece under hard cutting conditions. During each test, surface roughnesses are compared with prediction values and cutting forces and chip dimensions are measured and analyzed with ANOVA.

1.5 Overview of thesis

The present thesis consists of six chapters and the contents of the thesis are as follows.

Chapter 1 provides an insight in the world of hard turning, brief introduction, and motivation behind this research. Lastly this chapter includes the research objectives along with significance of the study.

Chapter 2 presents a literature review on the machining of hardened steel. It includes hard turning process characteristics, cutting tool wear, cutting temperature, white layer formation and residual stresses. It also includes in detail the various current theories of saw tooth chip formation. In the chapter two some discussions on the key research publications have been done. That are helpful in understanding the machining process, analyzing the experimental results and summary of machining optimization techniques. It helps to a proper selection of the cutting parameters in hard turning.

Chapter 3 describes in detail the existing hypotheses and further experimentation based on developing new hypothesis. It presents procedure to calculate frequency of saw tooth chip in hard turning. Chapter also emphasized some related experimental review of different force components, surface roughness and chip dimension influencing factors. Design of experiment, experiment design and execution and working procedure of Taguchi techniques have also been clarified in detail in this chapter. A research application showed that using hard turning instead of grinding can cut the machining time. The process time in hard turning is less than in grinding.

Chapter 4 gives a experimental design along with experimental details and actual experimental procedure used in this research work the experiments conducted.
Chapter 1

It studies the effect of cutting parameters on the cutting forces, surface roughness and chip flow in machining of EN 31(AISI 52100) hard steel.

Chapter 5 gives the results and discussions of cutting forces, surface roughness and chip measurements. The data obtained gives a wide scope to understand the influence of cutting conditions such as the cutting speed, feed rate and depth of cut on the axial force, radial force and tangential force components and surface roughness ($R_a$, $R_z$, and $R_t$) values. It has been observed that the chip morphology under different cutting speed is different. The ANOVA technique and MINITAB15 software were used for analysis of results. It contains thorough study of effect of process parameters on material removal rate, cutting power, material removal rate per cutting power, surface roughness, cutting ratio and cracking frequency. It has been observed that the chip morphology under different cutting speed is different. The results presented in the thesis will be useful for application of EN31 steel for the development of turning finishing processes.

Chapter 6 outlines the brief summary of the work carried out and conclusions drawn based on discussions presented in earlier chapter and present a proposed scope for future work.

1.6 Significance of the study

From this research the following outcomes expected;

- Understanding the use of MB 8025 CBN Tool in terms of its characteristic and performance in hard turning application.
- Determination of the effectiveness of turning using MB 8025 CBN Tool steel.
- The study will be useful towards achieving effective and economical hard machining processes.
- The mathematical model will enable the prediction of the surface roughness.