EFFECT OF CUTTING PARAMETERS ON SURFACE FINISH AND NOISE PATTERNS FOR MACHINING OF EN-24 STEEL WITH TiAlN COATED TUNGSTEN CARBIDE INSERTS IN 3-AXIS VERTICAL END MILLING OPERATION

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in

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by

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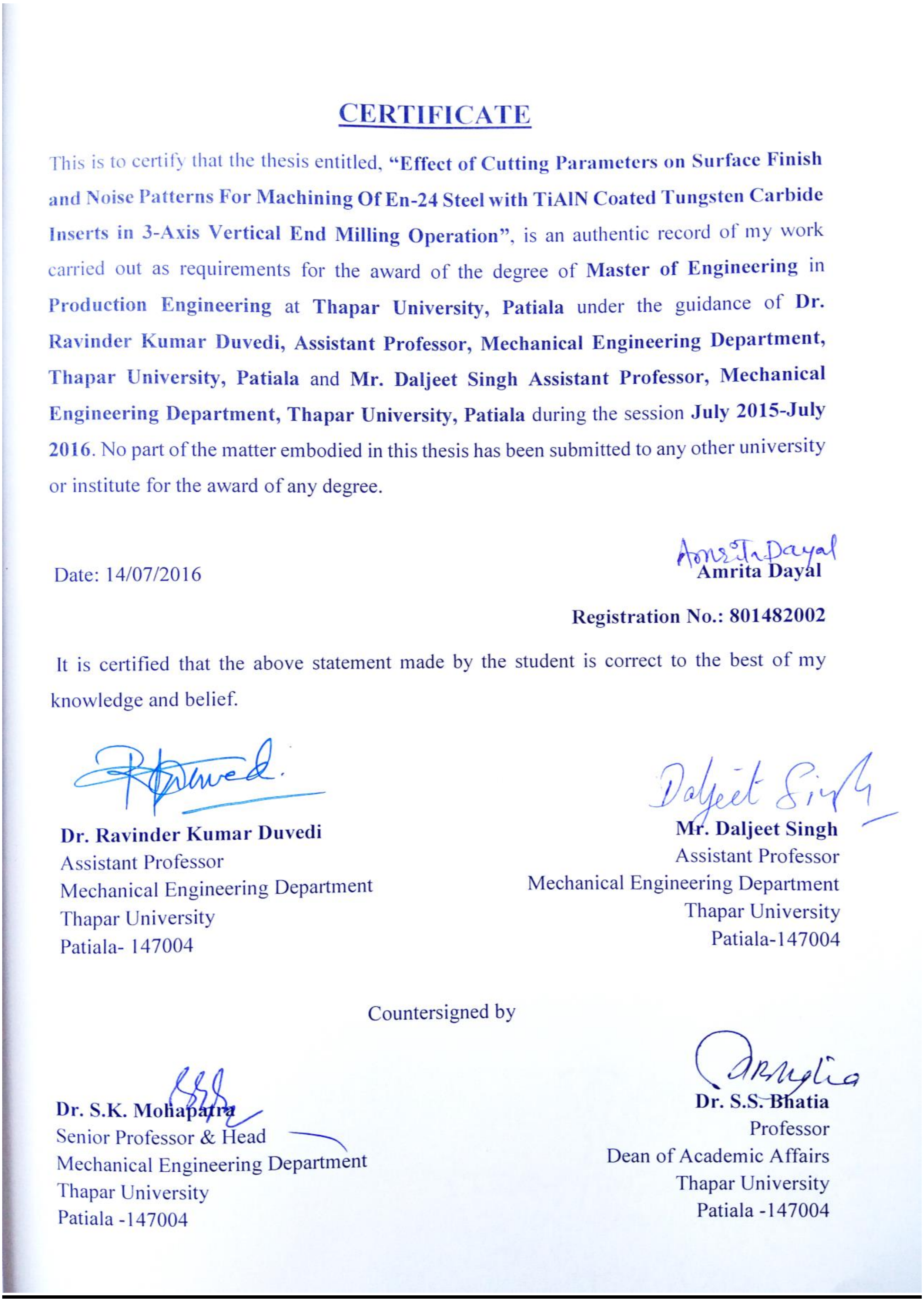

CERTIFICATE

This is to certify that the thesis entitled, **"Effect of Cutting Parameters on Surface Finish and Noise Patterns For Machining Of En-24 Steel with TiAlN Coated Tungsten Carbide Inserts in 3-Axis Vertical End Milling Operation"**, is an authentic record of my work carried out as requirements for the award of the degree of **Master of Engineering** in **Production Engineering** at **Thapar University, Patiala** under the guidance of **Dr. Ravinder Kumar Duvedi, Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala** and **Mr. Daljeet Singh Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala** during the session **July 2015-July 2016**. No part of the matter embodied in this thesis has been submitted to any other university or institute for the award of any degree.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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ABSTRACT

CNC machines are found to be very effectively beneficial and profitable in modern production floors. In industries surface finish is an important aspect of the end products produced. Although many efforts have been made to produce products of good surface finish with lesser tool wear and minimal machining cost but still research is going on regarding production of good surface finish of hardened material at high speed as well as reduction in the noise levels produced during machining. The machining operations are always accompanied by some peculiar noise pattern. Such noise in a shop floor may be a danger for human safety as well as behavioral changes. So it is also desirable that the machining noises should also be considered as a factor in study of effect of machining parameters on optimization of surface roughness thus obtained. In the existing thesis work an effort has been made to establish the optimum levels of cutting velocity, radial and axial cut depth to achieve a best surface finish of EN-24 alloy steel for wet machining conditions using Houghton Hocut B50S semi synthetic coolant while simultaneously observing the noise patterns generated during machining on 3-axis vertical end milling with tungsten carbide insert based flat end milling cutter. So that the best surface finish at minimum sound level can be achieved. The main aim of this work is to reduce the health risk of the operators. To optimize the machining parameters so that the best surface finish and minimum sound level can be achieved. Also, further online condition monitoring can also be achieved further for industrial use.

NOMENCLATURE

PARAMETERS	NOTATIONS	Units
Average Roughness	R_a	µm
A-Weighting Sound Level (with machining)	L_A	dBA
A-Weighting Sound Level (without machining)	L_{AWM}	dBA
Axial Depth of Cut	a_e	mm
Corrected A-Weighting Sound Level	L_{AC}	dBA
Corrected Z-Weighting Sound Level	L_{ZC}	dBZ
Degree of freedom	DOF	$-$
Diameter of Tool	D	mm
Difference between machining and without machining	Δ	dB
Feed	F	m/min
Feed per tooth	f	$m/tooth$
Number of teeth	Z	$-$
Radial Depth of Cut	a_d	mm
Root Mean Square Roughness	R_q	µm
Spindle Speed	N	rpm
Velocity	V	m/min
Z-Weighting Sound Level (with machining)	L_z	dBZ
Z-Weighting Sound Level (without machining)	L_{ZWM}	dBZ

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CHAPTER 1
INTRODUCTION

1.1 Introduction

CNC machines are found to be very effectively beneficial and profitable in modern production floors. They can be employed for various machining processes. CNC machines can be used for number of operations like end milling, face milling. In this modern era of development, there are multiple axis milling centre being used. Most commonly used are 3-axis milling centre. CNC milling centre being used now a days are of great benefits such as automated tool changer, immensely good flexibility, low production cost, excellent accuracy as well as repeatability. End milling operation is a one in which the cutter rotates on the axis of the workpiece vertically and the teeth are positioned on end face as well as the periphery of the cutter body. End milling operation can be used when complex and contour metal shapes are required so as to create number of metal structures like dovetails, threads, bevel, slots and ridges and various dies which can be further used for different shapes. Here in this experimental study 3-axis vertical CNC milling centre is used as shown in figure 1.1.

Figure 1.1: CNC milling machine

Now a days many alloy steels are widely used in industries. One of them is EN-24 alloy steel which is employed for the manufacturing of axles and axle components, arbors, pinions and shafts, shafts and wheel. In industries surface finish is an important aspect of the end products produced. Therefore, to produce good surface finish different machining parameters velocity, axial and radial cut depth are required to be optimized.

The machining operations are always accompanied by some peculiar noise pattern. Such noise in a shop floor may be a danger for human safety as well as their behavioural changes [20]. So it is also desirable that the machining noises should also be considered as a factor in study. So that the impact of these machining parameters on optimization of surface roughness can be thus obtained. In the present thesis work an effort has been made to establish the optimum levels of machining speed, radial and axial depth of cut to achieve the best surface finish for wet machining conditions and simultaneously observing the noise patterns generated during 3-axis vertical end milling with insert based flat end milling cutter.

1.2 Effect of Machining Parameter on Surface Finish

During cutting various cutting parameters such as feed, velocity, spindle speed, radial and axial cut depth conditions influences the tool life as well as surface integrity. The working environment affects the finish of the workpiece as well as fatigue life of the tool as most of the imposed stresses and forces are tolerated by them. The various machining parameters which affect surface finish are:

i. **Feed:** During machining, the distance moved by the tool in one revolution of the workpiece is known as feed. Feed can be measured in feet, inches or milli-meters per unit time. The feed can be used for describing the size of the deepest cut the tooth can make.

ii. **Cutting Speed:** Cutting speed (also known as tangential velocity) can be described as the relative velocity in between the cutting tool and the surface of the work-piece on which it is running on.

iii. **Axial Cut Depth:** It is generally quantified in inches or milli-meters. Axial depth of cut can be defined as the depth at which the tool cuts into the work-piece.

iv. **Radial Cut Depth:** The quantity measures that how wide the tool cuts into the work-piece.

v. **Spindle speed:** It refers to the speed at which tool is rotating. Spindle speed is measured in revolutions per minute (rpm).

1.3 Effect of Cutting Tool and Geometry in End Milling

In addition to machining parameters certain other conditions that the surface quality of the workpiece includes cutting fluid, heat generation, tool material, geometry of tool, grain structure of workpiece. During machining stresses are imposed on the workpiece therefore, machining conditions in which cutting is being performed greatly affects the surface finish of workpiece and tool life. Some of these machining conditions are discussed below.

i. **Lubricating condition:** Cutting fluids plays a remarkable role in machining operation and strongly affects the productivity of tool life as well as on the quality of workpiece. The basic purpose of cutting oil is to reduce and control the temperature by cooling and lubricating the workpiece and tool surfaces which are in contact and the lesser important function of cutting fluid is to swipe away the chips from the tool/workpiece interface to prevent a finished surface from becoming damaged and also to reduce the occurrence of built-up-edge.

With the reference to the study done by [9, 13, 15] on the different lubricating conditions. The different conditions are wet condition, dry condition, and mist lubrication. In the present study wet condition is employed using a semi synthetic cutting oil.

ii. **Heat generation:** During machining process due to friction heat is generated in a large amount. Heat generated causes thermal deformation due to which tool wear increases as well as properties of the workpiece also varies.

iii. **Grain structure of workpiece:** When machining the temperature of the affected part increases due to which change in grain structure starts. These changes in the microstructure leads to the change in the physical properties of the workpiece.

1.4 Factors to be considered during End Milling Operation

For an effective conditions to be achieved the recommended range of parameters used are to be preferred corresponding to the recommended ranges of the cutting tools and inserts being used. These factors affects the deflection of the tool due to variation in depth of cut, chip thickness decreases if velocity increases, chip load also decreases if parameters are varied.

i. **Type of tool:** The cutter/tool type usage are specified according to the location plane on which machining is to be done to achieve the desired contours. The different type of tool types are end mill, face mill, slab mill and shell mill.

ii. **Tool material:** There are different type of material used for milling operation and choice of the material is done on the basis of hardness, wear resistance and toughness required. The different type of material that are mainly used as a tool are carbon tool steel, high speed steel, cemented carbide, ceramics, diamond any many other. The tool can be of two types solid tools and inserts based tools.

The solid tool consist of grooves. The angle at which these grooves are arranged can be straight or helical. Straight flutes would have whole impact load get transferred to them when inserted in the workpiece which causes reduction in accuracy and surface finish. On the other hand inclining them to some angle (known as helix angle) reduces vibration as well as also helps in getting better finish.

During machining tool wear takes place which leads to the consumption of the whole tool. Therefore, to reduce the expenditure on the whole tool inserts are used. Now a days various varieties of inserts are used like tungsten carbide inserts, titanium carbide inserts, ceramic inserts diamond inserts and many other. In order to get a good and enhanced tool life, coatings are done on the inserts with the help of physical vapour deposition (PVD) and chemical vapour deposition (CVD). The coated tools helps in achieving good surface finish [25] and it is cost effective as inserts have many sides which can be used for machining.

The work undertaken in this study is to machine the hardened alloy steel EN-24 using tungsten carbide inserts with TiAlN coating. The tungsten carbide inserts are used as they are capable to perform high speed machining operation on hardened material along with less minimal cost.

iii. **Type of milling operation:** As describes above there are different type of milling cutters therefore, different type of milling operation are end milling, face/flank/side milling, end and face milling simultaneously. In end milling generally cutter rotates on a vertical axis being perpendicular to the work piece. Face milling operations creates a flat face on a large part. Whereas, in face milling, the cutter is mounted on a spindle and the rotational axis of rotation is perpendicular to the work piece surface.

1.5 Effect of Machining Noise on Operator

Noise can be termed as an unwanted sound. There are different types of noise sources in industries. Some of them are noise arising during unloading and loading of material, transportation noise for the period when materials are moved from one shop to another, and most important and seriously affecting machining noise.

When the operators work on the shop floor where a number of machines are simultaneously creating a humming sound. This annoying sound affects the health of the workers it causes insomnia as well as restlessness. Not only this but after some period of time when the workers gets habituated to these noise levels then they become ineffective to these levels which can be dangerous to them in any emergency conditions. The parameters employed later in the further study are discussed below.

1.6 Physical Properties of Sound [17, 20-21, 28-29]

1.6.1 Sound Pressure Level: Sound waves travel in the form of pressure waves. Sound pressure level (L_p) is measured as the loudness of the sound waves propagating as disturbance in ambient pressure level and it is expressed in decibels. Decibel is the logarithmic scale of the ratios of two quantities. The human ear correspond to $20Hz$ to $20kHz$ and is generally measured Decibel (dB) by using the equation 1.1 used below:

$$L_p = 20 \times \log_{10} {}^{P}/_{P_o} \qquad 1.1$$

Where, P is the sound pressure being measured

P_0 is the reference sound pressure i.e. 20μPa (the threshold of hearing).

1.6.2 Sound Intensity: Sound Intensity can be termed as the sound power per unit area kept perpendicular along the direction of propagation of sound pressure waves. Sound intensity tells us about the difference in intensities of the sound levels which cannot be detected by a microphone. The reference sound intensity level is at $0dB$ as it corresponds to$10^{-12}\ W/m^2$.The sound intensity level (SIL) will have same value as that of sound pressure level (SPL) and the relationship between sound pressure (p) and intensity (I) can be written as equation 1.2 used below:

$$p^2 \propto I \qquad 1.2$$

1.6.3 Sound Power: Whenever sound is produced, a transfer of energy from the source to the surrounding air takes place by emitting, reflecting, or transmitting energy. The rate of energy transfer is called sound power. The unit of sound power is Watt (W). Sound pressure level. The sound pressure gives the measure of sound level about a point closer to the source but sound power gives the measure of total power generated around the source and mathematically, it can be represented as equation 1.3 used below:

$$I \propto P \qquad 1.3$$

1.7 Background Noise [28]

It can be defined as the any type of noise that is not the sound that we are specifically listening to or willing to monitoring. In order to remove this, background noise correction is done either through graphs or through mathematical formula which are later described in Chapter 3.

1.8 Loudness [17, 20-21, 28-29]

Loudness is also one of the characteristics of sound. The perception of loudness is difficult than A-weighting sound level therefore, filters are used for A-weighting to adjust the sound level

which corresponds to the loudness which can be perceived by human ear.

1.9 Weighting Curves [17, 20-21, 28-29]

1.9.1 A-weighting: A- weighting sound level is a relative loudness that can be perceived by a human ear. The most common weighting used in noise measurement is A-Weighting. Similarly A-weighted measurements are also expressed as frequency spectrum in terms of dB A or dB (A) [20-21].

1.9.2 Z-weighting: Z-weighting indicates the zero frequency weighting. It represents the linear frequency weighting. Z-weighting is basically used for comparison of the frequency responses obtained as it represents the fixed values [20-21].

1.9.3 Equivalent Continuous Sound Level: The time-averaged value of sound level is known as Equivalent Continuous Sound Level (L_{eq}). Equivalent Continuous Level can also be depicted as an uninterrupted noise level which would have been same for total A-weighted sound energy as that would be of the fluctuating noise level when taken into account for the equal interval of time. It can be represented as following equation 1.2 [20-21]:

$$L_{eq} = 10\log_{10}\frac{1}{T}\int_0^T\left(\frac{p}{p_{ref}}\right)^2 \tag{1.2}$$

Where T= total measurement time

p_{ref}= reference acoustic pressure which is taken as 20µPa

p= A- weighted instantaneous acoustic pressure

1.10 Frequency Analysis [17, 20-21, 28-29]

Sound signals can also be divided into frequency components and these results can be presented on a spectrogram chart. Sound level up to 20 Hz to 20 kHz frequency range can be divided into sections/bands. Frequency analysis can be carried out using uninterrupted percentage filters. The constant percentage filter (generally octave band types) are mostly parallel the way the auditory system of human ear analyses sound.

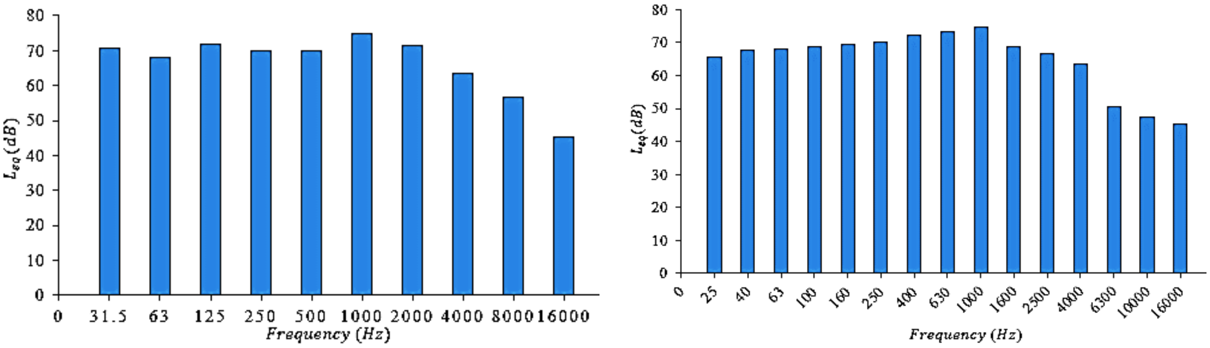
1/1 octave band is a frequency band where the highest frequency is twice of the lowest frequency which is shown in equation 1.3. The 1/1 octave band covers 31.5Hz to 16000Hz range of mid-frequencies.

$$f_{upper} = 2 \times f_{lower} \tag{1.3}$$

1/3 octave band a frequency is said to be a third octave has a width of 1/3 of that of an octave band as shown in equation 1.4. The 1/3 octave band covers 25Hz to 16000Hz range of mid-frequencies.

$$f_{upper} = 2^{1/3} \times f_{lower} \tag{1.4}$$

The 1/1 and 1/3 octave band graph readings are shown in figure 1.2a and 1.2b for one level of machining parameters which are 150m/min velocity, 1 mm axial depth of cut and 1.5mm radial depth of cut. The 1/3 octave band gives more detailed values of sound level at different frequencies as compared to 1/1 octave band.



(a) **(b)**

Figure 1.2: (a) 1/1 Octave Band (b) 1/3 Octave Band

1.11 Noise Measuring Instrument

Noise measuring devices helps to receive the sound signals originating from the source using sensors. Besides, detecting the noise from the source, these sensors also perceives the ambient background noise. Therefore, the value recorded is not accurate as it also includes the background noise. There are different varieties of instruments available to measure and analyse noise levels but most widely used instrument is sound level meters.

1.12 Sound Level Meter

Sound level meter is a device that serves the purpose to measure and display L_{eq}. The Sound Level Meter (SLM) SC310 as shown in figure1.3 is used in the further study and helps to assess and measure noise level exposure to noise and also the data required to inform about the significance and potential risks of the results of the assessment and measurement. The SLM denotes the actual sound level and helps to design as well as run a noise reduction programme and also to choose the most appropriate hearing aids.

1.12.1 Sound level meter specification

The sound level meter used in this study is SC-310 (make: CESVA) and it consists of the following specifications as shown in table 1.1.

Table 1.1 Sound level meter specification

Specifications	Parameters
Modules	Spectral Analyser module in 1/1octave band(31.5Hz-16kHz) and 1/3-octave bands(25Hz-10kHz), FFT analysis(20-1000Hz)
Sound level meter mode	A-, Z-, C- frequency weightings (0-160dB), Percentiles with A-weighting
Dimension	341x82x19 mm
Weight	550gm
Resolution	0-1dB
Minimum frequency range	0.5Hz

1.12.2 Calibrating sound level meter

Calibration is done to check the sensitivity of the measuring instrument before and after the each measurement. So that observations made are precise and accurate.

1.12.3 Using sound level meter

Actual measurements of the acoustical noise levels can be analyzed after applying these correction factors like background noise correction and correction regarding reflection of nearby surfaces and ambient pressure.

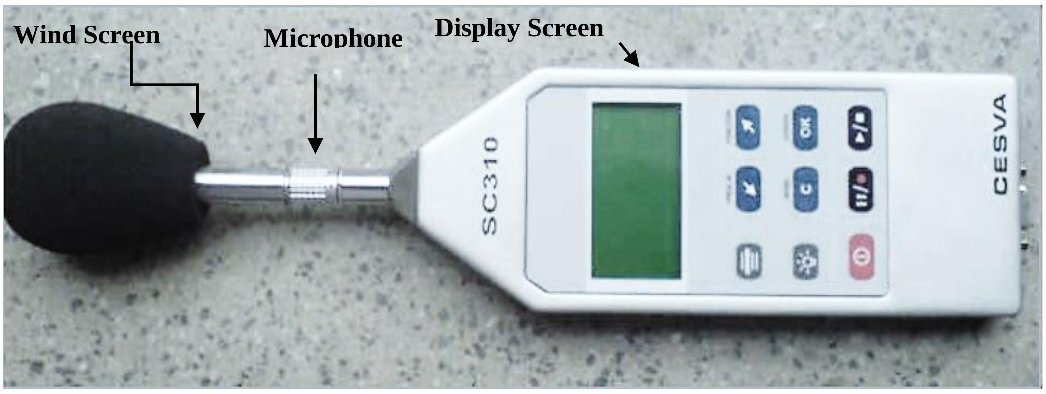


Figure 1.3: Sound Level Meter

1.13 Present Work

In the present study machining of alloy steel EN-24 using tungsten carbide inserts with titanium aluminium nitride (TiAlN) coating based flat end milling cutter is done in wet condition using semi synthetic cutting oil with an aim of optimizing the machining parameters like velocity, axial and radial cut depth keeping feed per tooth constant so as to optimize surface finish. Simultaneously sound levels of different weightings are also observed regarding this experimental plan. The literature review regarding this study is done in chapter 2. The methodology used and results are discussed in chapter 3 and chapter 4. Further, conclusion and future scope are reviewed in chapter 5.

In this chapter, the review of literature on the different parameters of machining which affect the cutting force, tool wear and surface finish have been collected from scientific journals and information on net. To get a good understanding of the proper behaviour/pattern of surface roughness, tool wear with respect to sound levels few studies have been carried out. Important conclusions from the following investigations are explained below.

2.1 Effect of Machining Parameters on Surface Finish in End Milling

Hassanpour et al. [1] did the study on the surface roughness, microhardness testing and white layer thickness on the AISI 4340 (EN-24) with the use of minimum quantity of lubrication. Now four milling parameters like velocity, axial and radial cut depth as well as feed rate along with three levels were varied. Surface roughness results were analysed which showed that feed rate had noteworthy effect of followed by cutting speed, radial and axial depth of cut.

Gopinath et al. [4] investigated the influence on aircraft grade aluminium alloy while machining using peripheral milling with flat end mill cutter having cutters made up of carbide The experiments were designed in a way so that the three different types of cutters such as flat end mill, ball nose end mill and insert type were used to perform milling with corresponding other machining parameters. The surface finish was minimum when flat end cutter was used.

Pohokar et al. [5] studied about optimizing of parameters such as geometric or machining using neural networks based approach. In this investigation, the various machining parameters like cutting velocity, feed given, axial as well as radial cut depth and rake angle were varied and their effect on the tool wear using ANN techniques was observed. The material used was AISI 1040 MS plate of $140 \times 120 \times 10\ mm$ work piece and machining using HSS tool on CNC milling machine under dry run condition. It was concluded that tool wear was directly proportion to tool life and it could be modified for better results.

Safari et al. [3] studied about the cryogenic high-speed end milling of Ti-6Al-4V by characterization in cutting force as well as surface finish. High spindle speed in end milling was performed at multiple cutting speeds, constant cut depths, and two feed rates. Increasing the cutting velocity slightly reduced force required during cutting. It was also indicated that with coated inserts or tools as well as increased cutting velocity results in finished machined worktop.

Qiu et al. [6] studied the micro-ball end milling and influence of tool inclination on quartz glass. Experiments were carried out on a well-polished quartz glass and machining setup used is ultra-precision, micro-milling machine with a TiAlN-coated cemented carbide tool. When the angle of tilt was about 50°, the maximum cutting force was made as the velocity was maximum, on the cutting edges point, when the radius of ball-end mill was 0.25mm and the depth of cutting was 0.4mm kept constant.

Pathak et al. [7] investigated about the measurement of machining parameters effect on forces required for cutting and surface finish on Al-(1-2) Fe-1V-1Si alloys. Two different Al-alloys with different compositions were casted in the shape of plates so as to study the consequence of composition in Fe on machinability when subjected to machining in dry atmosphere using high speed steel in end milling as a cutting tool. From experimental results, it was observed that force was most considerably affected by the axial as well as radial cut depths, thereafter, followed by feed and cutting velocity

Bassoli et al. [10] investigated on high-speed milling on steel tool dies made from aluminium extrusion and surface finish. Die finish was important so as to ensure a good quality of extruded parts made up of aluminium so hot work tool steel AISI H13 was machined on a 3-axis CNC vertical milling machining center. The minimum quantity of surface roughness was observed near 0.5 μm by minimizing the feed per tooth per revolution and maximizing the cutting speed.

Quintana et al. [11] has performed modelling on ball-end milling operations for power consumption. The control of the process parameters on consumption of power in a ball-end milling operations at high-speed was held on $AISI\ H13$ steel in 3-axis vertical milling center. The parameters like spindle speed, radial as well as axial cut depths, and feed per tooth were varied to analyze their effect on power consumption. By increasing the feed given per tooth (f_Z) allowed the spindle speeds to be degraded.

Ding et al. [16] studied a comparative investigation using end-milling AISI H13 steel surface finish and residual stresses produced with the use of parallelogram inserts and the round inserts. The four parameters varied were cutting velocity, feed given, measurement of the deepness of cut made vertically or horizontally respectively. Surface roughness decreased with the increase in the values of cutting velocity, lower values of feed as well as cut depths. The end-milling cutter with the parallelogram insert generated more compressive residual stress than the round inserts.

Medicus et al. [13] investigated on the high speed milling performed on aluminium bronze while machine with different types of coatings TiN, TiAlN, and TiCN were tested to analyze the tool wear and surface finish. It was concluded that the maximum tool wear occurred when the tool was uncoated and with the coatings TiN, TiAlN, and TiCN tool wear decreased in the ascending order.

Tomori et al. [23] studied the effects of the concentration of filler along with the cutting parameters on material properties. The SiC filler concentration as well as machining process parameters were varied. Resultant cutting force increased with the increase in the SiC-filler concentration percentage and feed rate but decreased with the increase in the cutting velocity. Surface finish as well as tool wear were increased with the increase in the filler concentration percentage of the total weight.

From the literature survey done above the different results were incurred. [1, 10-11] investigations done showed mostly the same results that the rate at which tool is feed have a significant effect on finish of the worktop followed by other machining parameter. Also, coatings done on inserts helped in reducing tool wear.

2.2 Effect of Type of Lubrication in End Milling

Fratila et al. [9] performed an assessment on the cooling influence as well as quality of worktop to face milling of $AlMg_3$ using several cooling lubrication methods. In this article face milling process with a coated carbide tool on $AlMg_3$ was done. The article analyses the variations in the temperature of the cutting zone under flooded oil-water environment, near dry machining condition and also dry cutting conditions were analyzed along with it the parameters like axial as well as radial cut depths, rate at which tool is fed, cutting speed, and lubrication flow rate were also varied. Flood lubrication gave the best results.

Siow et al. [14] studied on the tool wear as well as finish of worktop during low-speed milling of stainless steel under flood and mist lubrication. The study examines the performance of AlN/TiN coated carbide tool during milling of modified AISI 420 stainless steel of 35 and $55\ HRC$ under flood and mist lubrication with feed rate and cut depths were kept constant. Flank wear increased with the increase in the work-piece hardness. It was also found that in milling $55\ HRC$, despite the tool was being exposed to rigorous wear, the finish of the worktop was more superior to that of 35 HRC.

Silva et al. [15] did the analysis by performing milling operation with coated cemented carbide inserts on the tool wear of carbon steel in different lubrication system. AISI 1047 grade of steel (25 HRC) is used. Cutting speed and feed rate per tooth were varied. Different lubricant system MQL, reduced flow rate and flooded lubricating system. Then surface roughness test was done on the machined part and ranged between 0.15-1.1μm.

The study done in the above literature [2-4] showed that among three types of lubrication dry, mist and flooded. Wet cutting conditions shows the best surface finish.

2.3 Reduction of Machining Noise and Vibration

Quintana et al. [12] reviewed the role efficiency of chatter in the machining processes. Chatter has been classified into two categories viz. primary and secondary. The border between no chatter and with chatter can be pictured with respect to the axial depth of cut as a function of the spindle speed is known as stability lobe diagram (SLD). They are used to find the specific combination of machining parameters which would result in the maximum chatter-free MRR.

Bediaga et al. [19] in order to obtain stability in high-speed milling an automatic spindle speed selection strategy to with the objective to produce a strategy that could detect the emergence of chatter vibration during machining. The analysis of detection of the real spindle speed at any given time allowed the chatter frequency to be correctly identified.

Quintana et al. [18] observed milling sound information by sound mapping for identification of stability lobe diagrams in the milling processes. Stability lobe diagrams showed the stability frontier as combination of spindle speeds and radial depths of cut. As observed the chatter could be easily recognized from the loud noise that accompanied it.

Gindy et al. [24] inspected about an approach of systematic design for condition monitoring systems for milling processes. The material used were aluminum plates and a set of 27 experiments were performed using six accelerometers and acoustic emission sensor. The ASPS approach is employed. The dynamometer used and acceleration of spindle were the least utilized sensors on the other hand acoustic emission sensors and acceleration system of workpiece were the optimum system throughout the analysis.

Smith et al. [26] studied about stabilizing chatter by automatic spindle speed regulation. On theoretical basis behind a system to elimination the chatter produced in milling would be through the spindle’s automatic speed regulations. This technique was found to be most effective in milling operations where the tooth passing frequency could approach the natural frequency of the mode responsible for chatter. Experimental data were quoted to illustrate typical improvements in metal removal rate.

Altintas et al. [27] described about suppression of chatter as well as in-process detection and during milling. The use of a continuously variable spindle speed as a means of suppressing chatter in milling was investigated. Simulation and experimental results indicated that the stability of milling could be improved by early detection of chatter, and subsequent spindle speed oscillation in order to disturb the wave regeneration.

Jeyapalan et al. [30] demonstrated the noise predictions of the machineries at the design stage using acoustic modelling. Given a force input to a structure (machine) and the subsequent vibration response, this could be calculated by finite element or other means that provided a quick and easy method of accurately predicting overall root mean square of sound levels. It was applicable to any machine which could be identified as a distribution of separate sound sources.

Lai et al. [25] investigated on control of shear cutting noise-effectiveness of enclosures. The effectiveness of three noise abatements enclosures used for roll former shears in sheet metal production firms were compared after a regular period of time. In this study three enclosures were analysed. To make the enclosure 'Acousteel' on outer surface, inner surface of perforated steel and inner cavity of Rockwool of different thickness were made. Outlets like windows and doors were also provided with perfect insulation were provided on each and every enclosures.

.

The results finally indicated that noise reduction up to 4-5dB was achieved at operator's end.

From the above literature investigated above following inferences was deduced that chattering, vibration and noise generated during machining can be detected using different sensors and can be further used in online conditioning monitoring.

2.4 Conclusion

In the above study different methodology to reduce tool wear and its correlation with the noise is done. Different techniques were used for optimization of different machining parameters to obtain good surface finish. Various machining parameters and machining conditions employed during milling process were also optimized in order to get the less tool wear during milling process.

2.5 Research Gap

Good surface finish is an important aspect which are required during machining processes in industries. Due to large number of machines being used simultaneously in the industries for mass production generates a peculiar noise which leads to risk factor for the health of the operator. From the literature review, it was found that limited analysis was done regarding correlation between surface roughness and noise during milling. Also, [1] have done minimum quality lubrication during milling machining on EN-24 alloy steel. Therefore, an attempt has been made to establish the optimum levels of machining speed, radial cut depth and axial cut depth to achieve the best surface finish for wet machining conditions while simultaneously observing the noise patterns generated during 3-axis vertical end milling with insert based flat end milling cutter which could is further utilized for online condition monitoring. Furthermore, in Chapter 3 and Chapter 4 problem formulation and results regarding them are discussed respectively.

CHAPTER 3
METHODOLOGY

3.1 Introduction

In this experimental work, surface roughness of material EN-24 alloy steel is correlated with noise patterns observed during machining at different operating parameters such as velocity, axial along with radial cut depth. These values were framed in a design of experiments using response surface methodology (RSM) and further regression equation is done.

3.2 Material and Tools Used

The tools and material used in this study are further described in detail in this section.

3.2.1 Tool

The tool used in the sets of experiments is from Sandvik Coromant. The tool holder used is equipped with the Hydro-Grip adapter T40-SHYD20-095M. The tool holder was from Birla Kennametal. The inserts are first fixed into the tool holder, then, into the adapter and finally tool is clamped into the 2-jaw chuck of the CNC Milling Machine by pressing the Tool Clamp button on JOG mode. The tool and inserts are shown in the figure 3.1 a and 3.1 b and their specifications are mentioned below in table 3.1.

(a) **(b)**

Figure 3.1: (a) CNC Tool Holder Hydro-Grip adapter T40-SHYD20-095M (b) Tungsten Carbide inserts with Titanium Aluminium Nitride (TiAlN) coating

Table 3.1: Tool Specification

Specification	**Parameter**
Diameter of tool	20mm
Inserts type	Parallelogram shaped
Inserts	Tungsten carbide
Coating used	Titanium Aluminium Nitrate(Ti-Al-N)
Tool Holder used	Hydro-Grip adapter T40-SHYD20-095M

3.2.2 Workpiece

The material used in my sets of experiments is EN-24. The American AISI/SAE name of EN-24 is 4340. The mechanical properties and the chemical composition of the EN-24 observed after spectroscopy results are shown below in table 3.2 and table 3.3.The figure shown below consist of 4 plates used during experimentation in figure 3.2.

Table 3.2: Mechanical properties of EN-24

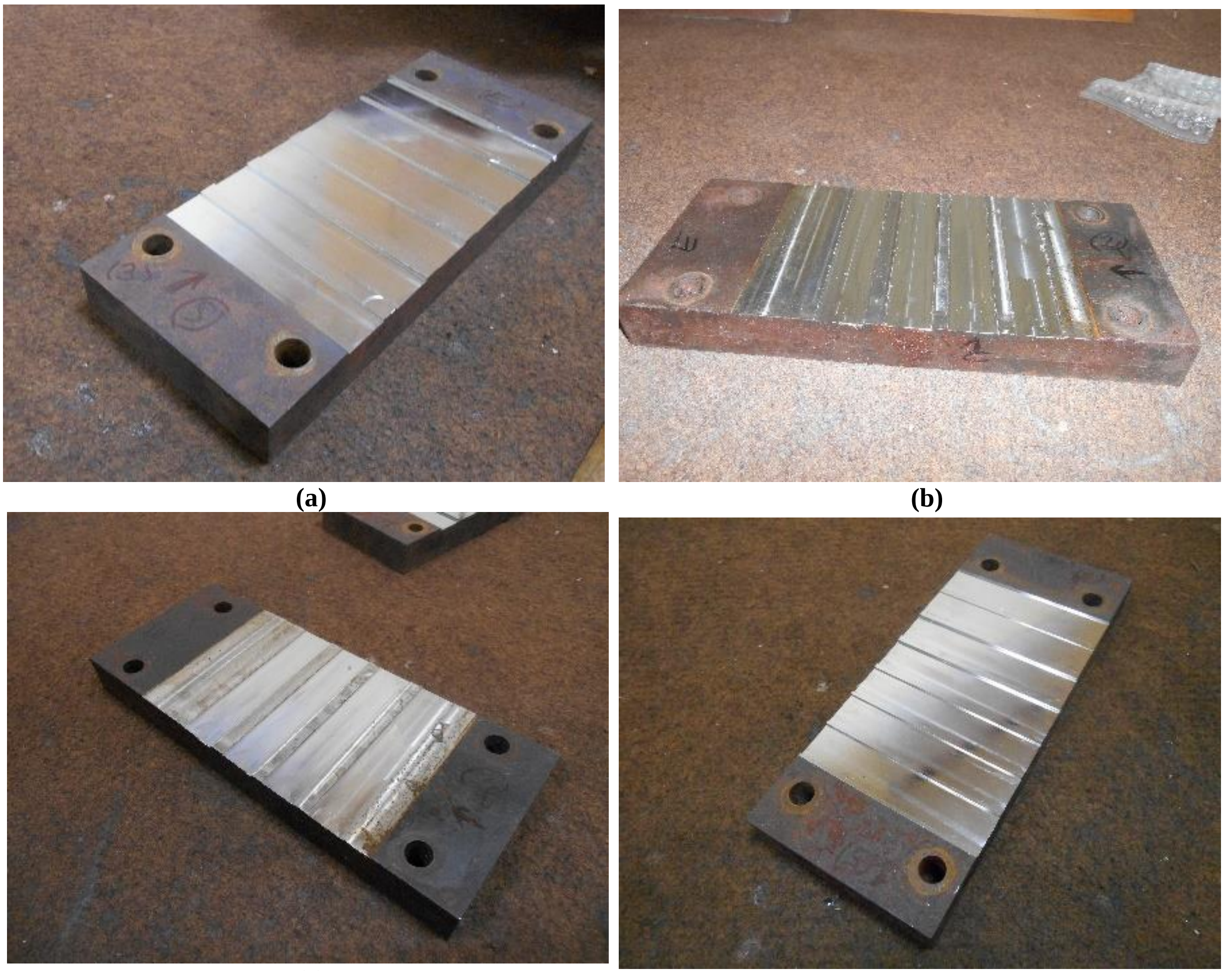
Hardness	Melting point	Density	Tensile Strength	Yield Strength	Elastic modulus
25-33HRC	1427°C	7.85g/cc	75MPa	470MPa	190-210GPa

Table 3.3: Chemical Composition of EN-24

Chemical Compound	Percentage
Carbon, C	0.394
Iron, Fe	96.98
Manganese, Mn	0.650
Silicon, Si	0.215
Sulphur, S	0.015
Phosphorous, P	0.013
Chromium, Cr	1.015
Molybdenum, Mo	0.271
Vanadium, V	0.025
Copper, Cu	0.000
Tin, Sn	0.000
Titanium, Ti	0.000
Tungsten, W	0.000
Cobalt, Co	0.000
Aluminium, Al	0.000

The material was hardened up to 45-50 HRC through case hardening on overall dimension. EN-24 is an alloy steel with high tensile strength and high toughness. The dimension of the workpiece taken was 100×135×25 (length×width×height) in mm.

It is used in manufacturing various parts which include automobile and other engineering products like gears, heavy duty shafts, studs, bolts, axles, spindles, couplings, pins, crankshafts, machine tool applications, automotive systems etc.



(a) (b)

(c) (d)

Figure. 3.2: EN-24 Alloy Steel Plate

3.2.3 Cutting Fluid

The experiments are performed were in wet condition. The cutting fluid used here is Houghton Hocut B50S semi-synthetic metal cutting coolant. It helps in corrosion protection. It is cost effective and also eco-friendly as it is chlorine free. When machining is done 4-6% cutting oil diluted with 96-94% of water is used.

3.3 Experimental Setup

During the experimental investigation the setup used are discussed below.

3.3.1 CNC milling centre

CNC Milling Machine used in this experimental work is of model Chandra plus and make BFW 3-axis vertical milling centre. The 20 station automatic tool changer is employed in it. The specifications are as shown in table 3.4 and it figure is described in the chapter 1, figure 1.

Table 3.4: Specifications of CNC Milling Machine

Specification	Units	Parameters
Table(width×length)	mm	315/1060
Stroke(X/Y/Z)	mm	800/350/380
Power	kW	3.7
Spindle speed	rpm	60-6000
Feed Rate	mm/min	1-5000
Current	$Ampere$	26
Voltage	$Volt(DC)$	415
Total Load (STD Load)	kVA	11

The machine table is divided into three slots and the distance of slots is $17mm$ and width of table from centre to centre distance between slots is $100mm$. So to get the maximum cuts on the plate the dimensions of the work-piece taken was 135mm width-wise and $100\times32mm$ length to height dimensions.

3.3.2 Response Surface Methodology [32]

Design of experiment (DoE) is a fundamental and systematic way to determine as well as define a particular relationship between different factors affecting a process and the output that is taken into consideration.

The technique applied in the present work is Response Surface Methodology (RSM). In this, design of experiment involves planning a particular set of experiments in which a set of parameters affecting the process are created, then, results are analysed. At first, RSM was established by Box and Draper in 1987.

Response surface methodology is a set of mathematical as well as statistical techniques which are very valuable for modelling and analysing a particular set of response of our interest which is being influenced by several operating parameters through which we can also optimize our responses generated.

The variables varied are velocity(V), axial cut depth (a_e), radial cut depth (a_d) in the experiments can be expressed as a function of surface roughness (R_a).

The percentage contribution of each variable on outcomes can also be deduced. The graphs can be plotted depicting the effect of each and every parameter on the outcomes. Not only can this but the responses can be graphically presented in 3-D or in the form of contour plots to get the knowledge of how the two parameters simultaneously relate on the response surfaces. The design of experiments formed in the set of experiments were as follows.

The set of levels varied are shown below in table 3.5 and table 3.6 shows the design of experiement.

Table 3.5: Different Levels of Parameters

Parameters	**Levels**		
	1	**2**	**3**
Velocity (V)	150	170	190
Axial depth of cut (a_e)	0.5	1	1.5
Radial depth of cut (a_d)	1	1.5	2

Table 3.6: Design of Experiment

Block	**Run Order**	**Std. Order**	**V** m/min	**a_e** mm	**a_d** mm
1	1	8	190	0.5	1.0
1	2	18	170	1.0	1.0
1	3	13	190	1.0	1.5
1	4	2	170	1.0	1.5
1	5	6	190	1.5	1.0
1	6	1	170	1.0	1.5
1	7	7	170	1.0	1.5
1	8	10	170	1.0	1.5
1	9	16	150	0.5	1.0
1	10	12	170	1.0	1.5
1	11	3	190	0.5	2.0
1	12	4	170	0.5	1.5
1	13	9	170	1.0	1.5
1	14	14	150	1.0	1.5
1	15	15	170	1.0	2.0
1	16	17	150	1.5	1.0
1	17	11	150	0.5	2.0
1	18	19	190	1.5	2.0
1	19	5	170	1.5	1.5
1	20	20	150	1.5	2.0

3.3.3 ANOVA Table

Analysis of variance (ANOVA) can be described as a statistical technique to compare different fundamental parameters. For ANOVA the data collected to examine the effect on the operating parameter, following these requisites are required. The degree of freedom (DoF), in statistics, is the number of quantities in the final design of a statistic which were free to fluctuate. Degree of freedom is the amount of independent values which can be assigned to a statistical distribution.

F-Value: F-Value can be described as the ratio of two dissimilar measures of variance. When we consider the null hypothesis as real, then both these approximations of similar entities and their ratios would be one.

p-Value: The p-value is an observed function of the samples that results relative to a statistical model, which measures how extreme the observation is.

Seq SS: Seq SS stands for Sequential Sum of Squares. Sum of square indicates the measure of variation from its mean. Sequential SS depends upon the order of parameters entered into the model. It tries to explain in what amount of remaining variation one factor explains, given that another factor is already in the model.

Adj SS: Adj SS stands for Adjusted Sum of Squares. It includes the measure of variation of different parameters in the model. Adj SS does not depends on the order of parameters entered in the model. It gives the unique lot of SS regression described by a parameter.

Adj MS: Adj MS stands for adjusted mean squares. It quantifies the amount of variation that a model explains. Not like adjusted SS, it also takes into account the DOF.

3.3.4 Noise Measurement Device

During cutting at particulars set of operating parameter, the noise level was recorded through Sound Level Meter (SLM). The sound level meter used was SC-310 as shown in figure 3.3 and specification are mentioned in table 3.7. SLM is an acoustics measurement device and used to display equivalent continuous sound pressure level with respect to time and frequency spectrum. It helps to design and run a reduction programme and to choose the most appropriate hearing protectors. SLM gives measurements in the sound level meter mode, 1/1 octave band mode, 1/3 octave band mode. The mode used in the present set of experiments was 1/1 octave band.

Table 3.7 Specifications of sound level meter

Specifications	**Parameters**
Modules	Spectral Analyser module in 1/1octave band(31.5Hz-16kHz) and 1/3-octave bands(25Hz-10kHz), FFT analysis(20-1000Hz)
Sound level meter mode	A-, Z-, C- frequency weightings (0-160dB), Percentiles with A-weighting
Dimension	341x82x19 mm
Weight	550gm
Resolution	0-1dB
Minimum frequency range	0.5Hz

Figure 3.3: Sound Level Meter

3.3.5 Surface Roughness Tester

The surface roughness parameter R_a can be measured using surface roughness tester. The one being used in this study was **MITUTOYO SJ-400** surface roughness tester. R_a gives the average surface roughness values of all the peaks and valleys. The average result is a contact type surface roughness and evaluated results can be easily measured on a touch-panel LCD Monitor. The surface roughness tester before measurements is calibrated by using a reference step specimen. Figure 3.4 shows the surface roughness tester and the specifications are mentioned in table 3.8 is as follows:

Table 3.8: Specifications of Surface Roughness Tester

Specifications	**Parameters**
Measuring Method	Skidless / Skid Measurement
Cut-off length	0.08, 0.25, 0.8, 2.5, 8mm
Measuring Speed	0.05, 0.1, 0.5, 1.0mm/s
Returning Speed	0.5, 1.0, 2.0 mm/s
Measuring Range	800µm, 80µm, 8µm
Detection method	Differential inductance method
Minimum resolution	0.000125µm
Stylus tip	Corn 90°, Radius 5µm, Diamond
Measuring force	4mN

Figure 3.4: Surface Roughness Tester

Table 3.9: Material and equipment used for experiment

Machine used	CNC Vertical Milling Machine
Material	En-24 (Flat Plate)(135*100*25) in mm
Tool inserts	Tungsten Carbide Inserts(TiAlN Coating)
Tool holder	R390-020A20-11L
Tool holder specifications	20mm Diameter
Tool adapter	BT40-SHYB20-095M
Environment	Flood lubricant machining (Semi)
Measure	Surface Roughness Parameter(SJ-400) Noise Patterns (SC-310)

3.4 Procedure

During the examination of noise generated in milling operation, the following procedure was adopted:

i. The workpiece was first machined up to 0.25-0.5mm axial cut depth in order to get a plane surface.
ii. After getting a perfectly plane base the machining noise generated during different levels of operating parameters were recorded.
iii. Similarly, the values of corresponding values of surface roughness parameters were also examined.

iv. Now correlation between surface roughness parameter (R_a) with equivalent noise level of A-weighting (L_a) as well as with Z-weighting (L_z) after removal of background noise were deduced.

v. According to the response surface methodology (RSM) the values of surface roughness values were analysed with regression analysis. Along with different levels of parameters frequency spectrum analysis was also done. The graphs of 1/1 octave band analysis are also depicted in subsequent chapters.

vi. Optimal values of surface roughness parameter (R_a) were deduced for reducing sound level.

CHAPTER 4
RESULTS AND DISCUSSION

In this chapter the correlation between noise levels and surface roughness is done along with the analysis and statistical modelling of average surface roughness R_a using response surface methodology. As discussed in chapter 3, the set of experiments were performed, the required effect of different machining parameters like velocity V, axial cut depth a_e and radial cut depth a_d on surface roughness parameters is optimised as well as correlation between noise and surface roughness parameters is also examined. The analysis was done on EN-24 an alloy steel using tungsten carbide inserts with TiAlN coating on 3-axis vertical CNC milling centre to obtain the 1/1 octave band frequency spectrum using sound level meter SC-310 and also the average surface roughness parameter with the help of SJ-400.

4.1 Analysis of Noise Levels

The investigation of sound level was carried on different levels of velocity (150,170 & 190 m/min), axial cut depth (0.5, 1 & 1.5 mm), radial cut depth (1, 1.5 & 2 mm).

The observations regarding equivalent sound level of different weighting were recorded. Along with this surface roughness values were also acquired for all the levels. The data of sound level and surface roughness are presented in annexure A.1 and B.1.

From the table 4.1 the data gathered considered four machining parameters of sound level they were A-weighting sound level, Z- weighting sound level, 10 percentile and 90 percentile sound level. The values of sound level were recorded in decibels (dB).

The tables 4.3 and 4.4 and graphs depicted in figure. 4.1 and 4.2 describes about correlation between A-weighting sound level L_A and surface roughness parameter R_a and Z-weighting sound level L_Z and surface roughness parameter R_a respectively. The surface roughness parameters measured are in micron meter (µm).

The values of A-weighting sound level were corrected using background correction factor [28]. The background correction factor was employed only if difference between sound level with and without machining were lesser than $10dB$. If not then correction factor was not employed. For correction factor equation4.1 was employed. The values are shown in the tabular form in the table 4.1

$$L_{A_C} = 10 \times \log\left(10^{(L_A/10)} - 10^{\left(L_{A_{WM}}/10\right)}\right) \qquad 4.1$$

Table 4.1: Mean values of A-Weighting Sound Level

Std. Order	V m/min	a_e mm	a_d mm	R_a µm	$L_{A_{WM}}$ dBA	L_A dBA	Δ (dBA)	L_{A_C} dBA
8	190	0.5	1.0	0.0933	70.0	81.7	11.7	81.7
18	170	1.0	1.0	0.1079	72.7	81	8.3	80.3
13	190	1.0	1.5	0.116	72.7	84	11.3	84
2	170	1.0	1.5	0.1230	70.0	75.9	5.9	74.6
6	190	1.5	1.0	0.1234	70.0	77.1	7.1	76.1
1	170	1.0	1.5	0.1285	72.8	80.9	8.1	80.1
7	170	1.0	1.5	0.1314	72.8	85	12.2	85.0
10	170	1.0	1.5	0.1367	70.0	74.7	4.7	72.9
16	150	0.5	1.0	0.1450	72.7	81	8.3	80.3
12	170	1.0	1.5	0.1477	72.7	73.8	1.1	67.3
3	190	0.5	2.0	0.1490	72.8	82.5	9.7	82.0
4	170	0.5	1.5	0.1550	70.0	82.7	12.7	82.7
9	170	1.0	1.5	0.1575	72.8	77.5	4.7	75.7
14	150	1.0	1.5	0.1670	72.7	82.8	10.1	82.8
15	170	1.0	2.0	0.1764	72.7	82.9	10.2	82.9
17	150	1.5	1.0	0.1780	72.7	83.6	10.9	83.6
11	150	0.5	2.0	0.1950	72.7	78.3	5.6	76.9
19	190	1.5	2.0	0.1986	72.7	74.4	1.7	69.5
5	170	1.5	1.5	0.2043	72.8	81.2	8.4	80.52
20	150	1.5	2.0	0.2832	72.7	78.6	5.9	77.3

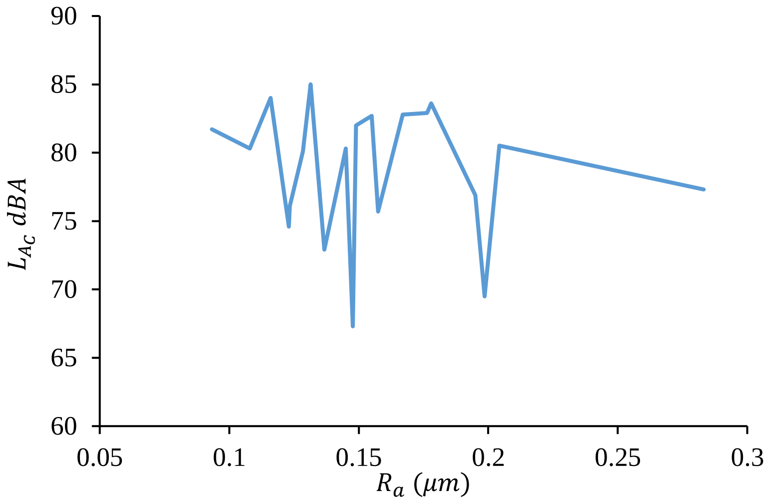


Figure 4.1: Plot between L_{A_C} and R_a

Similarly background correction factor were applied for Z-weighting sound level L_Z. The Z-weighting sound level is also correlated with the average surface roughness as Z-weighting sound level gives the absolute values of sound level. After that final graph was drawn between them. To get the final values with Z-weighting corrected values equation4.2 was used. The values are shown in the tabular form in the table 4.2

$$L_{Z_C} = 10 \times \log\left(10^{\left(L_{Z_M}/10\right)} - 10^{\left(L_{Z_{WM}}/10\right)}\right) \qquad 4.2$$

Table 4.2: Values Regarding Z-Weighting Sound Level

Std. Order	V (m/min)	a_e (mm)	a_d (mm)	R_a (µm)	$L_{Z_{WM}}$ (dBZ)	L_{Z_M} (dBZ)	Δ (dBZ)	L_{Z_C} (dBZ)
8	190	0.5	1	0.0933	71.6	82.6	11.0	82.6
18	170	1	1	0.1079	74.1	86.0	11.9	86.0
13	190	1	1.5	0.1160	74.1	86.1	12.0	86.1
2	170	1	1.5	0.1230	71.6	78.2	6.6	77.1
6	190	1.5	1	0.1234	71.6	78.4	6.8	77.4
1	170	1	1.5	0.1285	76.2	88.4	12.2	88.4
7	170	1	1.5	0.1314	76.2	86.0	9.8	85.5
10	170	1	1.5	0.1367	71.6	77.2	5.6	75.8
16	150	0.5	1	0.1450	74.1	85.6	11.5	85.6
12	170	1	1.5	0.1477	74.1	76.5	2.4	72.8
3	190	0.5	2	0.1490	76.2	83.0	6.8	81.9
4	170	0.5	1.5	0.1550	71.6	84.6	13	84.6
9	170	1	1.5	0.1575	76.2	79.8	3.6	77.3
14	150	1	1.5	0.1670	74.1	86.1	12	86.1
15	170	1	2	0.1764	74.1	85.6	11.5	85.6
17	150	1.5	1	0.1780	74.1	76.5	2.4	72.8
11	150	0.5	2	0.1950	74.1	83.0	8.9	82.4
19	190	1.5	2	0.1986	74.1	75.9	1.8	71.2
5	170	1.5	1.5	0.2043	76.2	86.4	10.2	86.4
20	150	1.5	2	0.2832	74.1	80.0	5.9	78.7

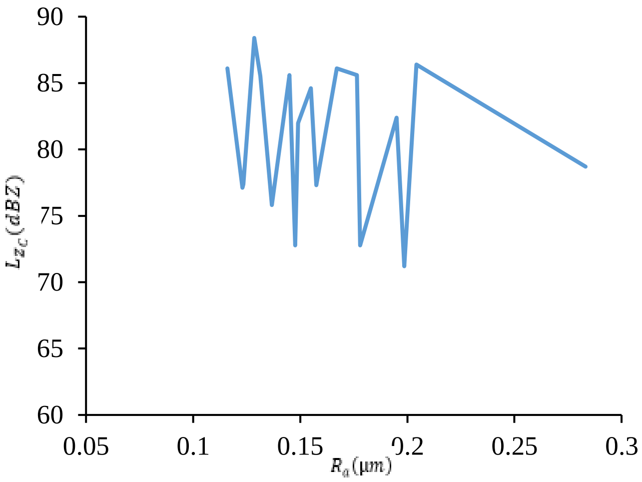


Figure 4.2: Plot between L_{Z_C} and R_a

It could be deduced from the above graphs as shown in figure 4.1 and 4.2 that no direct relationship exist between L_{Z_C} and R_a. To evaluate the relationship between average surface roughness R_a parameter and A-weighting L_{A_C} as well as Z-weighting L_{Z_C} sound level, Pearson correlation in Minitab software was employed. The results obtained from the software were:-

i. Pearson correlation of $R_a$and L_{A_C} = -0.152
ii. Pearson correlation of $R_a$and L_{Z_C} = -0.214

The above results (i) and (ii) indicated that sound level and surface roughness values have small correlation between them. The negative sign designated that the values were inversely proportional to each other.

Pearson coefficient correlation ranges from -1 to +1. If the value of coefficient is 1 then it shows that there is perfect relation between the two factors. If value comes out to be 0 then there is no relation between variables. If value of coefficient approaches towards -1 then it depicts the increase of one factor and decrease of another as shown in table 4.3.

Table 4.3: Pearson Coefficient correlation [32]

Coefficient Value	**Strength of Association**
0.1< ∣r∣< 0.3	Small Correlation
0.3< ∣r∣< 0.5	Medium/ Moderate Correlation
0.5 > ∣r∣	Strong Correlation

4.2 ANOVA Table

Since no such perfect relationship was derived from the plots of average surface roughness parameter R_a along with the sound levels. Therefore, statistical modelling was done to optimize the average surface roughness parameter and to determine its effect on different machining parameters. The statistical data of ANOVA for surface roughness is presented in table 4.4 and R-square value came out to be 95%.

Table 4.4: Data for analysis of variance of R_a (μm)

Source	**DOF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	9	0.033682	0.003742	0.003742	32.27	0.000
Linear	3	0.027123	0.000708	0.000236	2.04	0.173
Square	3	0.005573	0.005573	0.001858	16.01	0..000
Interaction	3	0.000987	0.000987	0.000329	2.84	0.092
Residual Error	10	0.001160	0.001160	0.000116		
Lack-of-Fit Pure Error	5 5	0.000327 0.000833	0.000327 0.000833	0.000065 0.000167	0.39	0.836
Total	19	0.034842				

Regression analysis was applied on the above generated values of average surface roughness values R_a so that percentage contribution of different machining parameters on surface roughness can be comprehended as shown in table 4.5. Along with that, the regression equation to find the coefficients associated with the parameters was also derived.

The regression equation is presented below:

$$R_a = 0.073 + 0.00157V - 0.204a_e + 0.106a_d - 0.000006V^2 - 0.0070{a_d}^2 + 0.143{a_e}^2 + (0.0374\, a_d \times a_e) - (0.000519a_e \times V) - (0.000304\, a_d \times V)$$

Table 4.5: Contribution of each factor on Surface Roughness

S No.	Source	Seq. SS	Percent contribution
1	V	0.008289	25
2	a_e	0.00626	19
3	a_d	0.012574	37
4	V^2	0.001622	5
5	a_d^2	0.000435	1
6	a_e^2	0.003516	10
7	$V \times a_e$	0.000215	1
8	$V \times a_d$	7.38E-05	0
9	$a_d \times a_e$	0.000698	2

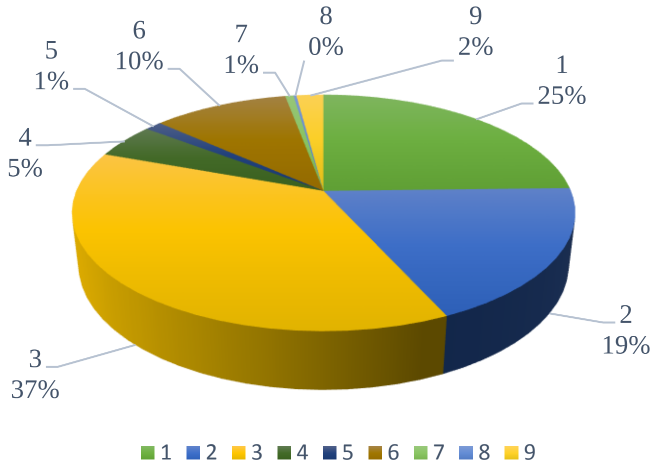


Figure 4.3: Pie-Chart of Contribution of Different Parameters

From figure.4.3 it could be inferred that the contribution of radial depth of cut contribution was maximum on the surface roughness followed by velocity, axial cut depth and other interaction factors.

The following trend of radial cut depth was observed as rise in radial cut depth leads to the high extent of material removal rate and also vibrations increase surface roughness of the material.Due to increase in velocity the surface roughness decreased because at low spindle speed built-up-edges were formed or chip fracture which yielded poor surface finish.

Whereas, if the cutting speed was increased built-up-edges (BUE) would vanish along with the decrease in chip fracture. The third factor axial cut depth also had substantial effect upon the surface quality. If depth of cut was increased cutting resistance also increased along with the amplitude of vibrations and cutting temperature. Due to this quality of the work-piece degraded.

The main plots of velocity, axial cut depth, and radial cut depth with respect to surface roughness parameter R_a were also evaluated as shown in figure 4.4 a, b, c.

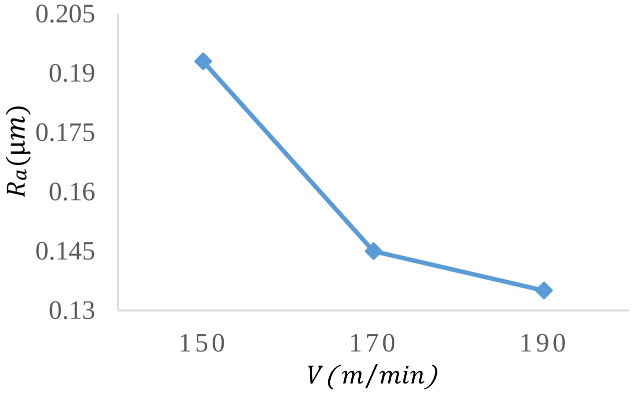


Figure 4.4a: Effect of velocity on surface roughness

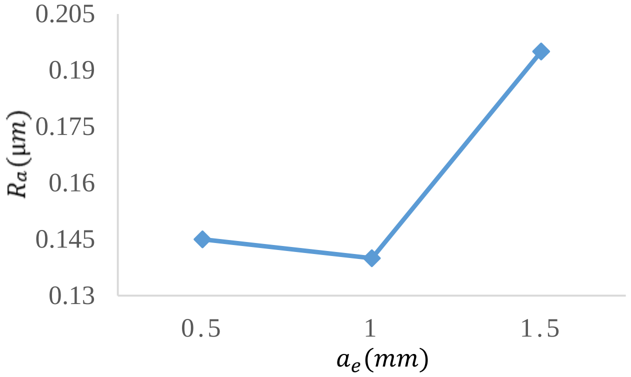


Figure 4.4b: Effect of axial depth of cut on surface roughness

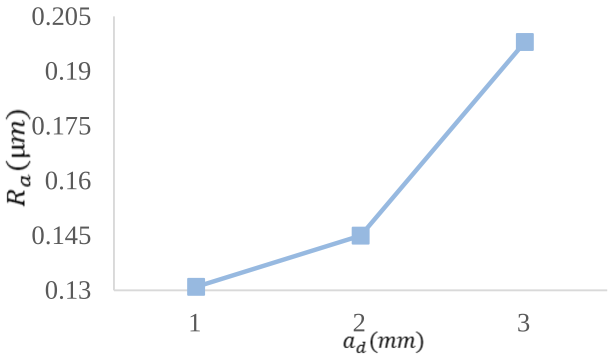


Figure 4.4c: Effect of radial depth of cut upon surface roughness

Interaction of dual factors of each parameter on surface roughness values were also observed. The observation made from figure 4.5 indicated that the surface roughness was minimum or best surface finish was at velocity 190m/min and 1mm axial cut depth.

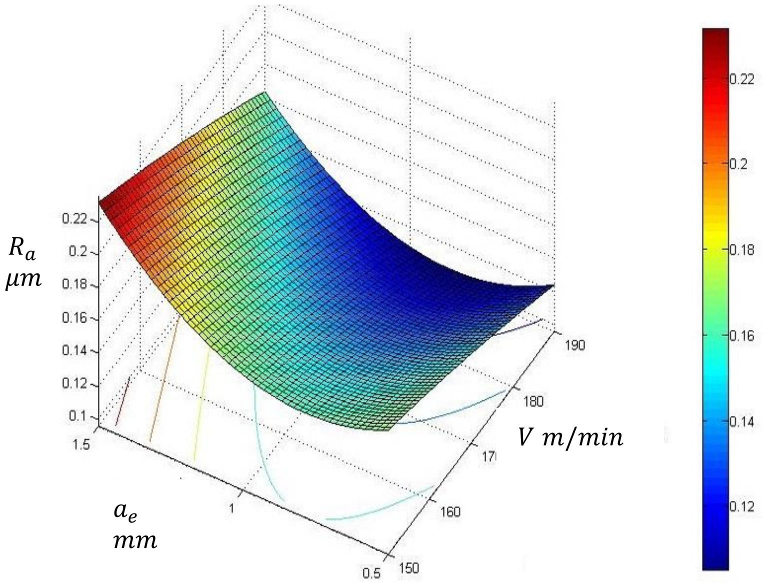


Figure 4.5: Dual effect of axial depth of cut (a_e) and velocity (V) on average surface roughness (R_a)

From Figure 4.6 it was observed that surface roughness was minimum or best surface finish was at radial cut depth at 1mm and 1mm axial cut depth.

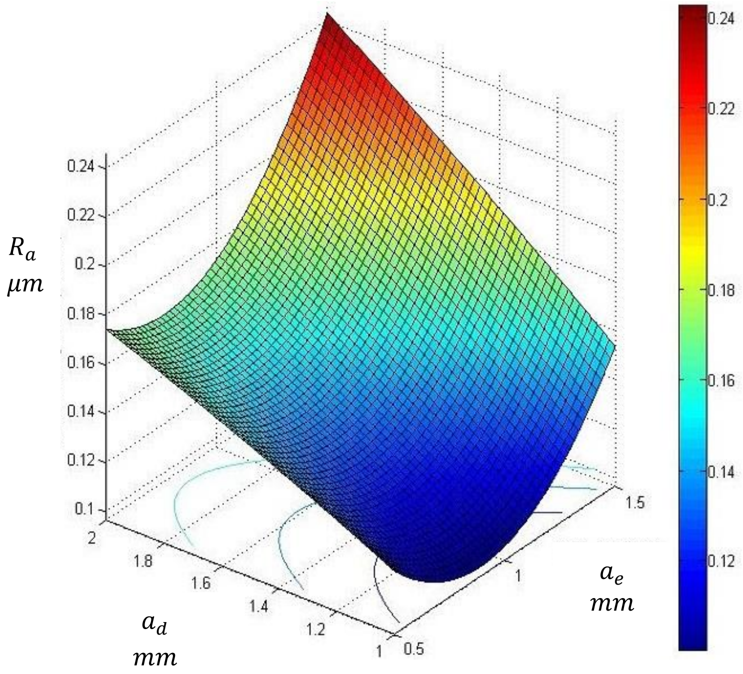


Figure 4.6: Dual effect of axial depth of cut (a_e) and radial depth of cut (a_d) on surface roughness (R_a)

It can be observed from the figure 4.7 that surface roughness was minimum or best surface finish was at radial cut depth at 1mm and velocity 190m/min.

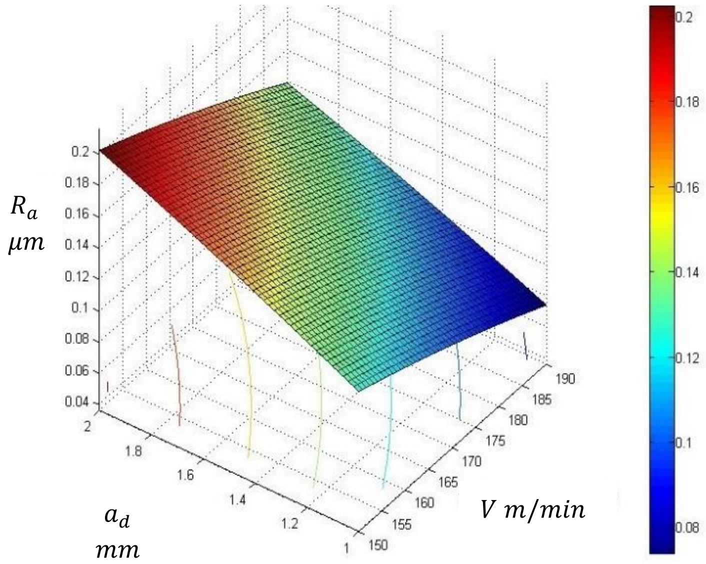


Figure 4.7: Dual effect of radial depth of cut (a_d) and velocity (V) on average surface roughness (R_a)

The graphs presented in figure 4.4 to 4.7 highlights that minimum surface roughness could be obtained at velocity 190m/min, axial cut depth 1mm and radial cut depth 1mm.

Within the experimental plan the best surface roughness value as shown in table 4.6 obtained is 0.09033 µm which was achieved at $190 m/min$ velocity, $1mm$ radial cut depth , $0.5mm$ axial cut depth but noise level was quiet high 81.7dBA. This much noise is frequently noticed on busy urban roads. On the other hand the minimal sound level $67.3dBA$ was achieved at $170\ m/min$ velocity, $1.5mm$ radial cut depth, $1mm$ axial cut depth with average surface roughness of $0.1477\mu m$.

Table 4.6: Surface Roughness Values

Std. Order	a_d	V	a_e	R_a	L_{A_C}
18	1	170	1	0.1079	80.3
8	1	190	0.5	0.0933	81.7
4	1.5	170	0.5	0.155	82.7
2	1.5	170	1	0.123	74.6
1	1.5	170	1	0.1285	80.1
7	1.5	170	1	0.1314	85
10	1.5	170	1	0.1367	72.9
12	1.5	170	1	0.1477	67.3
9	1.5	170	1	0.1575	75.7
13	1.5	190	1	0.116	84

In the above selected range of minimum surface roughness and less noise level occurred at standard order 8 and 12. Along with this optimal parameters investigated through statistical modelling were also measured. The readings are depicted in table 4.7.

Table 4.7: Optimized values of machining parameters

a_d	**V (m/min)**	**a_e (mm)**	**R_a (mm)**	**L_{A_C} (dBA)**
1.0	190	1.0	0. 1367	76.2
1.5	170	1.0	0.1866	67.3
1.0	190	0.5	0.1587	77.0

Now it can be verified from the table 4.7 that the minimum surface roughness values was obtained at $190m/min$ velocity, $1mm$ radial cut depth, $1mm$ axial cut depth with the 76.2dBA sound level. Since the surface finish obtained is best which is mainly desired by the industries and sound level is also in the range set by the Indian Standards [31] as shown in annexure C.1. According from the Indian Standards the sound level in industrial area should be $75dBA$ during day time from $6:00\ am$ to $10:00\ pm$ and $70dBA$ during night time from $10:00\ pm$ to $6:00\ am$.

In these selected set of readings as shown in table 4.7 for machining velocity ranged from $170m/min$ to $190m/min$ only at $1.5mm$ radial cut depth the various values of surface roughness were observed in the range of $0.0933\ \mu m$ to $0.1575\ \mu m$ which is a significant range for the industries.

At the same time the sound level observed at $170m/min$ velocity, $1.5mm$ radial cut depth, 1mm axial cut depth was $63.7dBA$ and found to be quite less compared to sound level observed in other set of values.

So it was concluded that since the surface roughness values were not varying much according to the industrial point of view so the best values could be obtained from $170m/min$-$190m/min$ velocity, $1mm$-$1.5mm$ radial cut depth and $0.5mm$-$1mm$ axial cut depth.

From the above discussion it can be concluded that if online condition monitoring is required for EN-24 alloy steel being machined by tungsten carbide using TiAlN coating on 3-axis CNC milling centre then these optimized values of machining parameters can be used with less health hazards to the operators.

On contrary if surface roughness near about $0.15\mu m$ is acceptable then machining parameters ranging $170m/min$ velocity, $1mm$ axial cut depth, $1.5mm$ radial cut depth can also be employed. The operators working in such environment will also be less affected with health problems generated due to high noise levels.

4.3 Comparison of Frequency Spectrum with Z-Weighting Sound Level

Graphs regarding frequency spectrum at particular velocity of $150m/min$ and corresponding sound level at Z-weighting were compared as Z-weighting sound level resulted the absolute values. Therefore, a comparison was done for these values.

4.3.1 Comparison of frequency spectrum with L_{Z_C} sound level at 150m/min velocity

For the constant velocity $150m/min$ the values regarding frequency spectrum is displayed in table 4.8 and depicted through figure 4.8. Also the values regarding Z-weighting sound level is presented in figure.4.9. The figure 5.8 revealed that at low- range and mid-range high sound level peaks were obtained at standard order 16 which includes $150m/min$ velocity, $0.5mm$ axial cut depth, $1mm$ radial cut depth and standard order 11 which includes $150m/min$ velocity, $0.5mm$ axial cut depth, $2mm$ radial cut depth. On comparing figure.4.8 and 4.9 it could be clearly deduced that similar high peaks were obtained at those standard orders 16 and 11 of around $85.6dB$ and $82.4dB$ were observed in both the graphs.

Table 4.8: Frequency Spectrum corresponding to different levels at 150 m/min velocity

Frequency Spectrum 1/1 octave	150,1.5,1 Std. Order 17	150,1.5,2 Std. Order 20	150,0.5,1 Std. Order 16	150,0.5,2 Std. Order 11	150,1,1.5 Std. Order 14
31.5	68.7	66.2	63.8	59.7	70.5
63	66.9	69.1	86.3	83.2	68.1
125	71.1	68.9	81.3	79	71.8
250	70.1	74.7	75.8	73.1	70.1
500	74.1	77.2	75.8	77	70

1000	78.6	84.3	78.9	86.7	74.9
2000	78.4	75.3	72.8	68.9	71.5
4000	68.2	67.2	64.6	65.2	63.5
8000	61.3	57.6	58.9	62.2	56.8
16000	46.1	44.7	47.4	47.6	45.4

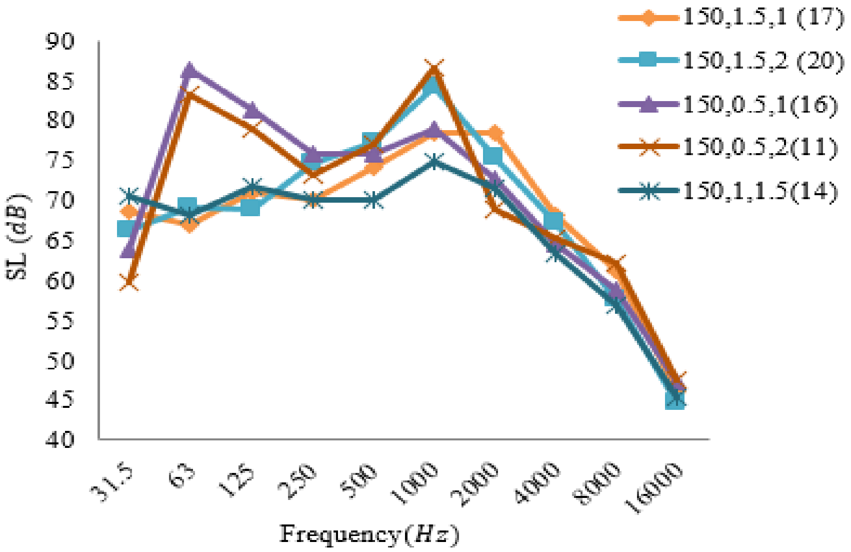


Figure 4.8: Graph corresponding to Frequency Spectrum at 150 m/min velocity

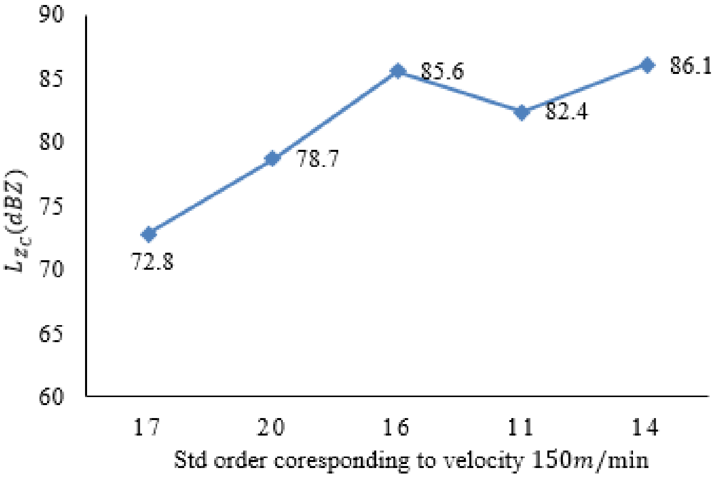


Figure 4.9: Graph regarding Z-weighting Sound Level at 150m/min Velocity

4.3.2 Comparison of frequency spectrum with L_{Z_C} sound level at 170m/min velocity

For the constant velocity 170m/min the values regarding frequency spectrum is displayed in table 4.9 and depicted through figure 4.10. Also the values regarding Z-weighting sound level is presented in figure.4.11. The figure 4.10 revealed that at low-range and mid-range high sound level peaks were obtained at standard order 18 which includes 170m/min velocity, 1mm axial cut depth, 1mm radial cut depth and standard order 1 which includes 170$m/$

min velocity, $1mm$ axial cut depth, $1.5mm$ radial cut depth. On comparing figure.4.10 and 4.11 it could be clearly deduced that similar high peaks were obtained at those standard orders 18 and 1 of around $86dB$ and $80.1dB$ were observed in both the graphs.

Table 4.9: Frequency Spectrum corresponding to different levels at 170 m / min velocity

Frequency Spectrum 1/1 octave	170,1,1.5 Std. Order 1	170,,1,1.5 Std. Order 2	170,1,1 Std. Order 18	170,1,1.5 Std. Order 10	170,1,1.5 Std. Order 7
31.5	65.3	59.1	60.9	61.9	54.4
63	75.9	63.8	67.0	68.9	61.3
125	77.1	63.5	69.5	71.7	63.4
250	78.3	65.4	80.7	78.6	70.2
500	81.1	69.6	80.3	81.1	68.7
1000	78.1	72.5	81.1	79.3	72.5
2000	76.6	65.8	75.9	77.3	60.4
4000	69.9	60.9	70.4	71.4	66.0
8000	62.4	54.7	60.9	65.4	62.6
16000	48.7	40.8	49.3	53.1	49.5

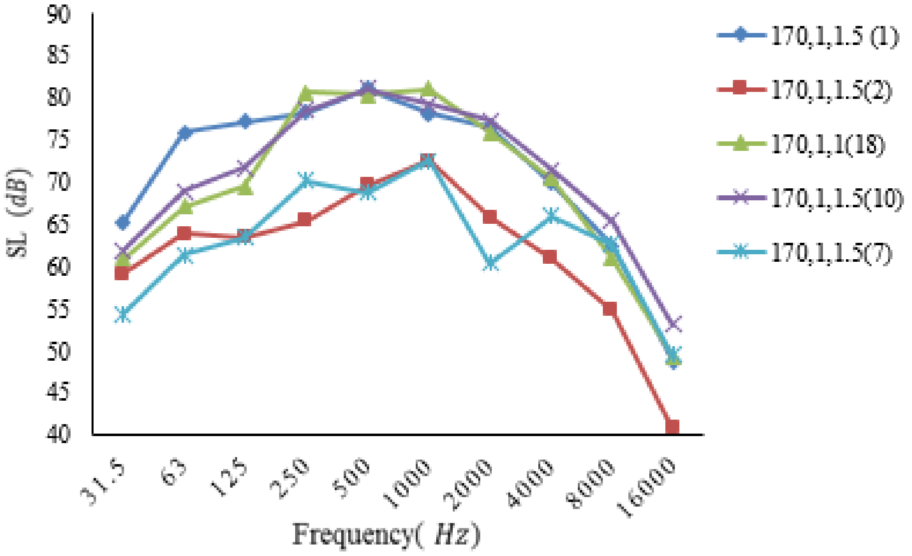


Figure 4.10: Graph corresponding to Frequency Spectrum at 170 m/min velocity

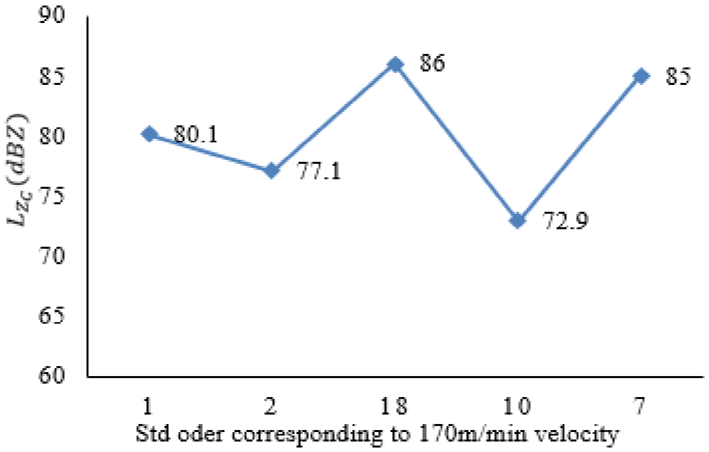


Figure 4.11: Graph regarding Z-weighting Sound Level at 170m/min Velocity

4.3.3 Comparison of frequency spectrum with L_{Z_C} sound level at 170m/min velocity

For the constant velocity $170m/min$ the values regarding frequency spectrum is displayed in table 4.10 and depicted through figure 4.12. Also the values regarding Z-weighting sound level is presented in figure.4.13. The figure 4.12 revealed that at low-range and mid-range high sound level peaks were obtained at standard order 15 which includes $170m/min$ velocity, $1mm$ axial cut depth, $2mm$ radial cut depth and standard order 12 which includes $170m/min$ velocity, $1mm$ axial depth of cut, $1.5mm$ radial depth of cut. On comparing figure.4.8 and 4.9 it could be clearly deduced that similar high peaks were obtained at those standard orders 15 and 12 of around $85.6dB$ and $86.4dB$ were observed in both the graphs.

Table 4.10: Frequency Spectrum corresponding to different levels at $170m/min$ velocity

Frequency Spectrum 1/1 Octave	170,1,1.5 Std. Order 12	170,1,2 Std. Order 15	170,0.5,1.5 Std. Order 4	170,1,1.5 Std. Order 9	170,1.5,1.5 Std. Order 5
31.5	60.6	65.6	59.8	62.4	56.5
63	65.5	77.2	75	77.3	64.8
125	62.8	78.3	77.6	80	62.7
250	71.8	78	75.8	79.1	70.5
500	73.3	80.4	75	76.4	70.3
1000	75.9	78.3	74.9	78	71.6
2000	72	76.6	70.2	72.8	60.3
4000	65.9	69.3	65.3	68.8	63.9
8000	61.1	61.8	60.8	64.6	60
16000	49.5	49.9	49.1	49.5	49.3

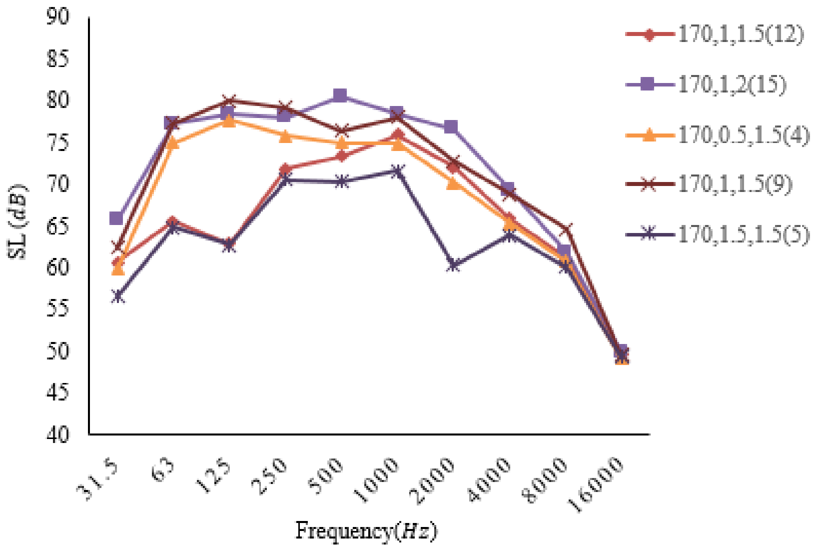


Figure.4.12: Graph corresponding to Frequency Spectrum at 170 m/min velocity

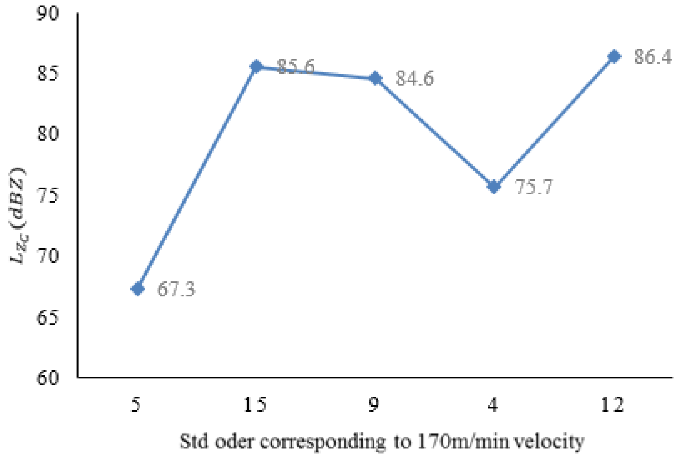


Figure 4.13: Graph regarding Z-weighting Sound Level at 170m/min Velocity

4.3.4 Comparison of frequency spectrum with L_{Z_C} sound level at 190m/min velocity

For the constant velocity 190m/min the values regarding frequency spectrum is displayed in table 4.11 and depicted through figure 4.14. Also the values regarding Z-weighting sound level is presented in figure 4.15. The figure 4.14 revealed that at low-range and mid-range high sound level peaks were obtained at standard order 13 which includes 190m/min velocity, 1mm axial depth of cut, 1.5mm radial depth of cut and standard order 8 which includes 190m/min velocity, 0.5mm axial cut depth, 1mm radial cut depth. On comparing figure.4.8 and 4.9 it could be clearly deduced that similar high peaks were obtained at those standard orders 13 and 8 of around 86.1dB and 82.6dB were observed in both the graphs.

Table 4.11: Frequency Spectrum corresponding to different levels at 190 m/min velocity

Frequency Spectrum 1/1 Octave	190,1,1.5 Std. Order 13	190,1.5,2 Std. Order 19	190,1.5,1 Std. Order 6	190,0.5,2 Std. Order 3	190,0.5,1 Std. Order 8
31.5	59.6	62.3	67.8	64.7	59
63	68	70.2	76.4	65.9	64.7
125	67.2	67.1	71.9	58.2	65.9
250	71.7	72.7	75.6	68	71.7
500	66.3	74.8	78.1	72.3	72.4
1000	68.1	78.3	78.9	72.7	71.1
2000	60.5	75.3	76.4	69.2	68.4
4000	71.2	72.4	71.8	70.8	68.1
8000	64.1	64.9	64.1	62.6	63.4
16000	52.1	52.9	52.9	53	53.2

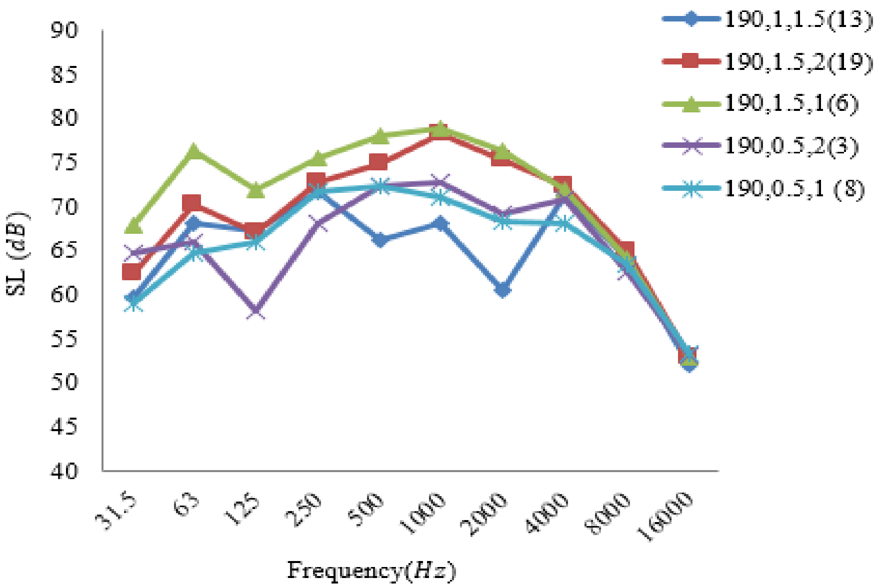


Figure.4.14: Graph corresponding to Frequency Spectrum at 190m/min Velocity

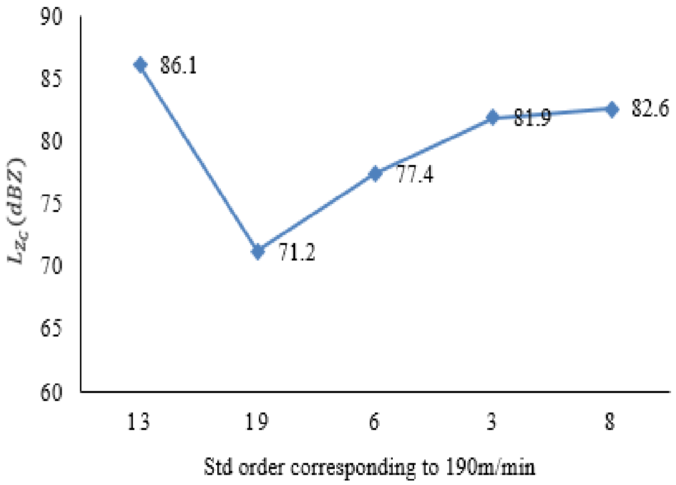


Figure 4.15: Graph regarding Z-weighting Sound Level at 190m/min Velocity

4.4 Interpretation of Other Sound Level

The values shown in the annexure A.1 shows the different sound level. A- weighting and Z-weighting sound levels are already compared with the surface roughness. The 10-percentile sound level were also recorded which shows that maximum level was obtained at 170 m/min velocity, 1mm axial cut depth and 1mm radial cut depth that was 85.5dB. Similarly, the 90-percentile sound level were also recorded which shows that maximum level was obtained at 150 m/min velocity, 1.5mm axial cut depth and 2mm radial cut depth that was 84.5dB.

CHAPTER 5
CONCLUSION AND FUTURE WORK

5.1 Conclusions

Statistical modelling was done on the surface roughness parameter to determine its effect on different machining parameters, as no such perfect relationship was derived from the plots of surface roughness parameter along with the sound levels.

The contribution of radial cut depth (figure.4.3) on surface roughness was 37% which was maximum as compared to velocity that was 25%, and axial cut depth being 19%. The overall effect of other interaction factors effect was only 19%. Other salient points that were observed during the present study are as follows:

i. The trend of radial cut depth was observed as increase in radial cut depth leads to the high extent of material removal rate and also vibrations increase surface roughness of the material.

ii. Due to increase in velocity the surface roughness decreased because at low spindle speed built-up-edges were formed or chip fracture which yielded poor surface finish. Whereas, if the cutting speed was increased built-up-edges (BUE) would vanish along with the decrease in chip fracture.

iii. The third factor axial cut depth also had significant effect on the surface quality. If cut depth was increased cutting resistance also increased along with the amplitude of vibrations and cutting temperature. Due to this quality of the work-piece degraded.

iv. It is concluded from results that the minimum surface roughness obtained was at $190 m/min$ velocity, $1mm$ axial cut depth and $1mm$ radial cut depth and the sound level recorded was also $76.2dBA$ which was within the prescribed limits according to the Indian Standards[31].

5.2 Future Scope

The presented study can be broadened in different directions, some of which are mentioned below:

i. With the help of the analysis done, similar work could also be extended to different materials and other tools as well as inserts.

ii. The machining parameters can be extended to different levels. Also different machining parameters can be varied like feed rate.

iii. The study can be extended to include other parameters like cutting force measurement and tool wear.

iv. Also, different machining conditions can be varied such as lubricating conditions.

ANNNEXURE: A
MEASURED VALUES OF NOISE LEVELS

The annexure A.1 consist of the measured values of noise levels observed during experimentation.

Table A.1: Mean values of sound levels

Std. Order	V m/min	a_e mm	a_d mm	L_A $dB(A)$	L_Z $dB(Z)$	L_{10} $dB(A)$	L_{90} $dB(A)$
8	190	0.5	1	81.7	82.6	76.5	74.5
18	170	1	1	81.0	86.0	84.5	82.5
13	190	1	1.5	84.0	86.1	75.5	73.5
2	170	1	1.5	75.9	78.2	85.5	84.5
6	190	1.5	1	77.1	78.4	83.0	81.5
1	170	1	1.5	80.9	88.4	79.0	78.0
7	170	1	1.5	85.0	86.0	81.5	80.0
10	170	1	1.5	74.7	77.2	75.0	73.5
16	150	0.5	1	81.0	85.6	81.0	80.5
12	170	1	1.5	73.8	76.5	75.0	73.0
3	190	0.5	2	82.5	83.0	77.5	76.5
4	170	0.5	1.5	82.7	84.6	78.5	77.5
9	170	1	1.5	77.5	79.8	84.0	82.5
14	150	1	1.5	82.8	86.1	78.0	76.5
15	170	1	2	82.9	85.6	83.0	81.5
17	150	1.5	1	83.6	76.5	83.0	81.5
11	150	0.5	2	78.3	83.0	82.0	79.0
19	190	1.5	2	74.4	75.9	82.5	78.0
5	170	1.5	1.5	81.2	86.4	74.0	73.0
20	150	1.5	2	78.6	80.0	85.5	84.5

ANNNEXURE: B

MEASURED VALUES OF AVERAGE SURFACE ROUGHNESS

The annexure B.1 consist of the measured values of average surface roughness observed during experimentation.

Table B.1: Mean values of surface roughness parameters

Std. Order	V m / min	a_e mm	a_d mm	R_a μm
8	190	0.5	1	0.0933
18	170	1	1	0.1079
13	190	1	1.5	0.1160
2	170	1	1.5	0.1230
6	190	1.5	1	0.1234
1	170	1	1.5	0.1285
7	170	1	1.5	0.1314
10	170	1	1.5	0.1367
16	150	0.5	1	0.1450
12	170	1	1.5	0.1477
3	190	0.5	2	0.1490
4	170	0.5	1.5	0.1550
9	170	1	1.5	0.1575
14	150	1	1.5	0.1670
15	170	1	2	0.1764
17	150	1.5	1	0.1780
11	150	0.5	2	0.1950
19	190	1.5	2	0.1986
5	170	1.5	1.5	0.2043
20	150	1.5	2	0.2832

ANNNEXURE: C
INDIAN STANDARDS OF AIR QUALITY WITH RESPECT TO NOISE

The annexure C.1 consist of the data issued by the Indian Standards to work in that ambient air quality conditions, so that the operators are not affected mentally or get physically disturbed.

Table C.1: Ambient Air Quality Standards in Respect of Noise

Area Code	**Category of Area/Zone**	**Limits in dBA (L_{eq})**	
		Day Time*	**Night Time****
A	Industrial Code	75	70
B	Commercial Code	65	55
C	Residential code	55	45
D	Silence zone***	50	40

***** Day time shall mean from 6.00 a.m. to 10.00 p.m.

****** Night time shall mean from 10.00 p.m. to 6.00 a.m.

******* Silence zone area comprises of not less than 100 meters around hospitals, educational institutions, courts, religious places or many other area which is declared as such by the competent authority.

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