CHAPTER 1

INTRODUCTION

1.1 OVERVIEW OF CNC TURNING

Turning is the most widely used process among all the machining processes. The increasing importance of turning operations is gaining new dimensions in the present industrial age, in which the growing competition calls for all the efforts to be directed towards the manufacture of machined parts economically and surface finish is one of the most critical quality measures in mechanical products. As the competition grows closer, the customer now has increasingly high demands on quality, making surface finish and tool wear which are the most competitive parameters in today’s manufacturing industry. In a machining operation, selection of machining parameters is the most critical job (Nikolaos & Manolakos 2010). It requires a number of experiments and considerable knowledge to get optimum machining parameters for a particular machining operation. Recently, rapid developments in the manufacturing industry have increased the significance of machining processes. CNC turning is one of the most popular and efficient machining operations, with which, the high surface finish of work piece can be easily obtained. CNC turning is especially preferred in the machining of hardened steel (Diniz & Micaroni 2002).
1.2 OVERVIEW OF STAINLESS STEEL

Stainless steels are widely used in engineering applications such as steam and water valves, pumps, turbines, compressor components, shafting, cutlery, surgical tools, bearings, aero space components and plastic moulds etc. Stainless steels contain a high proportion of chromium, generally 13% or more. All stainless steels resist corrosion, although the degree of resistance to attack varies. To enhance or supplement the effect of chromium, other alloying elements are added straight to chromium stainless steels as follows:

- Nickel - To stabilize the austenitic structure, improve forming properties, increase ductility, high temperature strength and corrosion resistance.
- Silicon - To increase scaling resistance and resist carburizing at high temperatures.
- Manganese - To improve hot working properties, increase yield and tensile strengths partially replaces nickel and stabilizes the austenitic structure.
- Molybdenum - To increase corrosion resistance, increase creep resistance, increase strength at elevated temperatures, expand range of passivity and counteract tendency to pit.
- Titanium, Columbium - Tantalum - To prevent inter granular corrosion by stabilizing the carbon as titanium or columbium carbides instead of chromium carbides, produce finer grain size, reduce stretcher strains from drawing and forming.
- Sulphur and Phosphorus - To improve machinability.
- Additional Chromium - To increase scaling, wear and corrosion resistance and increase tensile strength.
Stainless steels are generally difficult to machine due to their high tensile strength, high ductility, high work hardening rate, low thermal conductivity, and abrasive character. This combination of properties often results in cutting forces, temperatures, and tool wear rates, as well as a susceptibility to notch wear, chip-breaking difficulties, BUE formation, and poor machined surface finish (Gutakovskis et al 2010). Stainless steels are usually classified into four categories depending on their primary content of the matrix: ferritic stainless steel, martensitic stainless steel, austenitic stainless steel, and duplex stainless steel.

1.2.1 **Ferritic stainless steel**

Ferritic stainless steels are alloyed primarily with chromium, although molybdenum, titanium may be added to improve corrosion resistance properties. Ferritic Stainless steels are generally more machinable than other alloys. Their machinability generally decreases with increasing chromium content (David et al 2006).

1.2.2 **Martensitic stainless steel**

The 400 series stainless steels belong to the martensitic group which are hardenable by heat treatment and are magnetic. Varieties such as Types 403, 410, 420 and 440 find major applications as products that must resist atmospheric oxidation, mildly corrosive chemicals and wet or dry corrosion, such as in steam and gas turbine parts, bearings and cutlery. In addition to chromium, martensitic stainless steels may contain carbon, molybdenum, and nickel to increase strength. The machinability of martensitic stainless steels is influenced by hardness, carbon content, nickel content, and metallurgical structure. As with the most materials, increasing hardness typically reduces tool life and machinability (Childs & Maekawa 2000).
1.2.3 **Austenitic stainless steel**

The 300 series stainless steels are the most important members of the austenitic family. Austenitic grades may become slightly magnetic after cold working and hardenable only by cold working. Austenitic stainless steels contain nitrogen, carbon, and nickel or manganese in addition to chromium. They exhibit high strength, ductility, and toughness, and are typically more difficult to machine than ferritic stainless steel or martensitic stainless steel. Specific difficulties encountered when machining austenitic stainless steels include high wear rates due to high cutting forces and temperatures, BUE formation, chip control problems, poor surface integrity, and a tendency to chatter (Astachov 2006).

1.2.4 **Duplex stainless steel**

Duplex stainless steels have chemistry similar to austenitic stainless steels but are generally more difficult to machine due to their high annealed strength (Trent 2000, Youssef & Hassan 2008).

1.3 **CUTTING TOOLS**

Cutting tools play a very important role in the CNC machining method. There are two types of cutting tools widely used in the CNC machining industry such as high speed steel cutting tools and carbide cutting tools. However, carbide cutting tools are preferred over high speed steel cutting tools. Carbon is not only used in the direct carbide tool, but also in a combination of some other non-metals (boron, calcium and silicon) and metals (cobalt, titanium, tungsten and vanadium). These combinations differ according to the type of requirement of in the material cutting method. The combination of the two metals results in a fine grey powder and it is formed by a powder metallurgical method. Particularly carbide cutting tools are
classified in to two types such as cast iron carbides and steel grade carbides. Both are used in different types of cutting applications. Cast iron carbides are specially made up to cut cast iron materials. These tools are more resistant to abrasive wear which occurred during the cutting process of cast iron due to its highly abrasive surface. These carbides are able to protect the tool from edge wear. Steel grade carbides are specifically made to resist this. The different types of carbide used to cut different metals; the main carbide material in these cutting tools is tungsten carbide with cobalt binder. Tungsten carbide has resistance to abrasive wear and is very hard. When added with cobalt, the tool’s surface will further get tough (Lim et al 1999).

1.3.1 Cutting Inserts

Insert is a one of the cutting tools made up of a different combination of metal and non metal materials, which is mainly used in a CNC machine for a good surface finish with high accuracy. It is classified in to some grades according to the material components, type of applications and machining conditions (Ezugwu Okeke et al 2001).

1.3.2 Different materials for cutting inserts

1. Coated cemented carbide
2. Cemented carbide
3. Cermets
4. Ceramics
5. Cubic boron nitride
6. Polycrystalline diamond.
1.3.3 Different shapes for cutting inserts

1. Factors affecting choice of insert shape
2. Insert shape - number of cutting edges
3. Insert shape - depth of cut

The insert shape should be selected in relation to the entering angle accessibility required of the tool. The largest possible nose angle should be selected to provide insert strength and reliability. However, this has to be balanced against the variation of cuts that need to be performed. A large nose angle is strong, but requires more machine power and has a higher tendency for vibration. A small nose angle is weaker and has a small cutting edge engagement, both of which can make it more sensitive to the effects of heat (Nouari et al 2003, Ducros et al 2003).

1.4 COATING TECHNOLOGY

Demands on products and production processes are the driving factors behind developments in today’s cutting technologies. Innovations such as the application of advanced work material concepts, together with needs for non-pollutant machining processes, increased flexibility and improved cost-effectiveness trigger the application of high performance processes, imposing higher stresses on tools. This often reveals inadequate wear resistance in conventional tool materials. Coating technology is one of the means of achieving a crucial enhancement in tool performance. However, there is such a huge variety of available coating materials and coating processes that careful selection of a suitable coating system is essential using accessible know-how concerning coated cutting tools and their behavior in a wide range of different machining tasks. In order to select or develop a suitable tool coating, it is necessary to identify the primary wear mechanisms
inherent in the specific machining task. The ability of a coating to reduce wear sufficiently is the criterion for choosing it. There are two major ways in which a coating may influence tool wear.

1.4.1 Influence of the Coating Process

The morphology of a coating depends mainly on the coating process applied. The relevant processes for the coating of tools may roughly be differentiated into chemical vapor deposition and physical vapor deposition processes.

1.4.2 Chemical Vapor Deposition Process

The main characteristic of a CVD process is the high substrate temperature needed to deposit a coating. High temperatures during the coating process promote annealing processes in high speed steel substrates and also affect the toughness and the transverse rupture strength of cemented carbide substrate materials, due to the formation of a brittle. Using a standard CVD process at about 1100°C can reduce strength by 30 percent. The problem can be alleviated by using the moderate temperature process at 850°C coating temperature.

1.4.3 Physical Vapor Deposition Process

The PVD process is usually performed at 200°C to 500°C which has virtually no impact on the transverse rupture strength of the coated material. In PVD processes, the materials needed to form the coating material are evaporated and subsequently condensed on the tool substrate. Further components of the coating material can be added by using a reactive gas. The method used to evaporate the coating material is an important feature of a
specific PVD process. It can be induced by heating, by an electron beam or by sputtering with a process gas accelerated to the target.

1.5 CUTTING SPEED, FEED, DEPTH OF CUT, SURFACE FINISH, TOOL WEAR

In order to identify the process parameters that may affect the machining characteristics of turned parts, an Ishikawa cause effect diagram was constructed and is shown in Figure 1.1. The most essential parameters which affect the quality of turning process are:

![Ishikawa cause effect diagram for turning](image)

**Figure 1.1 Ishikawa cause effect diagram for turning**

1. Cutting tool-related parameters – Tool geometry and tool material
2. Work piece-based parameters – Composition, structure, strength and hardness
3. Machining parameters – Cutting speed, feed, and depth of cut, wet cutting and dry cutting (Wardancy & Elestawi 1997).
Cutting speed is the speed difference between the cutting tool and the surface of the work piece it is operating on. It is expressed in units of distance along the work piece surface per unit of time, typically surface feet per minute or meters per minute. It is also called as surface speed or simply speed. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same.

Feed is the relative velocity at which the cutter is advanced along the work piece; its vector is perpendicular to the vector of cutting speed. Feed units depend on the motion of the tool and work piece; when the work piece rotates, the units are almost always distance per spindle revolution or millimeters per revolution.

Depth of cut is practically self explanatory. It is the thickness of the layer being removed from the work piece from the uncut surface of the work to the cut surface, expressed in mm. It is important to note, though that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work.

Surface roughness is one of the most important requirements in machining process, as it is considered an index of product quality. It measures the finer irregularities of the surface texture. Achieving the desired surface quality is critical for the functional behavior of a part. SR influences the performance of mechanical parts and their production costs because it affects factors, such as friction, ease of holding lubricant, electrical and thermal conductivity, geometric tolerances and more. In turning operation the SR depends on cutting speed, feed, and depth of cut, tool nose radius, lubrication of the cutting tool, machine vibrations, TW and on the mechanical and other properties of the material being machined (Kopac et al 2002, Davim 2003, Ghani et al 2004, Tosun and Ozler 2004). This portion is presented in a graph with the X axis extending in the same direction as the average line and the Y
axis representing the magnitude. $R_a$ is represented by the equation shown below, in microns. Where, $L$ indicates the sample length, which is as noted in Figure 1.2.

\[
R_a = \frac{1}{L} \int_0^L |f(x)| \, dx
\]

**Figure 1.2 Arithmetical average surface roughness**

**Tool wear** which results in tool substitution is one of the most important economical penalties, so it is very important to minimize tool wear, and optimize all the cutting parameters like depth of cut, cutting speed and feed. The primary tool wear are classified as flank wear, crater wear and nose wear, which will affect the smoothness of the product, cost of operation and performance. During turning tool wear is caused by the normal load generated by interaction between tool work piece and tip (Aden Kendall 1998, Abou El Hossein & Yahaya 2005, Attanasio et al 2006). Flank wear probably occurs by both abrasive and adhesive wear mechanisms with abrasive wear being the major source of material removal since the temperatures at tool flank are lower than that on the rake face. Abrasive is mainly caused by the hard, martensitic structure of the hard work material. The relative motion between the newly cut surface and the flank of the cutting tool in the presence of hard particles results in the development of a flat of the flank faces of the cutting tool (Noordin 2007).

The TW mechanism depends on the combinations of the tool and work materials, cutting conditions, tool geometry etc. A few basic mechanisms dominate cutting tool wear and they are: 1. Diffusion wear affected by chemical loading on the tool and cutting material 2. Oxidation
wear - causes gaps to occur in coated film and results in a loss of the coating at elevated temperature, 3. Fatigue wear is a thermo-mechanical effect and leads to the breakdown of the edges of the cutting tool, 4. Adhesive wear occurs at low machining temperatures on the chip face of the tool and leads to the formation of a built up edge, and the continual break down of the built up edge and the tool edge itself, 5. Abrasive wear is affected by hardness of the work material and is controlled by content of the cutting material (Baley et al 1998, Braghini & Coelho 2001, Dolinsk & Kopa 2006, Antic et al 2006, Huang et al 2007, Jackson et al 2007).

1.6 SINGLE RESPONSE OPTIMIZATION

Taguchi method is a traditional approach for robust experimental design that seeks to obtain the best combination set of factors/levels with the lowest societal cost solution to achieve customer requirements (Jeyapaul et al 2006, Biermann et al 2013). Taguchi’s approach to design of experiments is easy to adopt and apply for users with limited knowledge of statistics; hence it has gained a wide popularity in the engineering and scientific community. In the Taguchi design method the design parameters (factors which can be controlled) and noise factors (factors which can’t controlled), which influence product quality, are considered (Montgomery 1997). The main thrust of the Taguchi technique is the use of parameter design, which is an engineering method for product or process design that focuses on determining the parameter settings producing the best levels of quality characteristic with minimum variation. Taguchi design provides a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions (Ross 1996, Ghani et al 2004, Prasad et al 2013).
1.7 MULTI RESPONSE OPTIMIZATION

Grey relational analysis is a measurement technique which focuses on the quantitative explanation and comparison of variation. It quantifies all effect of various factors on response and their relation which is called the whitening of factor relation. In grey theory, the black box is used to point out a system lacking internal information. The black is indicating as lack of information but the white is full of information. Thus, the information which is either incomplete or undetermined is called Grey. A system having incomplete information is called grey system. The Grey number in Grey system represents a number with less complete information. The Grey element represents an element with incomplete information. The Grey relation is the relation with incomplete information. GRA is a measurement technique in grey system theory that analysis the degree of relation in a discrete sequence (Deng1989, Lin et al 2002, Jeyapaul et al 2005, Tosun 2006).

1.8 MODELING AND PREDICTION

The response surface method (RSM) has been proposed to determine the influences of individual factors and their interactions. RSM is a technique for designing experiments, building models, evaluating the effects of several factors, and achieving the optimum conditions for desirable responses with a limited number of estimated experiments (Khuri & Cornell 1996, Suresh et al 2002, Sahin & Motorcu 2004). RSM helps to demonstrate how a particular response is affected by a given set of input variables over some specified region of interest. The RSM was initially developed for determining optimum operating conditions in the chemical industry, but it is now used in a variety of fields and applications, not only in the physical and engineering sciences, but also in biological, clinical, and social sciences (Ravi Kumar et al 2009). Optimization process involving one variable at a time method is a time consuming process and it neglects the interaction between
variables involved and it does not guarantee the attaining of optimal point (Khuri 2001). Box Behnken optimization design abolishes these disadvantages, besides it creates empirical model equations that correlate the relationship between variables and responses BBD designs require fewer treatment combinations than a central composite design in cases involving 3 or 4 factors (Srinu Babu et al 2007, Ranjith Kumar et al 2012).

1.9 OVERVIEW OF THIS STUDY

Most of the researchers concentrated on the effect of the tool geometry, performance of the different cutting fluids, coating methods of the cutting tool, performance of the CBN and PCBN cutting tool on turning stainless steels. Moreover the researchers had conducted turning experiments with high cost tools like CBN and PCBN on stainless steels. Coating on cutting tool is important to achieve an essential improvement in tool performance with low cost. However the performance of the coated tools in CNC turning on stainless steels has received less attention. In this work, an attempt has been made to investigate the different coated tools on AISI316 and AISI410 in CNC turning under dry conditions. Coated with TiCN/Al₂O₃ insert was selected for case-I, coated with TiAlN insert was selected for case-II, coated with Ti(C, N, B) insert was selected for case-III, coated with B-TiC insert was selected for case-IV and coated with B-Al₂O₃ insert was selected for case-V. Tool geometry of CNMG120408 and tool holder of PCLNR25 × 25 M12.1 was selected for all cases. The objective is to minimization of surface finish and tool wear against the different cutting speed (110, 160 and 210 m/min), feed (0.1, 0.2 and 0.3 mm/rev) and depth of cut (0.7, 1.4, 2.1 mm). In this research, Taguchi method was applied to single response optimization and grey relational analysis was employed to multiple response optimizations. New approach namely Box Behnken design was used
for modeling and prediction to provide the sufficient information about the main and interaction effects with a limited attempt of experiments.

1.10 SCHEME OF THIS STUDY

Chapter 1 presents the introduction of the CNC turning, an overview of the stainless steels, the coating on cutting tool, machining parameters, responses, solving single response problem, multi response problem, modeling and prediction, an overview of this study and scheme of this study. Chapter 2 describes the literature review of CNC turning on stainless steel and methodologies adopted for solving single response problem, multi response problem and mathematical modeling and prediction. Chapter 3 deals the selection of different coated tools. Chapter 4 provides a detail description of the experimental work carried out and the measurement of responses. Chapter 5 deals with the discussion of the use of Taguchi method for solving single response optimization of machining parameters for turning stainless steel using different coated tools. Chapter 6 deals with the multi response optimization for turning stainless steel using grey relational analysis in Taguchi method. Chapter 7 discusses modeling and prediction by box benhken design for turning stainless steel using different coated tools. Chapter 8 deals with the discussion of results obtained by various methodologies. Finally, chapter 9 details the conclusions drawn from the experiments. Contribution of this research study and scope for the further work are also discussed. The scheme of this research work is shown in Figure 1.3.
Experimental Study of Machining Parameters for Turning Stainless Steel Using Different Coated Tools

Selection of Different Coated Cutting Tools
1. TiCN/Al₂O₃
2. TiAlN
3. Ti(C,N,B)
4. B-TiC
5. B-Al₂O₃

Turning on AISI316 Using Different Coated Cutting Tools
Turning on AISI410 Using Different Coated Cutting Tools

Measurement of Surface Roughness and Tool Wear

Single Response Optimization Using Taguchi Technique

Multi Response Optimization Using Grey Relational Analysis in the Taguchi method

Modeling and Prediction Using Box Benhken Design

Result and Discussion

Conclusion

Figure 1.3 Scheme of the research work