

Numerical Analysis and Experimental Investigation of Residual Stress and Surface Roughness in Cylindrical Grinding of Stainless-steel 440



HANGATU HARUN MAMU

A Thesis Submitted to

Department of Mechanical Engineering

School Of Mechanical, Chemical and Material Engineering

Present in Partial Fulfillment of the Requirements for Degree of Master's in
Mechanical Engineering (Specialization in Manufacturing Engineering)

Office of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

Numerical Analysis and Experimental Investigation of Residual Stress and Surface Roughness in Cylindrical Grinding of Stainless-steel 440C

HANGATU HARUN MAMU

Thesis Advisor:

Dr. G.M.SAYEED AHMED

A Thesis Submitted to

Department of Mechanical Engineering

School Of Mechanical, Chemical and Material Engineering

Present in Partial Fulfillment of the Requirements for Degree of Master's
Mechanical Engineering (Specialization in Manufacturing Engineering)

Office of Graduate Studies

Adama Science and Technology University

June, 2023

Adama, Ethiopia

ACKNOWLEDGEMENT

First and foremost, praises and thanks to the ALLAH, the Almighty, for His showers of blessings throughout my research work to complete the research successfully. I want to express special thanks and gratitude to my Advisor Dr. SAYEED G.M associate professor in Program of Mechanical Design and Manufacturing Engineering, Adama Science and Technology University for his continuous support, guidance, comment. It was a great privilege and honor to work and study under his guidance.

I'd like to thank Adama Steel Factory and FDRE technical and vocational institute for providing me with the opportunity to carried work on the cylindrical machining and surface roughness tester and spectroscopy machine. Last but not least, I would like to express my deepest gratitude to my KB, Family, and friends for their invaluable assistance, and I am deeply grateful to everyone who has contributed to the successful completion of this Thesis.

Declaration

I hereby declare that this Master Thesis entitled “Numerical Analysis and Experimental Investigation of Residual Stress and Surface Roughness in Cylindrical Grinding of Stainless-steel 440C” is my original work. It is not been submitted for the award of any academic degree, diploma, or certificate in this university and any other universities. All sources of materials that were used for this thesis have been accordinglyacknowledged through citation.

Hangatu Harun Mamu

Student Name

Signature

Date

Recommendation of Advisors

I, the advisor of this thesis proposal, hereby certify that I have read the revised version of this thesis entitled “Numerical Analysis and Experimental Investigation of Residual Stress and Surface Roughness in Cylindrical Grinding of Stainless-steel 440C” prepared under my guidance by Hangatu Harun Mamu submitted in partial fulfillment of requirements for the degree of masters of science in Manufacturing Engineering.

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. G.M.SAYEED AHMED

Major Advisor/supervisor


Signature

24-08-2023

Date

Approval Sheet by Advisor

I, the advisor of the thesis entitled “Numerical Analysis and Experimental Investigation of Residual Stress and Surface Roughness in Cylindrical Grinding of Stainless-steel 440C” and developed by Hangatu Harun Mamu; hereby certify that the recommendation and suggestions made by examiners are appropriately incorporated into final version of the thesis.

Dr. G.M.SAYEED AHMED

Major Advisor/supervisor


Signature

24-08-2023

Date

Approval of Board of Examiners

We, the undersigned, members of the Board of examiners of the thesis by Hangatu Harun Mamu have read and evaluated the thesis entitled “Numerical Analysis and Experimental Investigation of Residual Stress and Surface Roughness in Cylindrical Grinding of Stainless-steel 440C” and examined the candidate during open defense. This is therefore to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Manufacturing Engineering.

Chairperson

Signature

Date

Internal Examiner

Signature

Date

Endalkachew Mosisa (PhD)



August 24/2023

External Examiner

Signature

Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head

Signature

Date

School Dean

Signature

Date

Office of Postgraduate studies dean

Signature

Date

Abstract

Machining is a finishing technique in which work pieces are produced to the desired dimensions and surface finish by gradually removing extra material from the prepared blank in the form of chips with the help of cutting tool. Regression models were conducted using full factorial. Analysis of variance was used to assess the validity of the developed model. Experiments were performed on a CNC (Computer Numerical Control) machine on workpiece of stainless steel (AISI 440) which is used in the construction of bearings, nozzles, aircrafts, and wear parts of pumps, mold inserts, and surgical tools. The findings showed that feed rate contributed 95% that it was the most significant parameter affecting surface roughness. Minimum surface roughness of $0.6\text{ }\mu\text{m}$ was achieved at lowest value of cutting parameters speed of and maximum surface roughness of $6.52\text{ }\mu\text{m}$ were achieved at highest value of cutting parameters. The highest temperature of 60.929°C was observed for higher cutting parameters and the lowest temperature (45.592°C) for lower cutting parameters. An optimization problem was solved using a response surface methodology in design experiment 13. By carrying out response optimization process from RSM are observed that R_a of $0.343285\text{ }\mu\text{m}$ when the material grinded at 550Rpm, 2mm/min and depth of cut was 0.02mm. Simulation was done using LS-DYNA. An optimum value observed from simulation are Optimum temperature value is 47.5503°C at combination of the grinding parameters were at work piece speed (Rpm) of 550.01Rpm, feed rate of 0.012004 mm/min and depth of cut were at 0.0399856mm. Optimum range deformation value were 6.40611 mm at combination of grinding parameters were at work piece speed of 550.126Rpm, feed rate of 0.06846mm/min and depth of cut were at 0.02mm. Optimum equivalent stress value were 1068.58 Mpa at combination of grinding parameters were at work piece speed of 550.001Rpm, feed rate of 0.1125mm/min and depth of cut were at 0.0397mm. D-spacing calculated by using data from XRD on origin software. Micro-strain was calculated and Residual stress was calculated based on hooks law.

Keywords: Response Surface Methodology, LS-DYNA, XRD, Surface roughness, residual and stainless steel 440

Contents

ACKNOWLEDGEMENT	i
Declaration	ii
Recommendation of Advisors	iii
Approval Sheet by Advisor	iv
Approval of Board of Examiners	v
Abstract	vi
List of Tables	ix
List of Figures	x
List of Acronyms and Abbreviation	xi
1. INTRODUCTION	1
1.1 Introduction	1
1.2 Problem Statement	5
1.3 Objectives	6
1.3.1 General Objective	6
1.3.2 Specific Objective	6
1.4 Significance of the Studies	6
1.5 Scope of the Studies	7
1.6 limitation of the studies	7
1.7 Structure of the Thesis	7
2. LITERATURE REVIEW	9
2.1 Introduction	9
2.2 History of Grinding	9
2.3 Effect of Cutting Parameter on Residual Stress	10
2.4 Effect of Cutting Parameter on Surface Roughness	14
2.5 Mathematical Modeling	19
2.6 Optimization of Cylindrical grinding Process Parameters	20
2.7 Summary of Literature Review	23
2.8 Research Gap	25
3. Materials and Methodology	27
3.1 Introduction	27
3.2 Experiment Procedure	27
3.3 Machine and Equipment	29
3.3.1 Work-piece Material	29

3.3.2	Cutting Tool Materials.....	31
3.3.3	Grinding Machine	31
3.3.4	Surface Roughness Measurement	32
3.3.5	Measurement of workpiece Temperature.....	33
3.3.6	XRD	34
3.4	Selection of Process Parameter	35
3.5	Research Methodology	37
3.6	Design of Experiment	38
3.6.1	Analysis of variance (ANOVA).....	38
3.6.2	Response Surface Methodology	40
3.6.3	Model Prepared For Numerical Simulations.....	41
3.6.4	Grid Converge index analysis	41
4.	RESULTS AND DISCUSSIONS	42
4.1	Introduction.....	42
4.1.1	Result Values Obtained from Cylindrical Grinding Experiment	42
4.2	Surface roughness analysis and discussion.....	43
4.2.1	Statistical Analysis	43
4.2.2	Regression Model for Surface Roughness	46
4.3	Response Optimization: Ra.....	49
4.5	Simulation Result From Ls-Dyna	52
4.6	Measuring Of Residual Stress Using XRD.....	61
5.	Conclusion and Recommendation.....	66
5.1	Conclusion	66
5.2	Recommendation	67
5.3	Scope for Future Work.....	68
6.	REFERENCE	69
7.	Appendix	78

List of Tables

Table 2-1 summary of literature	23
Table 3-1 chemical composition of AISI 440C.....	30
Table 3-2 mechanical and physical properties of AISI 440c.....	30
Table 3-3 Process parameters selected by various researchers	36
Table 3-4 Levels of parameters and their range used for an experiment	36
Table 3-5 Design Matrix.....	38
Table 3-6 LS Dyna set ups	41
Table 4-1 Experimental Results.....	43
Table 4-2 Sequential Model Sum of Squares	44
Table 4-3 Model summary statistics.....	44
Table 4-4 Analysis of Variance for Surface Roughness	45
Table 4-5 Fit statistics.....	45
Table 4-6 Coefficients in Terms of Coded Factors for Ra	51

List of Figures

Figure 1-1 Classification of Material Removal Process	2
Figure 1-2 Grinding geometry Wasif et al., (2019).....	3
Figure 3-1 Schematic diagrams of experimental procedures	28
Figure 3-2 work-piece of material used in grinding	29
Figure 3-3 spectroscopy used to identify chemical composition	30
Figure 3-4 Wheel Grinding used in Grinding.....	31
Figure 3-5 DCS-002 Da CNC cylindrical grinding.....	32
Figure 3-6 Surface Roughness Testing Equipment	33
Figure 3-7 Infrared Thermometer	34
Figure 3-8 flow chart of residual stress	35
Figure 3-9 XRD machine XRD-700 X-RAY diffraction	35
Figure 3-10 Flowchart of RSM.....	37
Figure 3-11 2D element model	41
Figure 3-12 3D Element model	41
Figure 4-1 Fit summary	44
Figure 4-2 (a) Normal plot of residuals (b) Residuals vs. Predicted	47
Figure 4-3 Contour Plot of Ra vs. feed rate and work-piece speed	48
Figure 4-4 Surface Plot of Ra vs feed rate, work-piece speed	48
Figure 4-5 Optimization Graph	49
Figure 4-6 Residual and Main effect Plot.....	50
Figure 4-7 Prediction of Temperature	59
Figure 4-8 prediction of Range Deformation	60
Figure 4-9 Prediction of Equivalent Stress.....	60
Figure 4-10 Prediction of Absorbed Energy.....	61
Figure 4-11 Intensity vs 2 Theta.....	63
Figure 4-12 Residual Stress vs Micro strain.....	65

List of Acronyms and Abbreviation

Al ₂ O ₃	Aluminum oxide
AISI	American iron & steel institute
ANOVA	Analysis of variance
CBN	Cubic boron nitride
CNC	Computer numerical control
d	Depth of cut
df	degree of freedom
DoE	Design of experiment
er	error
E	young modules
f	Feed rate
Gpa	Gage Pascal
m	Meter
mm	Millimeter
Mpa	Mega Pascal
Ra	Surface roughness
s/n	Signal ratio
OA	Orthogonal array
RSM	Response surface methodology
V	Cutting speed
σ	Stress
ε	Strain
θ	Thetha

CHAPTER ONE

1. INTRODUCTION

1.1 Introduction

In the material removal process, excess material from the initial work piece is removed through a series of shaping operations to leave the desired final shape Guochao et al. (2014). Machining, collectively referred to as cutting, is the process by which a hard material, used as a cutting tool, removes unwanted portions from a soft material to give the work piece desired shape and final material. Removing the chip produces a new surface. Machining is most commonly used to give shape, dimensions and sometimes properties to raw materials to produce desired components.

Machining is the commonly used manufacturing process for the production of finished components of desired shape, size and accuracy. Machining process involves the usage of single or multiple point cutting tools to remove the unwanted materials from the stock in the form of chips Koinandurai, (2013). Among the various metal cutting process available, Grinding is one of the important metal cutting processes used extensively in the finishing operation of discrete components. It is a versatile and also finishes machining process in the production of component requiring close dimensional tolerances, geometrical accuracies and required surface finish Rajinohan et al. (2014). Most of the production processes are incomplete without grinding process. According to Subraailanian et al. (2019), it is a major manufacturing process, which accounts for about 25% of the total expenditure on machining operations in industrialized countries. Almost all the engineering components are processed in grinding machines at some stages of its production.

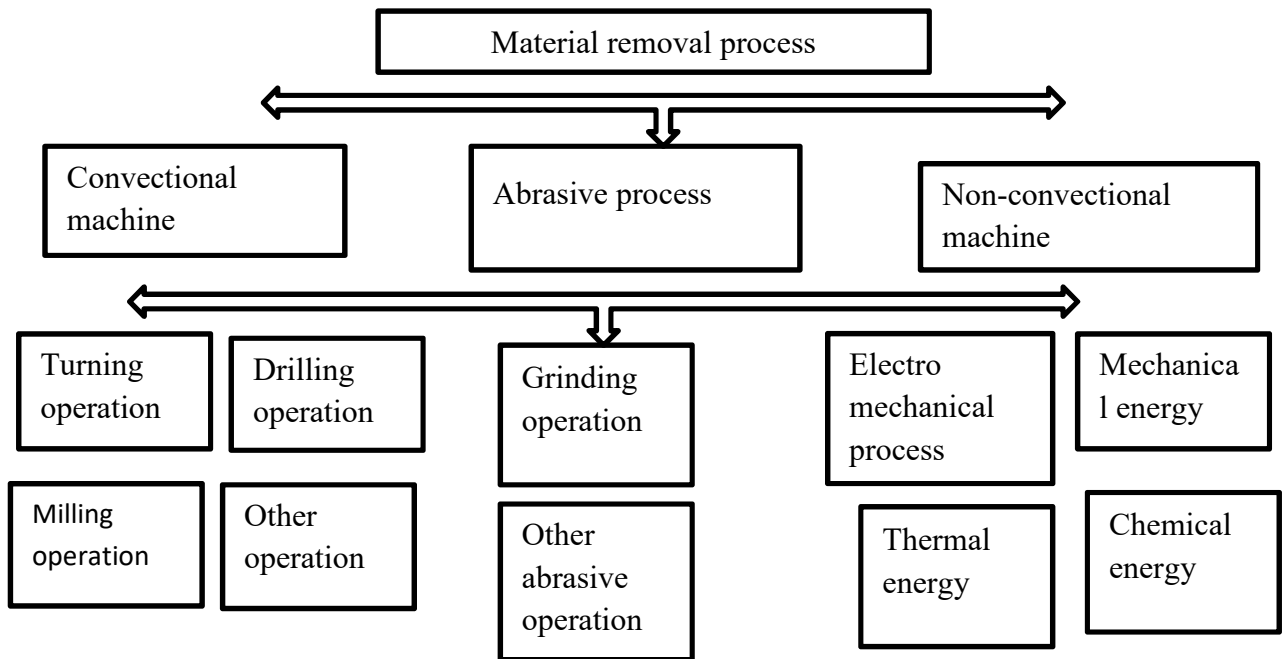


Figure 1-1 Classification of Material Removal Process

The machining process is considered one of the most important processes in the manufacturing industry. A huge amount of research on this topic has been conducted over the past decades, but there is always room for improvement Sreejith et al. (2019). The researcher's focus is on increasing productivity while ensuring sustainability and improving quality. The desire for excellence has driven the need for optimization in the machine and process areas Khan et al. (2020). Today, the competition among manufacturers is to produce products with the highest possible quality and productivity at the lowest possible cost. Therefore, controlling independent parameters that have a large impact on these reactions is an important goal in manufacturing.

In the metal cutting industry, Grinding is often chosen as a finish machining for the surface with a high requirement for accuracy and with small surface roughness. Therefore, the parameters of the surface quality of the machine parts when grinding are especially interested.so, Several parameters of the surface properties of the part, such as wear resistance, fatigue strength, chemical corrosion resistance, and joint strength (for tight joints), are directly affected by surface roughness. Therefore, surface roughness is a very important parameter.

In contrast to other material removal processes, a grinding operation requires more energy to remove the same material volume and thus has a higher specific energy. This indeed results in high generation of heat energy. The level of heat generated depends not only on the interaction forces within the grinding zone but also on the plastic deformation mechanism associated with the material removal process, the table speed and the grinding wheel speed. Consequently, the work piece temperature rises to a level governed by its thermal properties and the grinding conditions. As the work piece moves with table speed, the grinding temperature starts to decrease due to the cooling effect and thermal energy diffusion into the work piece.

Cylindrical grinding is an industrial machining process to produce a smooth finish on the flat surface of a work piece. In this process, there are abrasive grains adhered to the peripheral area of the grinding wheel; thereby, when this one rotates at high speed, it removes the surface layer of the work piece Zhu & Beaucamp, (2020). In Fig. 1.2, we consider the grinding wheel fixed with respect to the observer and the work piece moving from right to left at feed rate v_d . For not very conductive work piece, almost all the energy of the process is converted into heat, which is concentrated within the grinding area of width. This heat flux entering into the work piece leads to high temperatures that can damage the work piece (i.e., burning, phase transformations, or residual stresses); thus, many times coolant is applied onto the surface to avoid thermally induced damage Jamshidi & Budak, (2021).

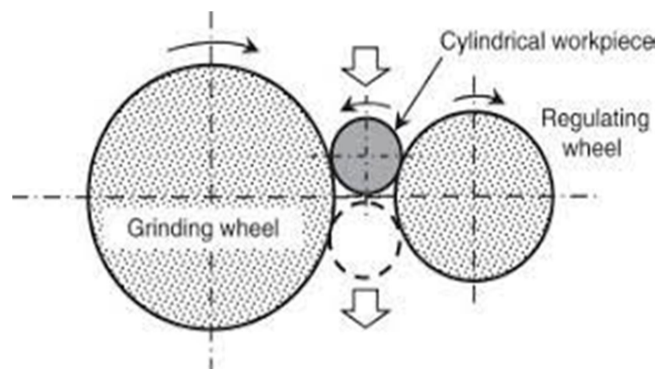


Figure 1-2 Grinding geometry Wasif et al., (2019)

The quality of a machined surface is becoming more and more important in order to satisfy the increasing demands of sophisticated component performance, longevity, and reliability so that they can achieve their functions according to geometric, dimensional and surface considerations. An understanding of surface finish provides much advantage in avoiding failures; enhance component integrity and costs saving. Grinding is most commonly used as a finishing process to achieve material removal and desired surface finish with acceptable surface integrity, dimensional tolerance and form tolerance. The surface quality produced in surface grinding is influenced by various parameters such as: i. wheel parameters abrasives, grain size, grade, structure, binder, shape and dimension; ii. Workpiece parameters fracture mode, mechanical properties and chemical composition; iii. Process parameters wheel speed, depth of cut, table speed and dressing condition; iv. Machine parameters static and dynamic characteristics, spindle system and table system.

Mechanical methods of residual stress measurement are limited by assumptions concerning the nature of the residual stress field and sample geometry. Being necessarily destructive, mechanical methods cannot be directly checked by repeat measurement. The residual stress is calculated from the strain or deflection produced by sectioning to relax the residual stresses present. Only in the limit of relaxing all of the residual stress in the body can the true residual stress present be determined. The sample geometry is usually limited to simple forms (plates, beams, cylinders, etc.) by the availability of closed form solutions to calculate residual stress from the measured change in strain. Finite element solutions can be developed for more complex geometries. Spatial and depth resolution are generally an order of magnitude less than those of x-ray diffraction.

X-ray diffraction residual stress methods calculate the residual stress present from the strains measured in the crystal lattice of the grains in the sample. Because the residual stresses are entirely elastic, the entire stress present is measured nondestructively without altering the sample. To determine the stress in one direction on the sample surface, the strain in the crystal lattice must be measured for at least two precisely known orientations relative to the sample surface. Therefore, x-ray diffraction residual stress measurement is applicable to materials that are crystalline, relatively fine grained, and produces diffraction for any orientation of the sample surface. Samples may be metallic or ceramic, provided a diffraction peak of suitable intensity and free of interference from neighboring peaks can be produced in the high back-

reflection region with the radiations available. X-ray diffraction residual stress measurement is unique in that macroscopic and microscopic residual stresses can be determined nondestructively.

1.2 Problem Statement

Grinding is one of the important metal cutting processes used extensively in the finishing operation of discrete components. Stainless steel 440C were applied in construction of bearings, nozzles, aircrafts, and wear parts of pumps, mold inserts, and surgical tools. It is a versatile and also finishes machining process in the production of component requiring close dimensional tolerances, geometrical accuracies and required surface finish Rajinohan et al. (2014). The cylindrical grinder is a type of grinding machine used to shape the outside of an object. An essential step in many manufacturing processes is cylindrical grinding, the process of using abrasive grinding to remove material from a work-piece. Various industries use cylindrical grinding machines, from automotive and aerospace to military and information technology. These machines shape pieces like cylinders, pistons and pins to suit the desired form and function. Although cylindrical grinding machines are helpful and simplistic, problems like burn surface and phase transformation can still occur during manufacturing. Preventing grinding problems is critical for ensuring production accuracy and avoiding damage to the cylindrical grinding machine. High in feed of the work-piece and material removal rate could also lead to grinding burn. Try reducing the wheel indeed rate and increasing the wheel traverse rate. When the cylindrical grinding operation doesn't meet the requirements and the work-piece is set incorrectly, work-pieces can be inaccurate. Using a slower traverse rate to dress the wheel, dressing the wheel parallel to the work-piece or replacing the wheel with a harder grade or finer grit may solve the issue. Make the final dressing in the opposite direction of the initial runs, and then flush the wheel with coolant after dressing to clean it. One of the most common cylindrical grinding problems is the presence of fine spirals or scratches on the work-piece, making the surface uneven. These imperfections come in several types, including: A thread pattern corresponding to the feed rate.

1.3 Objectives

1.3.1 General Objective

The General objective of this research was Numerical Analysis and Experimental Investigation of Residual Stress and Surface Roughness in Cylindrical Grinding of Stainless-steel 440C.

1.3.2 Specific Objective

1. To experimentally investigation the influence of the input machining parameters (workpiece speed, feed rate and depth of cutting) on output parameters cylindrical grinding of Stainless Steel 440.
2. To develop an empirical equation of each output responses in terms of input parameters based on the experimental data. Further this mathematical model is used to predict the output responses.
3. To optimization of the input process parameter based on the response optimizer techniques from RSM Further, optimal set of input parameters are investigated for these optimal responses.
4. To investigate the effect input process parameter on residual stress during cylindrical grinding of stainless steel 440C.
5. To conduct simulation of grinded stainless 440c by using LS-DYNA software.

1.4 Significance of the Studies

The proposed study work is to establishing a machining investigation to find out the cutting parameters which highly affect machining: feed rate, depth of cut and cutting speed at which optimum value can be simultaneously optimized is advantageous in terms of: -

- ✓ Improving service life of the product,
- ✓ Improving wear and corrosion resistance of parts,

- ✓ Improving machining precision,
- ✓ Improving excellent surface quality,
- ✓ Reduction in machining time,
- ✓ Reduction in machining costs, and
- ✓ Providing freedom for industrials to choose optimum cutting parameters.

Additionally, it will help the researcher to grasp theoretical and practical knowledge on research area and there are other beneficiaries from this study work such as students those are studying this research area, future researcher as literature and manufacturing industries in need of this grinding work.

1.5 Scope of the Studies

The scope of this research paper was centered on optimization of cutting parameters, to simultaneously optimize and establish the best combination of cutting parameters that influence the surface roughness and residual stress during grinding of AISI 440 tool steel on CNC machine as to increase the customer's satisfaction and improve plant productivity without taking into account the impact of cutting force, machine vibration, and tool nose effect on surface quality and productivity as it is difficult to measure vibration frequencies and force without a dynamometer. And three levels of the chosen parameters viz. wheel speed, table speed and depth of cutting was considered.

1.6 limitation of the studies

This study was limited by availability of the machine, since the start of the work the researcher proposed CNC surface grinding machine but it was not functional at the intended time, so after discussion with advisor the researcher changed to cylindrical grinder with similar material and methods.

1.7 Structure of the Thesis

This study entitled numerical analysis and experimental investigation of residual stress and surface roughness using cylindrical grinding of stainless steel 440 is organized into five chapters.

- ✓ Chapter one of the thesis is an introduction with an overview of the chosen workpiece and cutting condition, the statement's problem, its significance and objectives, and finally its scope and limitations.
- ✓ Chapter two provides an overview of previous research work related to this research, and the summary of the literature with the research gap is described.
- ✓ Chapter three discusses the materials and methodologies used in this research study. This includes detailed information about the workpiece and cutting tool used machines and equipment used, and the experimental procedure followed.
- ✓ In Chapter four, the main results of experimental studies and predictions are presented together with a detailed discussion. This chapter examines the effects of cutting parameters (cutting speed, depth of cut, and feed rate) on surface roughness and residual stress.
- ✓ At the last the whole study's conclusion, recommendations, and future research directions were given.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Introduction

The market demand for good surface quality of metal product at a reasonable cost has increased from time to time due to the final requirements of mirror surfaces required in the industry. These factors lead researchers to search for a better way to achieve these conflicting goals (Khan et al., 2020). Machinability is a term that describes the ease of performing a material removal process regardless of the machining method considered. Machining is a general term that deals with certain parameters that are usually described as output responses. In the metal removal process, output responses are mainly influenced by the appropriate selection of cutting parameters, so optimal cutting parameters must be determined to improve surface quality, increase productivity and reduce machining costs. To solve this, many researchers spent a lot of time to find out how these cutting parameters affect the output response and suggested the points where the optimal values are located, so this chapter gives an overview of the work of various grinding researchers. different workpiece materials and cutting tools. And what they found during experimentation and how cutting parameters and output responses logically affect each other and what optimization methods the researchers used for single and multi-objective optimization Benedicto et al (2017).

2.2 History of Grinding

The earliest practical abrasive dates back to the Neolithic period. The Neolithic period is also known as New Age Rock. Primitive operations were largely limited to manual operations due to the lack of machine tool technology. Grinding has been in production for over 100 years. Altzschner patented an early apparatus for finishing a sandstone grinding wheel in 1860. In the grinding process, hard abrasive particles are used as a knife. It started when prehistoric man wanted to sharpen his knife by rubbing it against sandstone. Today, the manufacturing is based on the grinding process. This was recorded as the cost of the finishing process alone accounting for 30% of the total machine cost in industrialized countries. Finishing always requires grinding at every stage of production, especially because of its precision.

2.3 Effect of Cutting Parameter on Residual Stress

In the residual production of materials (forging, machining, heat treatment, etc.), in grinding processes and in general in cutting processing processes, the shear energy causes temperature rise and plastic deformation, and therefore residual stresses occur due to thermo mechanical effects. to phenomena occurring during the process. Some studies on the relationship between residual stress and grinding wheel topography using finite element methods and feed input parameters. Research shows that residual stresses depend not only on the grinding parameter and material removal rate, but also on the topography of the wheel through instantaneous structuring. With proper structuring, it is possible to reduce or even eliminate the tensile residual stress by dry grinding (Rabiey et al., 2020), conducted a composite study on the phase transition in grinding of Ni18-25 steel using an A-finite element model and the specific volume and yield strength were considered to know more about the residual stress in micro milling, The results showed that the effect of phase changes on the residual stress was mainly reflected in the tangential surface. This study used a new approach to analyze the residual stress caused by micro grinding and determined two process optimization criteria to reduce the residual stress (Zishan Ding et al., 2020). (Kumar et al., 2020), conducted a study with a mobile XRD system using the $\cos \alpha$ method using 42CrMo4(4140) STEEL with the parameter Different loads during multiphase grinding and material structure of sequential multistage response to variable grinding. processes. It was shown that the final state of the material, which is usually achievable in post-process studies, can also be reliably achieved by sequencing the process in several stages of a conventional grinding process and strongly depends on the contact parameters in the non-linear phase. somehow It can be shown that even the de-sparking step can cause significant changes in the surface residual stress state.

Some researchers used AISI 1018 STEEL as a research material and Johnson-Cook material model to study the effect of cutting speed, feed rate and depth of cut on residual stress. The results showed that the calculated residual stress values were quite close to the values of experimental works. The average deviation between the calculated results and the experimental results is only about 15.96% (Borchers et al., 2020). (Shen et al., 2019), this researcher conducted a study based on surface residual stress and maximum compressive stress using finite element method and martensitic steel C-250 (3J33) with wheel speed,

working speed, grinding depth and its variable. effect on surface and surface Residual stresses and results show that surface residual stress and maximum compressive residual stress are highly dependent on grinding speed, and higher grinding speed produces higher compressive residual stress, while the depth of maximum compressive residual stress varies slightly with grinding parameters. Residual stress penetration depth increases with increasing grinding speed and grinding depth, and decreases with increasing workpiece speed. (Chang et al., 2019) used silicon carbide and finite element methods as the research material. Wheel speed and cutting speed show the effect on phase change, residual stress, microdamage, grinding chips, surface topography. The results show that the high-speed grinding (HSG) process can significantly improve workpiece integrity in terms of better surface finish, less damage, and controlled residual stresses at higher material removal rates. In addition, it has been demonstrated that a polytype phase transformation can be induced in the HSG process.

investigated the removal of macroscopic burrs by grinding using 304 stainless steel, input parameters with $\sim 1\text{--}2\text{ }\mu\text{m}$ thick ultraabrasive grain layer, and SCC initiation resistance and initial reaction techniques varying by residual tensile strength, which resulted in the removal of macroscopic burrs. grinding. reduced residual tensile strength but resulted in more extensive cracking. This paradigm shift shows the dominant influence of microstructure on oxidation over the mechanical driving force of SCC. (Chang et al., 2019). (Rajaei et al., 2018), these researchers mainly focused on pendulum grinding of bearing steel AISI 52100 using Finite Element Method (FEM) experimental methods and parameter input Thermomechanical loads and output Temperature gradients, microstructural evolution, thermal and phase change stresses .

Experimental and simulation studies and comparisons of measured and simulated residual stresses were performed in pendulum grinding. The depth of the subsurface zone where thermally induced microstructural changes occur varied according to changes in the process parameters. Experiments and simulations showed compressive stresses in the rehardened region and tensile stresses in the rehardened region. (da Silva et al., 2018), conducted a study on the cutting fluid used in the grinding process and its effect on the surface integrity of AISI 4340 hardened steel material and the methods of the minimum lubrication (MQL) technique, where the input. Parameters are different cutting fluids and the output variables are the

residual stress. The results showed that the type of cutting fluid affected the surface integrity of the plots. It was concluded that the results showed the use of mixing and MQL fluids as an alternative to the use of integrated and synthetic cutting fluids, which promotes environmentally correct and sustainable production. Three factors can be distinguished that influence the final residual stress state (Huang et al., 2015)

- The pressure of the tool/part causes friction in the workpiece material and thus plastic deformation, resulting in compressive residual stresses (mechanical stresses).
- Friction and heat from the tool/part during plastic deformation causes the part to heat up. The increase in temperature causes a momentary expansion of the surface of the material, which is limited by the bulk material. The resulting stresses may exceed the yield strength at the actual temperature and thus the surface material is plastically deformed. During subsequent cooling, thermal shrinkage causes residual stresses on the surface. These residual stresses are thermal residual stresses.
- If the temperature reached during cutting is high enough, phase changes can occur in the processed material. In this way, if the workpiece is made of hardened steel, martensite can form as a result of rapid heating and cooling, causing compressive stresses due to volume changes associated with the martensitic transformation.

The final stress state therefore depends on the relative importance of these three factors (mechanical, thermal and structural/phase change effects), which are determined not only by the physical and mechanical properties of the material being processed, but also by the processing parameters. Therefore, it is very important to check the effect of each cutting parameter on the final surface integrity of the workpiece to determine the most suitable machining parameters. (Denkena et al., 2016) studied the grinding residual stress and grinding process directions using 1.3344 PM steel, using the measurement $\sin^2$ method as an experimental design method and tool and process parameters to grind input process parameters to investigate the residual stresses. The results show that the grinding strategy has a great effect on the generation of residual stress in both main directions of the process. In addition, the shear grain size has a large effect on the residual stresses perpendicular to the shear

direction, while the feed rate has the greatest effect on the residual stresses along the shear direction.

A good surface finish is achieved with a small cutting edge size, low feed rate and forward grinding strategy. Several authors have observed an increase in residual surface area for different materials (e.g. (Dahlman et al. 2017) in AISI 52100 steel, Jang et al. 2018 in AISI 304 stainless steel, (Capello 2019) in various steels and Schlauer and Oden 2020 in Inconel 718).. However, other authors, for example: (Rech and Moisan, .2022) state that this only applies to a certain nutritional range. In relation to the cutting speed, something similar happens (ie there is no agreement between the authors): some authors. states that the surface residual stresses increase with the shear speed, but (Rech and Moissan, 2021) found that from a certain cutting speed, an increase in cutting speed leads to a decrease in surface residual stresses, so there is some consensus in the literature that the actual trend of residual stresses at feed and cutting speed In this work, an attempt was made to shed some light on the effect of cutting speed and eat the final state of surface stress in AISI 4340 steel. In addition to the cutting parameters, the final surface integrity of the machined parts is expected to be influenced by the tool properties, as the mechanical and thermal loads change as the tool properties change. Therefore, the effect of tool tip radius, tool chip breaker geometry and cutter coating on the surface integrity of the machined part was also investigated in this work.

Most of the studies in the bibliography on the effect of cutting parameters on the final stress state present the measured stresses in two directions: the cutting and feed directions. However, there is no indication that these directions are the main stress directions, so in this work, the full stress tensor is obtained for each studied case to obtain the maximum and minimum stress (main) stress and direction using Mohr's circle structure. Where are those main stresses located? In addition to the magnitude of the main stresses, it is also very important to know the direction, which is not usually done in the literature, because it can drastically affect the life of the components: if the direction of the maximum residual stress corresponds to the direction of the stress the voltage acting on the component resulting from the rated load (the load that the component suffers during normal use), the failure of the component occurs faster (catastrophic premature failure) than when both voltages are in different directions, because the residual stresses are added to the external stresses that the component undergoes during maintenance.

In general, it can be said that residual stresses are useful if they operate at the level of the stresses produced by the applied load and are opposite in meaning.

2.4 Effect of Cutting Parameter on Surface Roughness

(M. Nalbant et al., 2022) adopted the Taguchi method to discover the optimal cutting parameters for surface roughness in turning. The ANOVA method was used to study the performance characteristics of AISI 1030 steel bar turning with TiN-coated tools. The study reveals that feed rate and grain radius were the most important processing parameters affecting surface roughness in turning AISI 1030. (Ilhan Asilturk et al., 2018) focuses on optimizing turning parameters based on the Taguchi method to minimize surface roughness. (RaandRz). The experiment was performed on a CNC lathe using an L9 right angle table. Dry turning tests were performed using hardened AISI 4140 coated carbide tools. Feed rate was found to have the most significant effect on surface roughness.

Xavior et al., (2019) carried out an experimental study to investigate the effect of different cutting fluids on tool wear and surface roughness in AISI 304 carbide insert turning. In addition, an attempt was made to find out the effect of coconut oil as a cutting fluid on reducing tool wear and surface roughness in the turning process. The performance of coconut oil differed from the other two cutting fluids, namely emulsion and pure (unmixed with water) cutting oil. Research results have shown that coconut oil as a cutting fluid performs better than the other two cutting fluids in improving surface finish and reducing tool wear. (M.Z.A. Yazid et al. 2016) observed surface integrity during end-turning of Inconel 718, a highly corrosion-resistant nickel-based super alloy, under three cutting conditions (DRY, MQL 50 ml/h and MQL 100 ml/h).

Microstructural analysis using SEM on the machined surface indicates that severe deformation has occurred, causing a change in microstructure at ground level of a few to several micrometers in thickness. Micro hardness showed work hardening below the machined surface. The results of this study indicate that MQL can potentially improve surface integrity properties. In (Wang, Sun, et al., 2017), a multi-objective optimization of machining parameters in dry turning of IASI 304 austenitic stainless steel was carried out. Three imp properties MRR, shear strength and surface roughness were measured. In (Vahid et al., 2022), a design experiment was conducted to optimize turning parameters such as cutting speed,

depth of cut and duplex steel feed. Duplex steels are generally sensitive to mechanical strengthening during machining. Feed rate and cutting speed have a statistically significant effect on the surface roughness parameters Ra, Rz, where increasing the factors increases the surface roughness, but then the feed rate is fixed at 0.1 mm./rev cutting speed has less effect.

In (FlaviaLerraa et al., 2022) an attempt will be made to model and optimize hard-turned AISI D3 hardened steel using response surface methodology.

The combined effects of four machining parameters, including cutting speed, feed rate, hardness and tool corner radius, were investigated. Surface roughness is most affected by tool corner radius and feed rate. The interactive effect of feed rate and corner radius, hardness corner radius and cutting speed corner radius on surface roughness was significant. (Zhou et al., 2017) CBN blades used in cutting blades are cryogenically treated at -196 degrees Celsius, cutting parameters cut speed at feed rate Cryogenically treated CBN blades consume less titanium than AISI 440 C steel. In titanium alloy, side wear was lower than AISI 440 C. In (González-Santander et al., 2018), cutting parameters of red copper pipe, namely cutting speed, feed speed and depth of cut, are optimized using Taguchi. An orthogonal array, signal-to-noise ratio (S/N) is used to study the cutting characteristics of high-speed steel W18Cr4V cutters. In the experiment, the effect of various factors on the micro strip is investigated, the order of the primary and secondary effects of each factor on the surface roughness and the optimal processing method is obtained.

To reduce the surface roughness, the spindle speed should be reduced accordingly; nutrition and nutrition for tooth should be increased. In (Ali Rajaei et al., 2018) the optimization of cutting parameters was done in CNC turning of P20 steel. The effect of optimizing the cutting parameters (cutting speed, feed, depth of cut, nose radius and cutting medium) on the energy consumption of CNC startup is investigated. The Taguchi method and response surface methodology were used to compare energy consumption. Optimization of several quality parameters such as tool life, cutting force, surface roughness and power consumption in CNC turning of P20 steel using liquid nitrogen as coolant. The test results show that the highest desirability can be achieved with a low cutting speed, pitch and depth of cut, and a large tip radius. (Huang et al., 2015) conducted a study using carbon nitride hardened steel AISI52100 with grinding force and grinding temperature as input parameters as well as surface roughness, residual stress and white layer. The test results show that the grinding force and plastic

deformation are significantly reduced at higher grinding speeds. At the same time, the depth of the white layer and the value of the residual stress increase with the speed of the grinder, and the residual stress is well correlated with the depth of the milled white layer. The white layer during the rapid grinding process is due to the phase change due to the grinding heat and rapid cooling, while the plastic deformation can be ignored for the ground white layer.

Denkena et al (2016) investigated the milling residual stress and milling process directions using 1.3344 PM steel using the $\sin^2$ method measured as an experimental design method and tool and process parameters to investigate the milling input process parameters to study the residual stresses. The results show that the grinding strategy has a great effect on the generation of residual stress in both main directions of the process. In addition, the size of the shear grain has a large effect on the transverse residual stresses in the shear direction, while the feed rate has the greatest effect on the residual stresses in the shear direction. A good surface finish is achieved with a small cutting edge size, low feed rate and forward grinding strategy. (Huang et al., 2016) conducted a study on fine-grained martensite heat compensation using AISI5140 steel using an experimental design technique for thermal compensation with the input variables grinding force, hardening layer depth, and surface quality under the influence of power. variables bottom surface, surface roughness and micro hardness. The test results show that a deep-hardening layer with fine-grained martensite can be obtained by thermal compensation.

The ground surface of the workpiece produces a certain compressive residual stress, and the value of the compressive residual stress increases with the preheating temperature. As the preheating temperature increases, the grinding force decreases slightly, while the surface roughness increases slightly. Compared to the traditional hardening process, both the depth of the hardening layer and the residual stress distribution were significantly improved.

(Wang, Ge, et al., 2017), studied about contact angle between work piece and grinding wheels by using different mathematical formulas and inserting The contact angle and the Peclet Number as input and studied an effect on PHSF (profile of the heat source on the finished surface) results with, At small contact angles, the PHSF is right triangular. Under the conditions of very low Peclet Numbers and large contact angles, the PHSF is triangular. Under the conditions of large contact angles and high Peclet Numbers, the PHSF is parabolic. (Deng

et al., 2017), carried out a study by using 45 steel and experimental method of DEFORM-3D with a single grain, effects of pre-stress on grinding force, pile-up deformation, and plastic deformation of the machined surface layer and output response variable of metallographic structure and surface micro-topography, results with The pre-stress cannot change the average of grinding force directly, but has effect on the plastic deformation and phase transformation by affecting stress-strain and temperature in PSHG, and consequently has effect on residual stress. Besides, when releasing pre-stress, core materials have elastic recovery which results in additional compressive residual stress on surface. The pre-stress affects surface roughness by affecting pile-up deformation, dislocation density and grain volume, and surface damages.

(Zhou et al., 2016) also investigated the surface integrity during the grinding process on an experimental stainless steel (DSS) 2304 material using the input variables using surface and substrate change using Chevalier FSG-2A618 grinding machine experimental methods. Under impact, it has the output response variables residual stress, microstructure, surface roughness, and surface defects. The results provide insight into the effect of abrasive grain size, abrasive strength and lubrication on surface integrity. The greatest effect was found to be the amount of abrasive roughness. The main causes of damage caused by grinding operations were found to be a superficial, highly deformed surface layer and the generation of tensile stresses in the grinding direction. This study is dominated by residual stresses caused by mechanical effects. (Yao et al., 2016) investigated the improved surface finish and minimum residual stress values of Inconel718 in surface grinding using SA (single alumina) and CBN (cubic boron nitride) wheels with variable input temperature and grinding force and grinding chips f and surface roughness and topographic response variables. It can be concluded that a better surface is obtained using SA and taking Inconel718 $p = 0.005$ mm, $v_w = 16$ m/min, $v_s = 25$ m/s for grinding. This grinding had a surface roughness of $Ra0.112$ μm , a surface residual stress of 700 Mpa, and a surface roughness of 440 HV; the depth of the residual stress layer was 40-60 μm , the depth of the softened layer was 30-40 μm , and the depth of the plastic deformation layer was 10-15 μm .

(Ewald Kohls et al., 2021), conducted a study on surface grinding hardness using Finite Element Method (FEM) and AISI 4140 STEEL as the research material and the input and output parameters are cutting speed, feed and depth of cut. and thermal loads at the surface and

below the surface. In addition, correlations between hardness change and the Hollomon-Jaffe parameter are established, taking into account both the absolute temperature and its variation with time. Moreover, surface residual stresses have been shown to correlate with maximum local surface temperature gradients in the absence of significant hardening of the microstructure. (Chaudhari et al., 2021) conducted a study on minimum phase change and microhardness variation of AISI D2 TOOL STEEL using non-destructive magnetic technique with parameters Depth of cut and wheel pitch rate and surface roughness, 2-D surface profile, microstructure and micro hardness, etc. output variables obtained The test results showed that minimal soil phase change and micro hardness variation were observed in UVADG compared to CDG mode due to the periodic shearing effect of the abrasive grains on the work. material that limits excessive heat penetration. Lower surface roughness was observed in UVADG mode, which is R_a : 0.118 μm and R_z : 0.671 μm , respectively. (Weijie et al., 2021) investigated the average error during simulation and experimental investigation using the thermo mechanical Fe model and the parameters dd6 single crystal nickel-based super alloy with parameters such as wheel speed, depth of cut and feed rate and the residual stress as the output variable, they obtained the average errors using the new model between simulation and test below 16% and 20% for grinding temperature and residual stress, respectively.

In addition, the grinding-induced residual stresses in the end regions of the blade root workpiece were generally compressive (eg, -150 to -100 MPa in the vertical grinding direction DD6 alloy crystal direction) and from -100 MPa. 200 up to -150 MPa in the parallel grinding direction DD6 alloy crystal orientation), while they gradually changed to tensile stresses in the adjacent valley regions (Vahid et al., 2022), lower flow rates are considered. SQCL compared to. flooded cooling system to grind 420 stainless steel using the most common bending electro polishing method and dry, flooded, and small-volume cooling lubrication (SQCL). was observed due to the significantly lower flow rate of SQCL compared to the flood cooling system, therefore compressive residual stresses were observed at depth below the surface.(FlaviaLerraa et al., 2022) conducted a compressive study on the development of the grinding process. from a simulation involving multi-grain grinding, real grain geometry, bonding effect and real workpiece grinding kinematics using finite element methods in 42CrMo4 grinding. and the input response variables are depth of cut and wheel speed in surface hardness.

2.5 Mathematical Modeling

A mathematical model using statistical method provides a better solution. Regression analysis is suitable to find the best combination of independent variables which is speed, feed rate, and the depth of cut in order to achieve desired surface roughness. Unfortunately, regression model is obtained from a statistical analysis which has to collect large sample of data.

A. Regression Analysis

After the surface roughness is obtained for all experiments, a table needs to be filled in order to obtain several values for the analysis. In order to obtain regression coefficient estimates β_0 , β_1 , β_2 , and β_3 , it is necessary to solve the given simultaneous system of linear equations.

B. Calculation of the coefficients of the regression model

This step deals with development of mathematical model. A mathematical model is the one which shows the relationship between the input and output variables. In the process model it relates the input process variables to the response variable of the process. Hence it is able to predict the response of the process for input variable considered. In many problems there are two or more variables that are related and it's important to model and explore this relationship. In general if there is a single dependent variable or response 'Y' which depends on 'K' independent variables such as $x_1, x_2, \dots, x_k$, the relationship between these variables are characterized by a mathematical model called regression equation. The regression model is obtained using a set of experimental data. In some instances the experimenter knows the exact form of true relationship between y and $x_1, x_2, \dots, x_k$ i.e.

$y = f(x_1, x_2, \dots, x_k)$ but in most cases the true functional relationship is unknown and the experimenter chooses an appropriate function.

The equation for Regression is

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \text{ Equation 2-1}$$

Where, Y represents the response, X_1, X_2, X_3 represents the coded values of process parameters and $\beta_0, \beta_1, \beta_2, \beta_3$ Represents the regression coefficient to be determined. In this work the input process variables are speed feed and depth of cut. The output response is

surface roughness. Hence the relationship between these inputs and response variable are to be found out by developing a regression based mathematical model. Hence X_1 , X_2 and X_3 represents coded values of speed, feed and depth of cut respectively. Y_1 – surface roughness. The coefficient such as β_0 , β_1 , β_2 , and β_3 , have to be determined for the development of regression based mathematical model. Once the model is formed, the coded values of the actual process variables have to be substituted in the equation to get the predicted response of the process. In this work the values of regression coefficient are calculated using software statistical analysis software that can be used to create statistical mathematical model.

2.6 Optimization of Cylindrical grinding Process Parameters

Cylindrical grinding is an important process in the final machining of components that require smooth surfaces and precise tolerances. The different process parameters of a cylindrical grinder are the depth of cut, the hardness of the material and the speed of the workpiece, the size of the grinder and the speed of the grinder. Design of experiments is the arrangement of an experiment so that the correct data can be evaluated using statistical methods, resulting in reliable and relevant results. The Taguchi technique of experimental design provides a simple, efficient and systematic way to select the best cutting settings while investigating the interaction between factors. By increasing the efficiency of generating the data needed to find parameters that guide responses, it can lower research and development costs. The Taguchi S/N ratio technique is used to investigate how grinding parameters affect surface roughness and material removal. The signal-to-noise ratio (S/N) is a measure of the quality of the detected data and indicates the value of the test result. The terms "signal" and "noise" refer to acceptable and undesirable values, respectively. Noise factors are uncontrollable factors due to which the functional characteristics of the product deviate from the desired values. These factors can be classified as external (e.g. weather conditions and human error), production defects (e.g. parameter differences between units) and product deterioration (wear and tear). The parameter works better in the presence of noise factors when the S/N ratio is high.

The process parameter level with the highest S/N ratio is therefore the ideal level. An important processing step that lowers processing costs and ensures the quality of the finished product is the optimization of working parameters. Black in the GRA represents areas with missing data, while white represents areas with all available information. A system whose

information falls between black and white is called a gray system. Gray's theory provides a convincing solution for any system with an uncertain model or incomplete data. In addition, it provides a feasible answer to ambiguous, multicomponent and discrete data problems. When there is less information, this is a useful tool for evaluating the relationships between components. Hall's system theory was first proposed by Deng in 1982 and proved useful in dealing with imprecise, insufficient, and ambiguous data. The complex relationships of many performance parameters can be effectively solved using gray relationship analysis based on gray system theory. The gray relationship score is obtained using gray relationship analysis to evaluate different aspects of performance. As a result, optimization of a single gray ratio class can replace complex optimization of multiple performance attributes.

The main objective of this study is to show how Taguchi's design of experiments and gray correlation analysis can be used to predict grinding behavior and achieve optimal operating process parameters (GRA). Stainless steel (SS 304) was chosen for the test because it has many applications in the automotive, aerospace and food industries. It is more machinable and has better strength properties. The most popular austenitic stainless steel is SS 304. It has good corrosion resistance and formability and is often called 18/8 stainless steel. An analytical model of surface roughness was tested in a Milan Rice rum 1 cylinder mill (I M Chandran et al, 2018).

An empirical equation linking many process elements was created to select the best machine settings to achieve the best surface finish. The Taguchi optimization method was used to determine the ideal transverse parameters of feed, hardness and speed. (Rekha et al., 2017) used the Taguchi technique and metaheuristic algorithms to predict the optimal grinding parameters that satisfy machine performance indicators. (Deepak Pal et al., 2019) conducted a study to predict the grinding behavior and find the optimal machine parameters. In this work, Taguchi optimization was used to reduce the surface roughness (Ra). EN 24, EN 31 and Dieteräs were used as workpiece materials in this test. The authors used an orthogonal L9 array in their study. In this work, work speed, grinding wheel characteristics and material hardness were used as input factors. MATLAB software was used for optimization processes. The best value of surface roughness was found to be 1.07 m (M. Janardhan et al., 2021) used the Taguchi technique and developed a model with regression analysis to predict and optimize

process parameters. The main objectives of this research were to reduce the surface roughness (Ra) and increase the metal removal rate (MRR).

The tests were performed with a CNC cylinder mill using the EN8 standard as the workpiece material. Empirical models were developed using regression analysis to explain the relationship between treatment variables and responses. An L9 orthogonal array was designed to perform the experiments. The input parameters of this research were longitudinal feed (mm/min), operating speed (rpm) and depth of cut. The concepts of S/N ratio and ANOVA were used to measure the effect of process factors. The optimized Ra and MRR values for the cylinder process were 0.816 μm and 62.05 g/min, respectively. Palanisamy, A. et al. studied EDM machining operations and applied GRA to predict the most appropriate machining variables that satisfy all responses. Machining is essential to achieve high dimensional tolerances and surface finish. Mechanical processing is divided into turning, grinding, drilling, grinding, etc. Grinding is an effective material removal method for hard materials that require high surface quality and precision. Grinding cylindrical work and removing metal in small chips is called cylindrical grinding. With the cylindrical grinding method, an excellent finish can be achieved with high precision and close dimensions. In the cylindrical grinding operation, the work is supported in both centers, after which the process is carried out with a grinder (Ramish, z. et al., 2017). Due to the complex installation and the high sensitivity of several kinematic, dynamic and geometric influencing parameters, center less grinding is rarely used in limited mass production. Finishing of components requiring a good surface finish and large tolerances requires cylindrical grinding. Grinding is an expensive process that must be used with ideal parameters compared to other machining techniques. Milling, despite its widespread use in industry, is probably the least understood of the machining operations. Process parameters such as machine speed, cross feed, feed rate and coolant are the main operating inputs that determine the output parameters, viz. surface roughness, metal removal rate, tool wear and surface damage, among others. Da Silva, A. et al., (2021).

2.7 Summary of Literature Review

Table 2-1 summary of literature

Authors	Material used	Experimental design technique	Input parameter	Output\ result	Finding of the study
Huang, X., et al. (2016)	AISI5140 steel	thermal compensation	grinding force, harden layer depth and surface quality	ground surface, surface roughness and micro-hardness	The experimental results show that a deep harden layer with a fine grain martensite can be obtained with the thermal compensation. The ground workpiece surface produces a certain compressive residual stress, and the residual compressive stress value increases with preheating temperature. As the preheating temperature increases, grinding force slightly decreases, while there is slightly increment of surface roughness.
Zhou, N., R. (2016).	stainless steel (DSS) 2304	Chevalier FSG-2A618 grinding machine	surface and sub-surface changes	Residual stress, the microstructure, surface roughness and surface defects.	The results provide insights into the effect of abrasive grit size, grinding force and lubrication on the surface integrity. The abrasive grit size was found to have the largest influence. Surface defects, a highly deformed surface layer and the generation of tensile residual stresses along the grinding direction have been found to be the main types of damage induced by the grinding operation. Residual stresses induced by mechanical effects dominate over thermal effects in this study.
Zhou, Nian; (2017).	stainless steel 304L	3D optical topometer (Wyko NT9100) was used	abrasive grit size, machine power, and grinding lubrication on the surface integrity	The induced normal grinding force, grinding surface temperature, metal removal rate, and surface property	Surface finish and deformation were found to be improved by using smaller abrasive grits or by using lubrication during grinding. Increasing the machine power increased surface deformation while reducing surface defects. The results obtained can provide a reference for choosing appropriate grinding parameters when machining 304L; and can also help to understand the failure mechanism of ground austenitic stainless steel components during service.
Ali Rajaei et al(2018)	steel AISI 52100	Finite Element Method	Thermo-mechanical and	temperature and microstructure	Experiments and simulations showed compressive stresses in the re-hardened Zone and tensile stresses in the tempered

		(FEM).	metallurgical changes	changes	area.
da Silva, L.R.,(2019)	AISI 4340 hardened steel	minimum quantity lubricant (MQL) technique	different cutting fluids	residual stress	The results showed that the type of cutting fluid influenced the surface integrity of the ground pieces. It was concluded that the results showed the use of the mix and MQL fluids as an alternative to the use of the integral and synthetic cutting fluids, thus contributing to an ecologically correct and sustainable manufacture.
Do DucTrung, et al. (2020)	AISI 1018 STEEL	Johnson-Cook's material model	cutting speed, the feed-rate and the cutting depth	residual stress	The results showed that the residual stress values when calculating were quite close to the values from experimental works. The average deviation between the calculated results and the experimental results is only about 15.96%. T
Shen, (2020)	C-250 naraging steel (3J33)	Finite element method	wheel speed, workspeed, grinding depth	Surface and subsurface Residual stresses	Results show that the surface residual stress and peak compressive residual stress depend greatly on the grinding speed and higher grinding speed generates larger compressive residual stress, while the depth of peak compressive residual stress varies slightly with the grinding parameters. The residual stress penetration depth increases with the increase of the grinding speed and grinding depth, and decreases with the increase of the workpiece speed.
Rabiey, Mohamad; (2020).	100Cr6	Finite element method	Feed speed Cutting speed Depth of cut	residual stresses in direction of feed and perpendicular to the feed direction	The investigation shows that the residual stresses not only depends on the grinding parameter and material removal rate but also depends on topography of the wheel for instant by structuring. With proper structuring, it is possible to decrease the tensile residual stress or eliminate it even by dry grinding.
Ewald (2021).	AISI 4140 STEEL	Finite element method (FEM).	Cutting speed, feed rate and depth of cut	thermal loads at the surface and subsurface	The results show that the hardness change during surface grinding correlates with the maximum temperature rate at given maximum temperatures. In addition, correlations between the hardness change and the Hollomon–Jaffe parameter are identified, taking into account both the absolute temperature and its evolution over time. Furthermore, it was shown that

					the surface residual stresses correlate with the maximum local temperature gradients at the surface if no detectable tempering of the microstructure takes place.
Weijie Kuang (2021).	nickle based super alloy	Thermal mechanical Fe model	Wheel speed, depth of cut and feed rate	Residual stresses.	By using the new model, the average errors between the simulation and experiment of less than 16 % and 20 % for the grinding temperature and residual stress were obtained, respectively. Moreover, the grinding-induced residual stresses in the peak regions of the blade root workpiece were generally compressive (e.g., from 150 to 100 MPa along the vertical grinding direction crystal orientation of DD6 alloy), and from 200 to 150 MPa along the parallel grinding direction crystal orientation of DD6 alloy), while they were transformed gradually to the tensile stresses in the adjacent valley regions.
(Pawan Kumar, 2018)	tools on EN24 steel	Response surface methodology	Grinding wheel speed, table speed & Depth of cut	surface roughness and material removal rate	From the multi-response optimization, the optimal combination 3. of parameter settings are wheel speed of 850RPM, Table speed of 15m/min and Depth of cut of 11.94μm for achieving the required maximum MRR and minimum surface roughness From the multi-response optimization, the optimal combination 3. of parameter settings are wheel speed of 850RPM, Table speed of 15m/min and Depth of cut of 11.94μm for achieving the required maximum MRR and minimum surface roughness

2.8 Research Gap

The literature shows that process parameters such as cross feed, workpiece speed, wheel speed and depth of cut significantly affect the surface roughness, residual stress and production cost in the grinding process under different cutting conditions. Temperature, in turn, affects the finish of the workpiece and the life of the tool. To the best of the authors' knowledge, there is

no research on cylindrical grinding of AISI 440 steel to evaluate, compare and optimize contact temperature, residual stress and machining costs under dry and wet machining conditions. Again, the result obtained from the experiment and the result obtained from LS DYNA is not optimized, and the combination of RSM methodology and parameter optimization of the full factorial treatment is rare in the field. This study investigates the machinability of high carbon steel AISI 440. Carbon steel is alloyed with one or more alloying elements such as manganese, silicon, nickel, titanium, copper, chromium and aluminum to produce alloy steels.

These metals are added to provide properties not seen in ordinary carbon steel. Excellent durability, ductility and wear resistance under quenched and tempered conditions are desirable properties of AISI 440. Therefore, it has many applications in the field of technology. Therefore, in this research, the researcher optimizes the surface roughness and residual stress by grinding the surface of AISI 440 steel using the response surface methodology. Based on the above literature survey and Table 2.1, it can be said that the optimization of cylindrical grinding process parameters of AISI 440 steel by the method based on combined surface methodology (RSM) and Ls Dyna simulation for dry state is rarely studied. . The novelty of this work therefore lies in the investigation of parametric grinding optimization with response surface methodology (RSM) simulation using AISI 440 steel cylindrical grinding ls dyna. This work tries to fill the gap in these studies. Therefore, this study aims to add a new contribution;

- Reduce problems associated with dry grinding AISI 440 steel with CNC cylinder grinding
- Give industrial and process engineers the freedom to choose optimal values according to the desired output.

CHAPTER THREE

3. Materials and Methodology

3.1 Introduction

Investigational study was conducted to optimize cutting parameters in order to give best values of surface quality, and compressive residual stress simultaneously during cylindrical grinding of AISI 440 by using aluminium oxide wheel grinding. This chapter presents the details of the experimental procedures and property of material used for the study.

3.2 Experiment Procedure

In this research work experimental investigation was conducted according to research design prepared by using Response Surface Methodology. The general procedure of experimental investigation is presented in Fig.3.1 Input process parameters of the work piece material and cutting tool which are located and clamped into a corresponding tool holder.

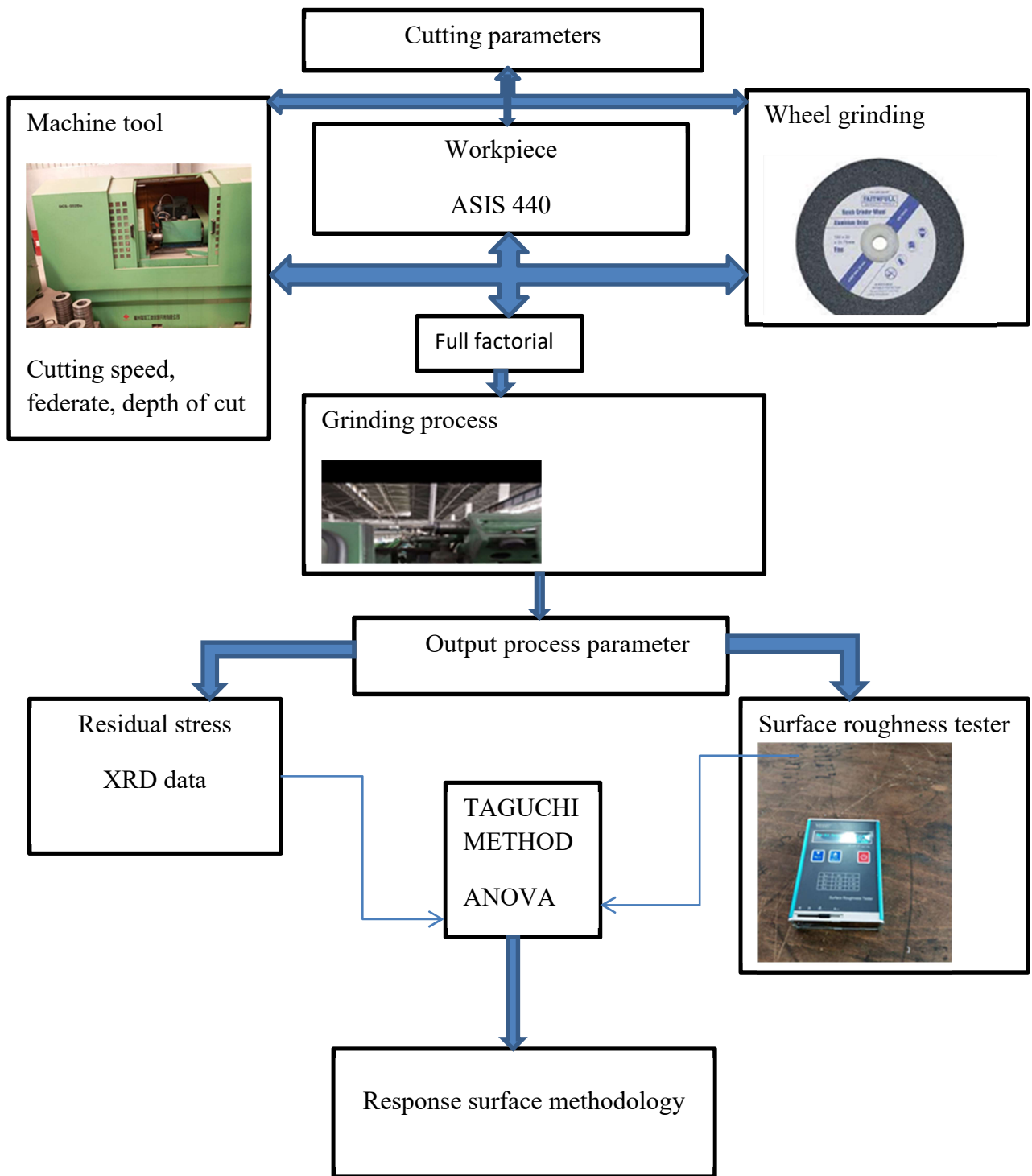


Figure 3-1 Schematic diagrams of experimental procedures

3.3 Machine and Equipment

This sub-topic describes the materials and machine tools used for the experimental investigation in the cylindrical grinding of AISI 440 steel under dry conditions.

3.3.1 Work-piece Material

The work-piece material employed for this experiment was AISI 440 Martensitic stainless steels have higher carbon and lower nickel. This type of steel is applied in construction of bearings, nozzles, aircrafts, and wear parts of pumps, mold inserts, and surgical tools and also used as knife blades. They can be hardened by conventional quenching and tempering like tool steels or higher carbon alloy steels. 410 can be machined as well as hot or cold formed, but the high carbon 440 grades can only be hot formed. Machining and cold forming are not viable options for 440 grades. AISI 440 used for grinding operations have diameter of 35mm and for each run 30 mm of length is allotted, machining was conducted at dry machining condition. The chemical compositions of AISI 440 was tested using spectrometry Figure 3.3 which is known as Oxford Instruments PMI-MASTER Smart the result is outlined in the following Table 3.1, and mechanical and physical properties of AISI 440 is given in Table 3.2

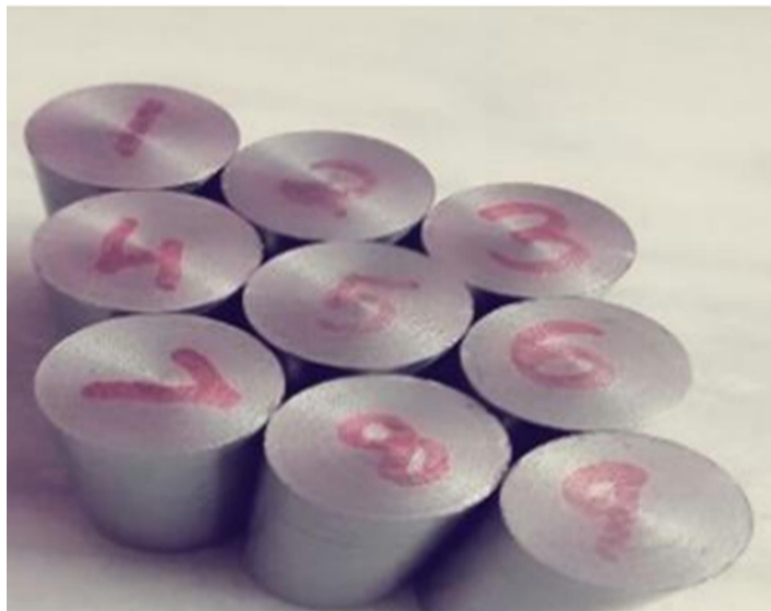


Figure 3-2 work-piece of material used in grinding



Figure 3-3 spectroscopy used to identify chemical composition

Table 3-1 chemical composition of AISI 440C

Contents		C	Mn	Si	P	S	Cr	Mo
Weight %	Min	0.95	-	-	-	-	16	-
	max	1.20	1	1	0.04	0.03	18	0.75

Table 3-2 mechanical and physical properties of AISI 440c

Tensile strength (Mpa)		1965
Yield strength (Mpa)		1895
Elongation in 50mm %		15
Density (cm ³)		7.8
Young modules (Gpa)		200
Ultimate tensile strength (Mpa)		760
Hardness	HB(Mpa)	2700
	Rc	58-60

3.1.2 Cutting Tool Materials

Grinding wheels are composed of thousands of small hard abrasive grains held together by a bonding material. Each abrasive grain has potential cutting edges. The main parameters used to describe a grinding wheel are the abrasive type, the abrasive grain size, the wheel hardness (grade), the wheel structure, and the bond type. These parameters define the wheel marking system. There are three types of abrasive wheel types such as; aluminum oxide which is mostly used for cutting steel, cubic boron nitride and diamond used for grinding harder steel and supper alloy and silicon carbide which is mostly used for grinding non-ferrous metal and cast iron. For this research grinding wheel in this experiment will alumina oxide vitrified. This grinding wheel (FE 38A100L5V) is uses in accordance with the machining circumstances and Manufacture's exhortations. Grade: L, indicating medium, i.e., neither soft nor hard.

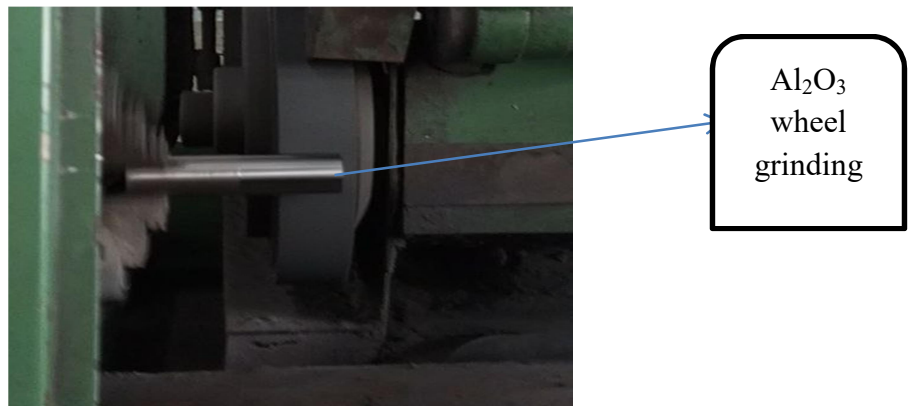


Figure 3-4 Wheel Grinding used in Grinding

3.3.3 Grinding Machine

Grinding machines are also regarded as machine tools. The distinguishing feature of grinding machines is the rotating abrasive tool grinding machine is employed to obtain high accuracy along with very high class of surface finish on the workpiece. there is many types of grinding machines are there such as: surface grinding machine, cylindrical grinding machine, internal grinding machine, tool and cutter grinding machine however there is two major classification of grinding. Namely convectional and non-convectional grinding machine a convectional grinding machine requires the operator to control the motion of the cutting tool during the grinding operation. Non-convectional also called cnc machines. Typically come with computer-aided manufacturing (CAM) and computer-aided design (CAD) programs. These

programs are essentially computer codes used to command cnc machine to perform certain tasks. a computer programmer writes and alters the code required to run various machining tasks.

This experimental investigation was conducted on DCS_002Da CNC cylindrical grinding which have capacity to grind workpiece having maximum length of 320mm, 500RPM 7.5 Kw spindle motor. CNC cylindrical used for grinding process is shown on Figure 3.5

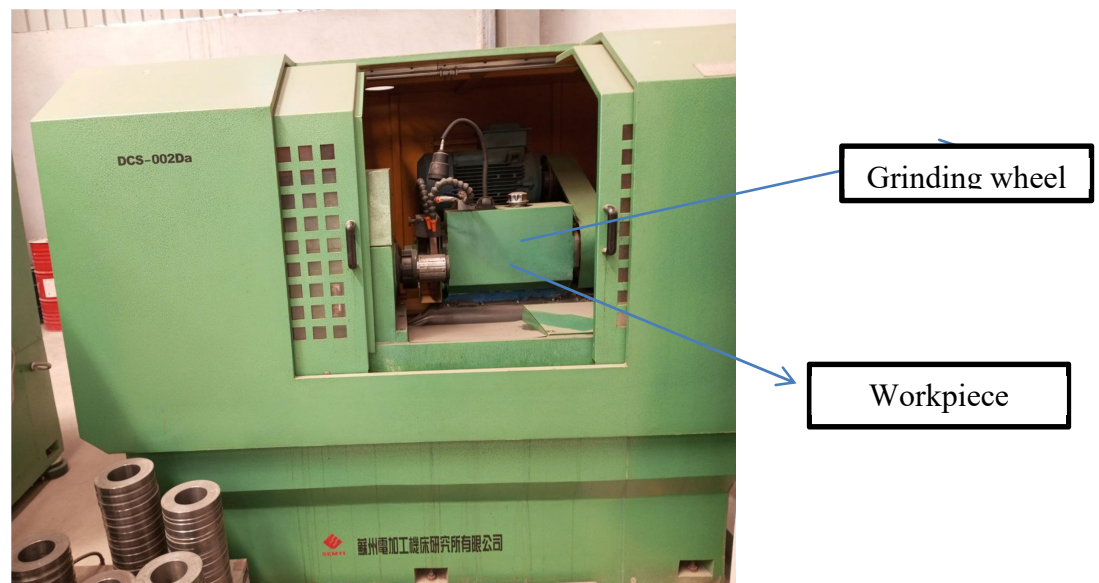


Figure 3-5 DCS-002 Da CNC cylindrical grinding

3.3.4 Surface Roughness Measurement

Surface roughness was measured by surface contact profilometer roughness tester known as VOGEL Surface Roughness Tester with 65711 models which is digital surface roughness tester as shown in Figure 3.6 This surface roughness tester displays roughness value in micro meter (μm). The measuring range of VOGEL Surface Roughness Tester 65711 is $0.02\mu\text{m}$ to $10\mu\text{m}$. A stylus attached to the detector unit of tester will trace the minute irregularities of work-piece surface. The vertical stylus displacement during the trace is processed and digitally displayed on the liquid crystal display of instrument.



Figure 3-6 Surface Roughness Testing Equipment

3.3.5 Measurement of workpiece Temperature

In order to measure and analyze the relationship between cutting parameters, workpiece and temperature, an infrared thermometer was used to measure the temperature of the workpiece. The temperature of the cutting area was measured during the machining time of each step. The working principle of an infrared thermometer is that it measures the surface temperature of an object. The optics of the device detect the radiated, reflected and transmitted energy, which is collected and focused on a detector. The device's electronics convert the data into a temperature reading that is displayed on the device. In laser devices, the laser is used only for orientation. Holding the meter by the handle and pointing it at the surface to be measured. To start the meter, grab and hold the trigger and it will be tested. As you continue to press the trigger, the laser pointer focuses on the cutting area. Release the trigger and handle; A screen will appear on the LCD to indicate that the reading is being held. We can choose 0C and 0F as temperature units. An infrared thermometer used to measure temperature is shown in figure 3.7 below;



Figure 3-7 Infrared Thermometer

3.3.6 XRD

There is no direct method available to measure stresses: they are calculated or derived from a measured quantity such as elastic strain or displacement. Residual Stress Measured by X-ray Diffraction. X-ray diffraction (XRD) is a well-established and accurate method to investigate the residual stress levels on the surface layers of crystalline materials. XRD measurement is useful for stress analysis when the following conditions are met:

- ☐ Material must have a crystalline structure
- ☐ Material should have small grains
- ☐ Material elastic constant needs to be known

Non-destructive measurement depth for steel and aluminium is few to tens of micrometers below the surface. The XRD machine used to calculate residual is XRD-700 X-RAY DIFFRACTOMETER (Shimadzu corporation ,japan).the detail for X-ray result basic data processing(BP) gives the most intensive peak information in terms of angular position (2θ), interplanar spacing(d), intensity(I) and full width half maximum (FWHM).

Step used while of calculating residual stress

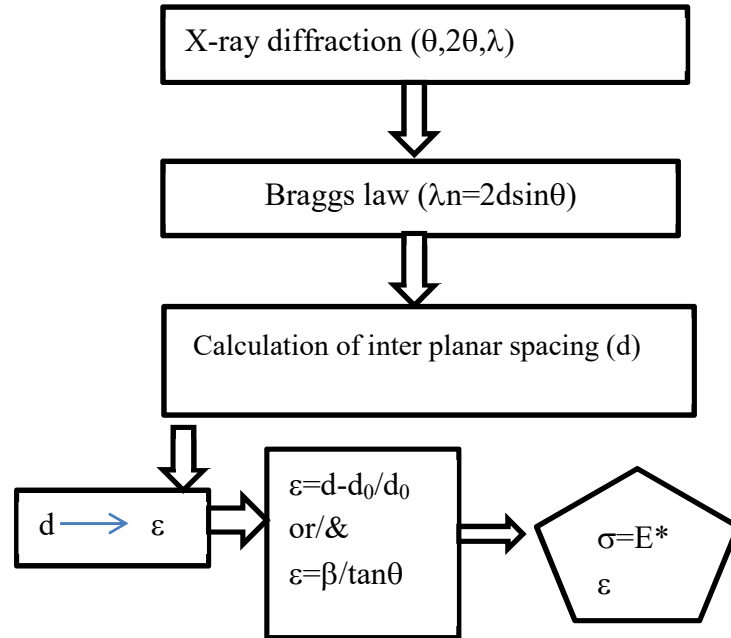


Figure 3-8 flow chart of residual stress



Figure 3-9 XRD machine XRD-700 X-RAY diffraction

3.4 Selection of Process Parameter

In grinding operation, the important task is to select cutting parameters for achieving high finishing performance. For experimentation purpose, cutting parameters for given workpiece steel will be selected depending on knowledge found from the literature, according to the recommendations of tool manufacturer, manufacturer's handbook recommended for the tested material, current industrial practice, and experience. The following table shows process parameters with material hardness used by different researchers.

Table 3-3 Process parameters selected by various researchers

Researcher	Material	Grinding wheel	Process parameter			Method
			Workpiece Speed	Feed rate	Depth of cut	
Taifa, I. W. R. et al. (2019).	EN45 steel	Aluminum oxide	270	0.02	0.025	Taguchi method
Sallem& Hamdi, (2015)	High alloy speed steel	CBN	600	0.03	0.08	FEM
Trauth, D., & Bergs,et al. (2018)	AISI 52100	CBN	700	0.25	0.04	FEM
Deshpande, V., & Taifa, et al. (2019)	EN45	Aluminum oxide	270	0.1	0.025	Taguchi
Do Duc Trung,,et al. (2020)	AISI 4140	Aluminum oxide	550	0.20	0.08	RSM
Shen, (2020)	AISI 440	Aluminum oxide	400	0.12	0.04	RSM
Rabiey, Mohammad; (2020).	AISI 4118	Aluminum oxide	850	0.085	0.6	Taguchi

Considering all above-mentioned factors, the following cutting parameter was employed for an experiment. The selected cutting parameters were shown in Table 3. 4.

Table 3-4 Levels of parameters and their range used for an experiment

Variable	Levels		
	Level I	Level II	Level III
Workpiece Speed (V_w) Rpm	550	850	1100
Feed rate (f) mm/min	0.075	0.095	0.12
Depth Of Cutting (D) mm	0.02	0.03	0.04

3.5 Research Methodology

Response surface Methodology was used to prepare design matrix and regression models. The steps involved in RSM techniques are as follows:

Designing a set of experiments for adequate and reliable measurement of the true mean response of interest

Following the performed experimental investigations, statistical processing, i.e. regression modeling, was developed for obtained results.

After obtaining regression equations, transformation and reduction were performed in order to obtain models with a high coefficient of determination to predict the measured responses (output process parameters) residual stress and surface roughness (Ra).

Analysis of variance (ANOVA) was performed, as well as diagnostics and adequacy checking of regression models.

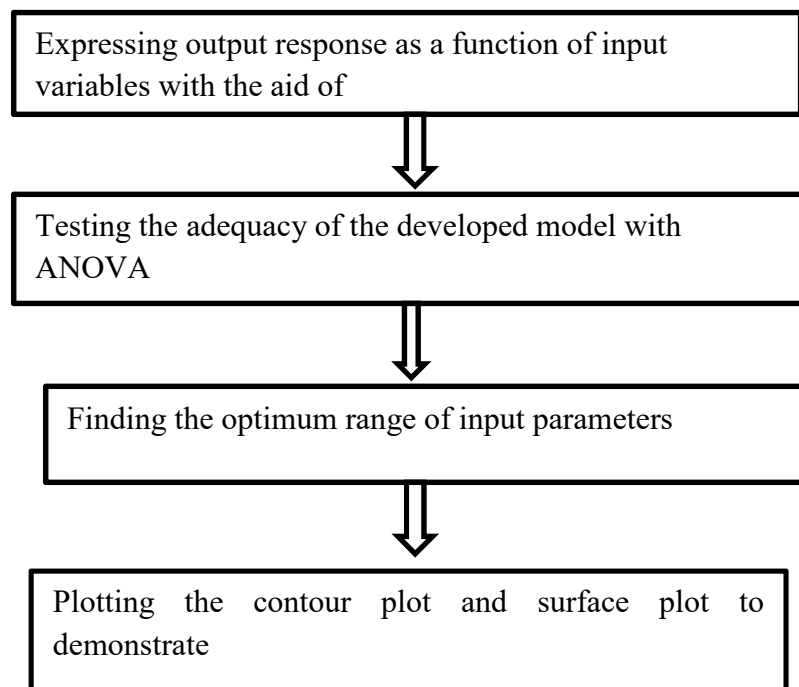


Figure 3-10 Flowchart of RSM

3.6 Design of Experiment

The design of experiments (DoE) technique is a very powerful tool, which permits us to carry out the modeling and analysis of the influence of process variables on the response variables. The response variable is an unknown function of the process variables, which are known as design factors or independent variables. In a grinding operation, there are many factors that can be considered as the machining parameters. But, the review of literature shows that the depth of cut (d , mm), workpiece speed (V , rpm) and feed rate (f mm/min) are the most widespread machining parameters taken by the researchers. In this research study these were selected as design factors while other parameters have been assumed to be constant over the experimental domain. These designs are rotatable (or near rotatable) and require 3 levels of each factor.

Experiments have been carried out according to the experimental plan based on full factorial. Experimental design matrix consisting of experiment runorder and coded values of the process parameters is shown in Table 3.5.

Table 3-5 Design Matrix

Run	Workpiece speed (V_w)(Rpm)	Feed rate (f)(mm/min)	Depth of cutting (d)(mm)
1	550	0.075	0.02
2	550	0.095	0.03
3	550	0.12	0.04
4	850	0.075	0.03
5	850	0.095	0.04
6	850	0.12	0.02
7	1100	0.075	0.04
8	1100	0.095	0.03
9	1100	0.12	0.02

3.6.1 Analysis of variance (ANOVA)

The purpose of the analysis of variance (ANOVA) was to find out which parameters significantly influence the quality characteristic. ANOVA is a statistical method used to find out the effect of all control parameters. Analysis of variance used the percentage of each control factor to measure the respective effects on performance characteristics. This analysis considered a 5% significance level, ie. 95% confidence level. ANOVA results indicate

whether or not differences in outcome measures are statistically significant. ANOVA analysis includes when values below 0.05 are significant and values above 0.05 are not significant. The percentage measures the percentage of each model member of the total sum of squares. A percentage is often a rough but effective guide to the relative importance of each model term.

The percentage of each influencing parameter was calculated based on analysis of variance. Each term used in the ANOVA table has been explained here Block: The block row shows how many response variations are assigned to the blocks. The block variation is removed from the analysis. Blocks are not tested (no F- or p-value) because they are considered an irreproducible and difficult to modify factor. Model: The model line shows how much variation in the response is explained by the model, along with the overall model significance test.

Terms: The model is divided into individual terms and tested independently. Residual: The residual row shows how much variation in the response is still unexplained.

Cor Total: This row shows the amount of variation around the mean of the observations.

Sum of Squares: The sum of the squared differences between the overall mean and the amount of variation explained by its line source.

df: degrees of freedom: the number of estimated parameters used to calculate the original sum of squares. Root Mean Square: Sum of squares divided by degrees of freedom. Also called dispersion.

F-value: A test to compare the baseline mean square with the residual mean square. Probability > F: (p-value) The probability of seeing an observed F-value if the null hypothesis is true (no factor effects). Small probability values require rejection of the null hypothesis.

The probability is equal to the integral under the curve of the F-distribution beyond the observed **F-value**. ie, if the Prob>F value is very small (by default below 0.05), the source tested significant results. Important model terms are likely to have a real effect on the answer. A significant lack of fit indicates that the model does not fit the observed replication data.

Mean: sum of squares for average effect. The "df" column gives the degrees of freedom for each source. In response surface methodology, the total number of degrees of freedom is equal to the number of model coefficients added row by row.

Mixture model: Let q be the number of components in the mixture. The degrees of freedom for the linear terms in the mixed model are $(q-1)$, not q , because the sums of squares are mean-corrected.

3.6.2 Response Surface Methodology

In Response Surface Methodology, regression analysis is used to identify relationships between responses and variables based on test responses to create a mathematical model that satisfies the relationship between a group of test factors and objective functions. This model is then used to investigate the optimal solution in the test region. Response surface methodology (RSM) is a set of mathematical and statistical techniques for building empirical models. Through careful design of experiments, the goal is to optimize a response (output variable) that is affected by a number of independent variables (input variables). An experiment is a series of tests, called runs, in which input variables are varied to identify the causes of changes in the output response. Response surface modeling techniques were originally developed to analyze experimental data and generate empirical models from observed response values. A particular strength of RSM is its suitability for studies with few observations, as physical examination is both very expensive and very time-consuming.

The main steps of Response Surface Methodology are

1. Determination of coating factors affecting surface roughness, Metal removal.
2. Developing an experimental design matrix, conducting experiments according to the above design matrix.
3. Development of a mathematical model.
4. Determining the standard coefficients of the developed model.
5. Testing significance of coefficients.
6. Test of appropriateness of the developed model with analysis of variance (ANOVA).

3.6.3 Model Prepared For Numerical Simulations

The dimensions and part name of the external cylindrical grinding system set ups are shown with table below and the model has been prepared.

Table 3-6 LS Dyna set ups

Sn	Names Of Model Parts	Dimension(mm)
1	Workpieces	Ø35X30
2	Bearings	Ø250X34
3	Workpieces mounting	Ø35X30
4	Grinding wheel	Ø250X50

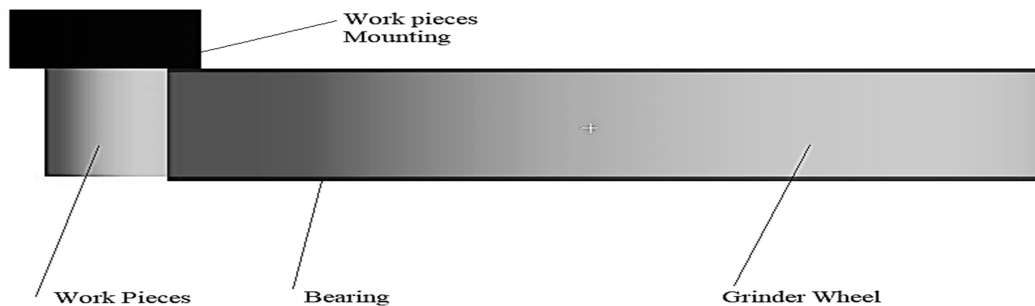


Figure 3-11 2D element model

3.6.4 Grid Convergec idex analysis

In order to minimize the numerical results error the final grid test that used on all aalysis of case studys are displayed with figure below. Fine meshed element model.

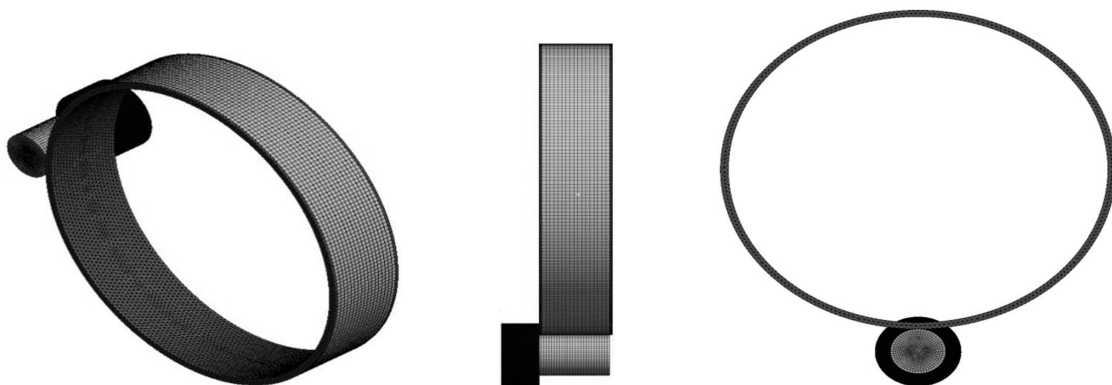


Figure 3-12 3D Element model

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

4.1 Introduction

Experimental work was conducted to evaluate the effect of grinding process parameter (work piece speed, feed rate, and depth of cut) on the surface roughness, material removal rate and residual stress by using aluminum oxide wheel. The experiment was carried out on DCS-002-Da cylindrical grinding Machine. Nine experiments were performed to identify the optimum condition. During and after machining operation, measurements were taken for each of the end responses, statistical analysis was made to get the optimum parameters according to the requirements and the main effects were identified. The values of responses that are conducted by full factorial design of experiments were analyzed using ANOVA. Statistical work was performed using Design Expert Version 13.

The results of each experiment were discussed in this chapter. The experiment was conducted in a controlled environment to minimize errors. The design of the experiment was used to identify the optimum cutting parameters and to identify the most influential parameters. Data analysis and regression model developing in Analysis of Variance was conducted on design expert version 13. This section presented the details of the result and discussion used for the study.

4.1.1 Result Values Obtained from Cylindrical Grinding Experiment

Data collection plays a significant role in the statistical analysis of any field, as it decides the progression of the analysis to the best or worst. A proper and suitable data collection leads to better results from the analysis. In such a focus, it is very much essential to choose a well suitable data collection technique for the analysis. The results values for each experiment in the grinding of stainless-steel 440 in Table 4-1.

Table 4-1 Experimental Results

Run	Factor 1 A:workpiece speed Rpm	Factor 2 B:Feed Rate mm/sec	Factor 3 C:depth of cutting Mm	Response Temperature C ⁰	Response Ra μm
1	550	1.25	0.02	47.20	0.4707
2	550	1.5833	0.03	45.592	0.4288
3	550	2	0.04	50.598	0.3441
4	850	1.25	0.02	58.118	0.4821
5	850	1.5833	0.04	63.52	0.4399
6	850	2	0.03	57.796	0.3555
7	1100	1.25	0.04	56.541	0.5049
8	1100	1.5833	0.03	58.86	0.4627
9	1100	2	0.02	60.929	0.3783

4.2 Surface roughness analysis and discussion

4.2.1 Statistical Analysis

4.2.1.1 Fit Summary

Fit Summary is program tool that helped to start regression calculation in order to fit all the polynomial models to the selected response. The program calculated the effects, for all model terms and produced statistics such as p-values, Predicted and adjusted R-squared values for comparing the models. This tool collected the important statistics used to select the correct starting point for the final model fitting and suggested model.

For table 4.3 the fit summary table linear model were selected in order to express the relationship between dependent variable (surface roughness) and independent variables (work-piece speed, feed rate and depth of cut) but quadratic model were considered as aliased since white comb score where lower when compared to 2FI and linear model.

Figure 4-1 Fit summary

Source	Sequential p-value	Lack of Fit p-value	Adjusted R ²	Predicted R ²	
Linear	< 0.0001		0.9936	0.9873	Suggested
2FI	0.9370		0.9866	0.9173	
Quadratic					Aliased

From, Table 4-3 and Table 4-4 indicated linear vs mean model was suggested while 2FI and quadratic model was aliased i.e., it is the highest order model that explains significantly more of the variation in the response (p-value small), insignificant lack of fit (p-value > 0.10) and reasonable agreement between Adjusted R-squared and Predicted R-squared (within 0.2 of each other). The predicted R-squared for the selected case having (0.9960) which was the higher from other models this indicates how well a regression model predicts responses for new observations. This statistic helps us to determine when the model fits the original data but is less capable of providing valid predictions for new observation.

Table 4-2 Sequential Model Sum of Squares

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	1.66	1	1.66			
Linear vs Mean	0.0266	3	0.0089	417.82	< 0.0001	Suggested
2FI vs Linear	0.0000	3	5.612E-06	0.1255	0.9370	
Quadratic vs 2FI	0.0001	2	0.0000			Aliased
Residual	0.0000	0				
Total	1.69	9	0.1876			

Table 4-3 Model summary statistics

Source	Std. Dev.	R ²	Adjusted R ²	Predicted R ²	PRESS	
Linear	0.0046	0.9960	0.9936	0.9873	0.0003	Suggested
2FI	0.0067	0.9967	0.9866	0.9173	0.0022	
Quadratic					*	Aliased

4.2.1.2 Analysis of Variance for Surface Roughness

The ANOVA is where the descriptive statistics and statistical tests are presented. In general, look for low p-values to identify important terms in the model. From the Analysis of Variance for surface roughness in Table 4-5 The Model F-value of 417.82 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B is significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The Predicted R^2 of 0.9873 is in reasonable agreement with the Adjusted R^2 of 0.9936; i.e. the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 52.125 indicates an adequate signal. This model can be used to navigate the design space. From ANOVA table two input parameters namely feed rate and work piece speed have a significant effect on surface roughness with contribution percentage of 73.13% and 5.59% respectively, but the third input parameter depth of cut were not significant on surface roughness. Since the model term was linear for prediction purpose, no interaction terms were not considered.

Table 4-4 Analysis of Variance for Surface Roughness

Source	Sum of Squares	df	Mean Square	F-value	p-value		%contribution
Model	0.0266	3	0.0089	417.82	< 0.0001	significant	
A-workpiece speed	0.0015	1	0.0015	68.86	0.0004		5.59%
B-Feed Rate	0.0196	1	0.0196	920.43	< 0.0001		73.13%
C-depth of cut	6.269E-08	1	6.269E-08	0.0029	0.9588		
Residual	0.0001	5	0.0000				
Cor Total	0.0268	8					

Table 4-5 Fit statistics

Std. Dev.	0.0046	R²	0.9960
Mean	0.4297	Adjusted R²	0.9936
C.V. %	1.07	Predicted R²	0.9873
		Adeq Precision	52.1254

4.2.2 Regression Model for Surface Roughness

This model used to determine the statistical relationship between cylindrical grinding input parameters and surface roughness. The change process parameters associated with the change in the surface roughness was ascertained by using this model.

Regression Equation

$$Ra = 0.4221 + 0.0168 A - 0.0633 B + 0.0001C$$

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

4.2.2.1 Parametric Influence on Surface Roughness

The graph of Normal Probability plot versus internally residual on figure below a showed that the residuals follow a normal distribution, thus follow straight line. And the graph of Residuals vs. Predicted on figure 4.2 b which is a plot of the residuals versus the ascending predicted response values used to test assumption of constant variance and the plot showed a random scatter or constant range of residuals across the graph that indicates there is no need for a transformation. So, the model is suitable to conduct analysis on effect of individual parameters on surface roughness.

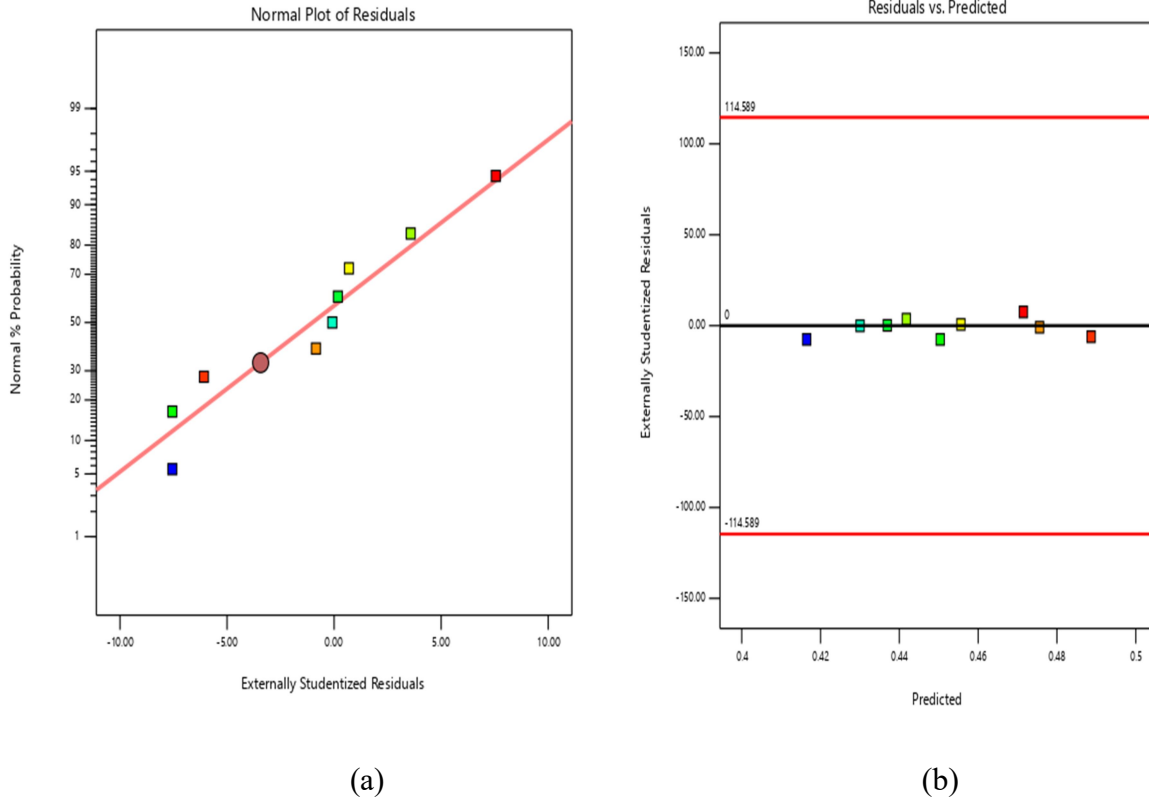


Figure 4-2 (a) Normal plot of residuals (b) Residuals vs. Predicted

4.2.2.1 Effect of Feed Rate and work piece speed on Surface Roughness

Effect of feed rate on surface roughness is shown on Figure 4.3; it was observed that as feed rate have significant effects on surface roughness with the increase the work piece speed values. The best surface quality is achieved at smallest feed rate of 1.25 mm/s and worst surface quality is found at highest feed rate which is 2mm/s. It was observed from study and from ANOVA feed rate is significant factor affecting surface roughness. ANOVA was employed to recognize the level of significance of the machining parameters on the performance characteristics of surface roughness (SR). They found that feed rate was the most affecting parameter on surface roughness followed by work piece speed. Figure 4-3 shows 3D Surface projection of the contour plot graph for Interaction effects of feed rate and work piece speed. Regarding the effect of cutting speed on surface roughness, the latter decreased with higher values of cutting speed Huang et al. (2015). The main reason for this can be that at higher cutting speeds the temperature increases because the material removal is more violent, producing the phenomenon of softening that improves the cutting process and thus diminishes

superficial roughness Zhou et al. (2017). Moreover, when the grinding is performed at a low speed, a subsurface material fracture occurs, which contributes to increasing surface roughness; by increasing the cutting speed this effect disappears Wang, Sun, et al. (2017). Surface roughness increased when depth of cut (d) and feed rate (f) increase, while decreases with higher cutting speeds (V_c). Furthermore, cutting speed contributes 65.59%, feed rate 73.13% and depth of cut 0.52 % to surface roughness.

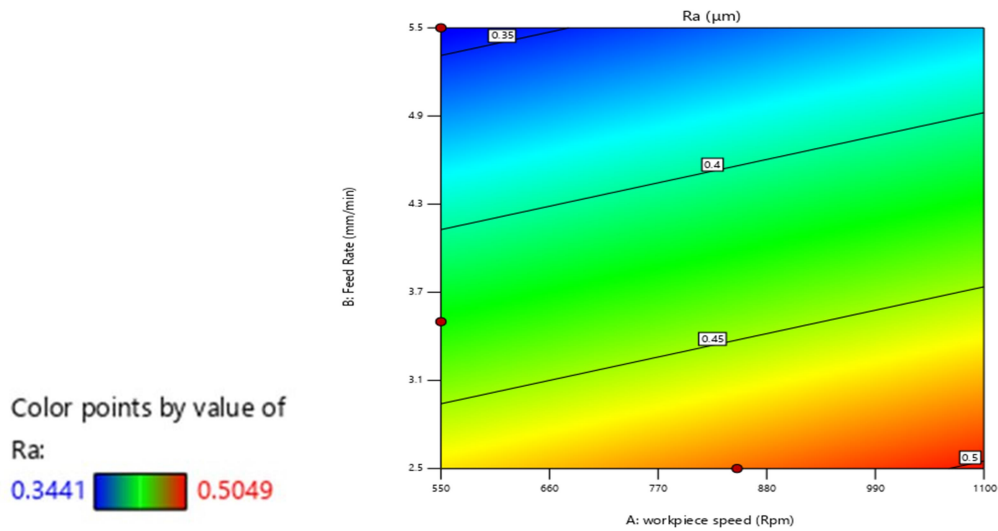


Figure 4-3 Contour Plot of R_a vs. feed rate and work-piece speed

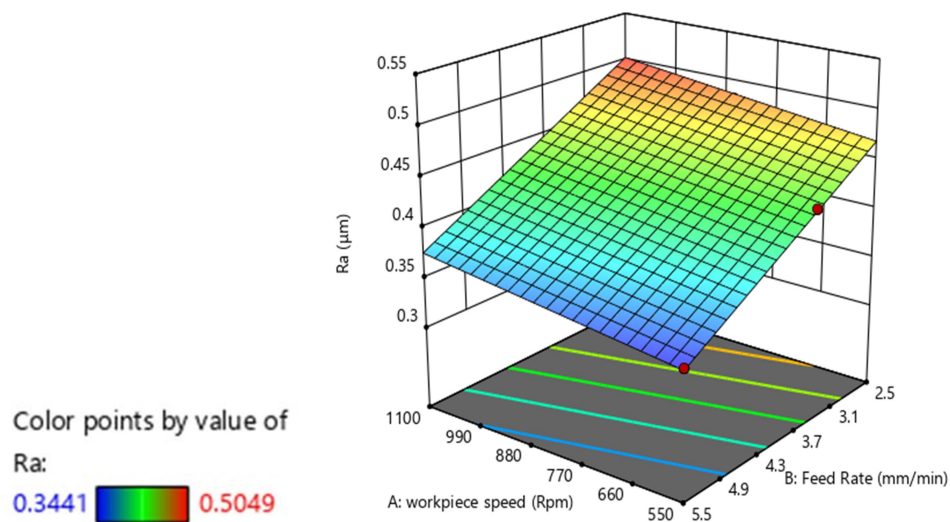


Figure 4-4 Surface Plot of R_a vs feed rate, work-piece speed

4.3 Response Optimization: Ra

Optimization process was carried on the Design expert version 13. After the grinding of stainless steel 440C using cylindrical grinding, optimization of input parameters were carried out in order to get optimum combined value of surface roughness. Here in this study surface roughness was minimization problem in below optimizations of Ra using response surface methodology. The goal of optimization of the response was minimization problem. The target value 0.3441 and upper value where 0.5049 weight 1 and importance 1 from the given input parameters. By carrying out response optimization process from response surface methodology there observed that Ra of 0.343285 μ m when the material grinded at 550Rpm, 2mm/min and depth of cut was 0.02mm.

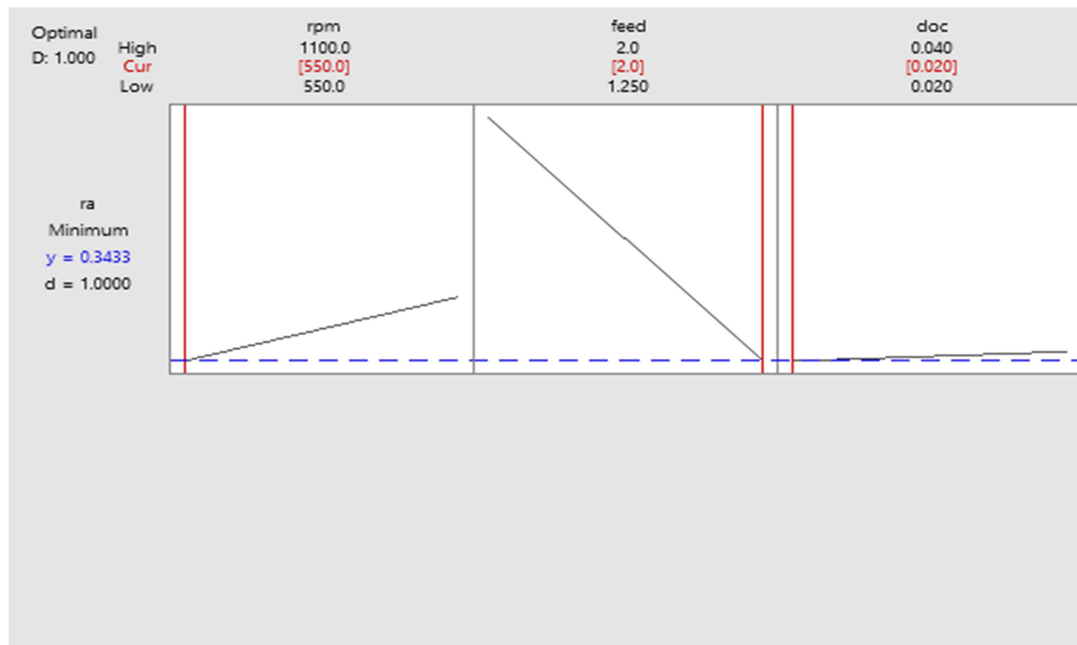


Figure 4-5 Optimization Graph

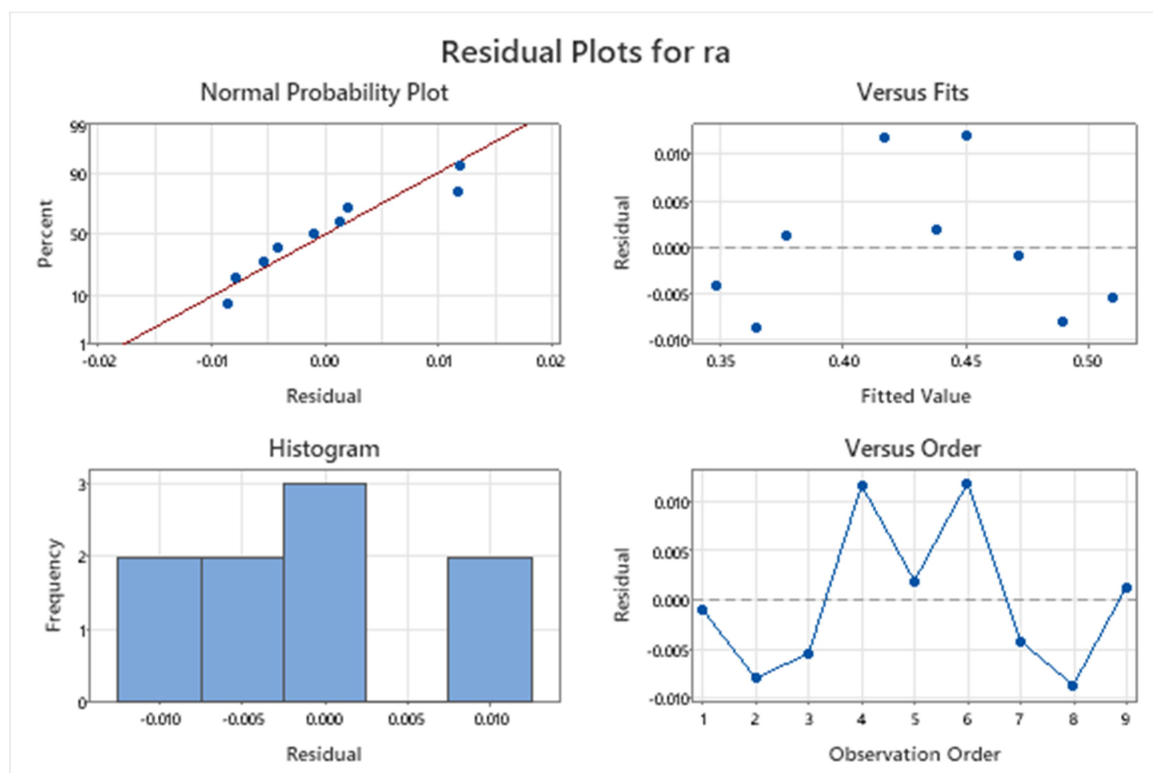
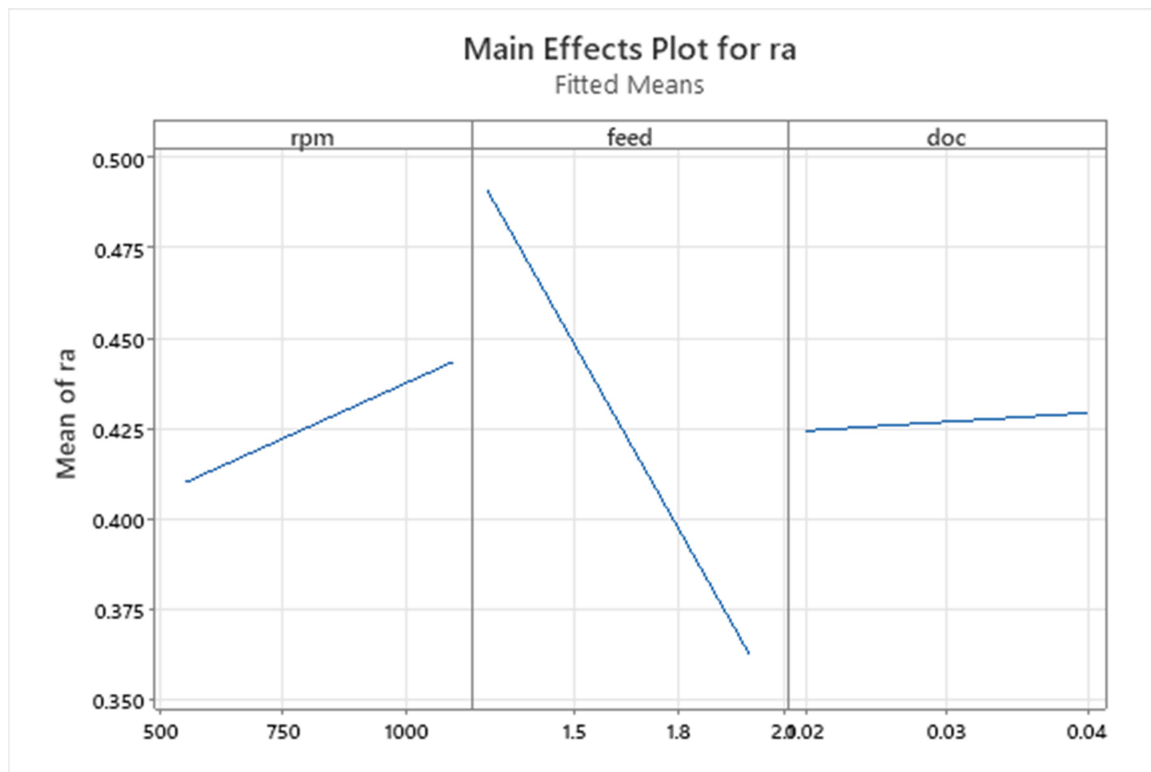


Figure 4-6 Residual and Main effect Plot

4.4 Development of Mathematical Model for Grinding Process Parameters of Ra

Regression analysis combines mathematical and statistical techniques for empirical model building. A model of the response to certain independent input variables can be obtained by conducting experiments and applying regression analysis, The mathematical models commonly

used are represented by,

$$Y = \Phi (V_w, f \text{ and } d) \pm er,$$

Where Y is the grinding responses, Φ is the response function and V_w , f and d are machining independent variables and er are the error. It also confirms that this model provides an excellent explanation of the relationship between the Independent factors and the responses. The second order response surface representing the surface roughness can be expressed as a function of machining parameters V_w , f and d The relationship between the response and machining

parameters has been expressed based on equation as follows

$$Ra = 0.4221 + 0.0168 A - 0.0633 B + 0.0001C$$

Table 4-6 Coefficients in Terms of Coded Factors for Ra

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	0.1118	1	0.1465	-0.2648	0.4884	
A-workpiece speed	0.0168	1	0.0040	0.0067	0.0270	1.0000
B-Feed Rate	-0.2568	1	0.0160	-0.2978	-0.2157	1.02
C-depth of cut	0.0495	1	0.0800	-0.1562	0.2552	1.02

The coefficient estimate represents the expected change in response per unit change in factor value when all remaining factors are held constant. The intercept in an orthogonal design is the overall average response of all the runs. The coefficients are adjustments around that average

based on the factor settings. When the factors are orthogonal the VIFs are 1; VIFs greater than 1 indicate multi-colinearity, the higher the VIF the more severe the correlation of factors. As a rough rule, VIFs less than 10 are tolerable.

Final Equation in Terms of Coded Factors for Ra

$$Ra = +0.1118 + 0.0168A - 0.2568B + 0.0495C$$

Equation 4-1

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Final Equation in Terms of Actual Factors

$$Ra = 0.647012 + 0.064 V - 0.171168f + 0.0247506d$$

Equation 4-2

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space.

4.5 Simulation Result From Ls-Dyna

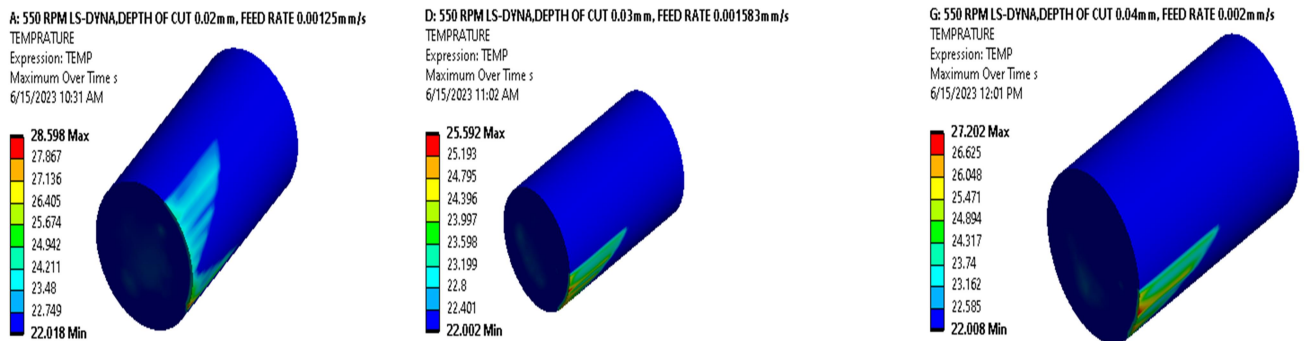
CASE I

Input parameter	Level I	Level II	LEVEL III
workpiece speed(Rpm)	550	550	550
Feedrate(mm/s)	0.00125	0.00158	0.002
Depth of cut (mm)	0.02	0.03	0.04

I. Temprature Result

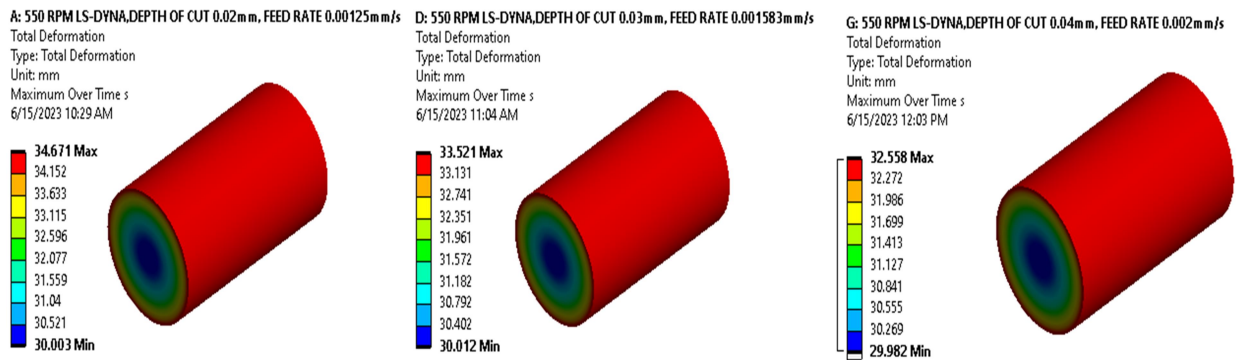
The temprature results obtained from cylindrical grinding simulations are shown in the following figure below. the first level of temprature results according to the input parametrs, speed of workpiece, depth of cut and feed rate of workpiece is maximum 28.598°C. The second level maximum over time is 27.592 °C maximum over time is 27.202 °C. The result plot

shows that the maximums temperature is obtained at the first level of work pieces speed 550rpm , feeding rate 0.00125 mm/s and Depth of cut 0.02mm. Supplementary the result shows that, at this 550rpm, when the workpiece increases in the value of both feedrate and depth of cut , the result of temperature of the surface slightly decreased. The figure of contour used to tell results temperature at three levels.



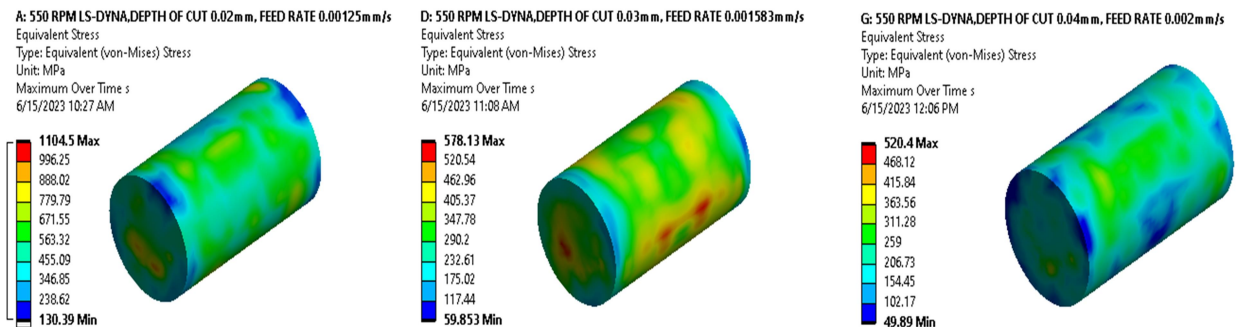
II. Deformation Result

The deformation results obtained from cylindrical grinding simulations are shown in the following figure below of temprature results according to the input parametrs, speed of workpiece , depth of cut and feed rate of workpiece is maximum 34.671 mm. The second level maximum over time is 33.52 mm maximum over time is 32.558 mm. The result plot shows that the maximums total deformation is obtained at the first level of work pieces speed 550rpm , feeding rate 0.00125 mm/s and Depth of cut 0.02mm. Supplementary the result shows that, at this 550rpm, when the workpiece increases in the value of both feedrate and depth of cut , the result of total deformation of the surface slightly decreased. The figure of contour used to tell results of total deformation.



III. Equivalent Stress

The equivalent stress results obtained from cylindrical grinding simulations are shown in the following figure below of equivalent stress results according to the input parameters, speed of workpiece, depth of cut and feed rate of workpiece is maximum 1104 Mpa. The second level maximum over time is 578.13 Mpa maximum over time is 520 Mpa. The result plot shows that the maximum temperature is obtained at the first level of work pieces speed 550rpm, feeding rate 0.00125 mm/s and Depth of cut 0.02mm. Supplementary the result shows that, at this 550rpm, when the workpiece increases in the value of both feedrate and depth of cut, the result of equivalent of the surface slightly decreased. The figure of contour used to tell results of equivalent stress.



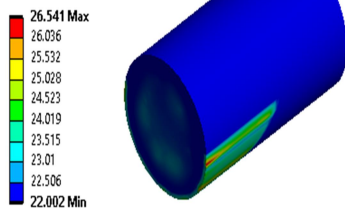
CASE II

Input parameter	Level I	Level II	LEVEL III
workpiece speed(Rpm)	850	850	850
Feedrate(mm/s)	0.00125	0.00158	0.002
Depth of cut (mm)	0.03	0.04	0.02

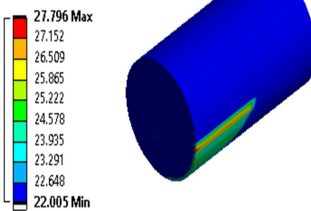
I. Temprature Result

The temprature results obtained from cylindrical grinding simulations are shown in the following figure below, of temprature results according to the input parametrs, speed of workpiece , depth of cut and feed rate of workpiece is maximum 26.54°c. The second level maximum over time is 27.796 °c maximum over time is 28.118°c. The result plot shows that the maximums temprature is obtained at the third level of work pieces speed 850rpm , feeding rate 0.002 mm/s and Depth of cut 0.02mm. Supplementary the result shows that, at this 850rpm, when the workpiece increases in the value of depth of cut and in minimum of feedrate, the result of temprature of the surface slightly decreased. The figure of contour used to tell their results.

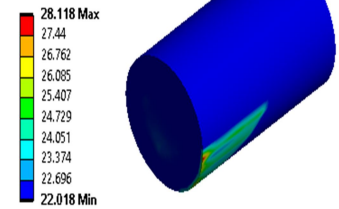
B: 850 RPM LS-DYNA,DEPTH OF CUT 0.03mm, FEED RATE 0.00125mm/s
TEMPERATURE
Expression: TEMP
Maximum Over Time s
6/15/2023 4:43 PM



E: 850 RPM LS-DYNA,DEPTH OF CUT 0.04mm, FEED RATE 0.001583mm/s
TEMPERATURE
Expression: TEMP
Maximum Over Time s
6/15/2023 5:08 PM



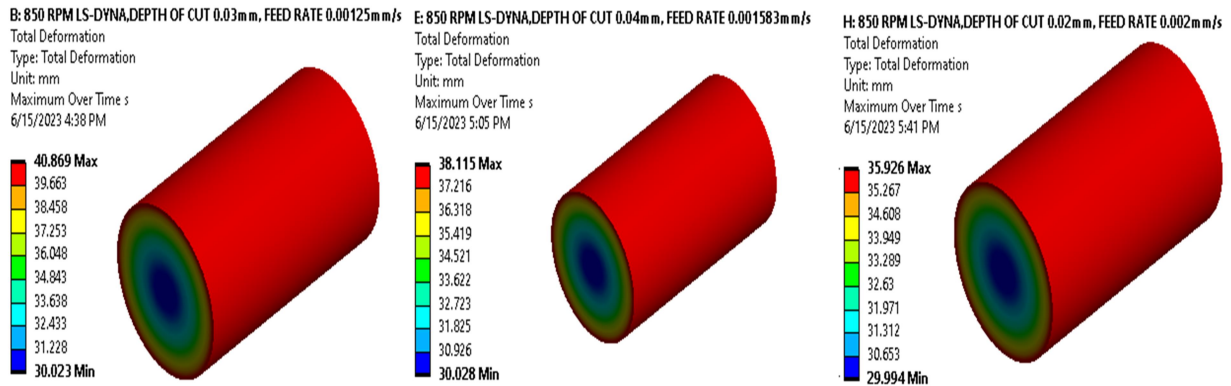
H: 850 RPM LS-DYNA,DEPTH OF CUT 0.02mm, FEED RATE 0.002mm/s
TEMPERATURE
Expression: TEMP
Maximum Over Time s
6/15/2023 5:39 PM



II. Deformation Result

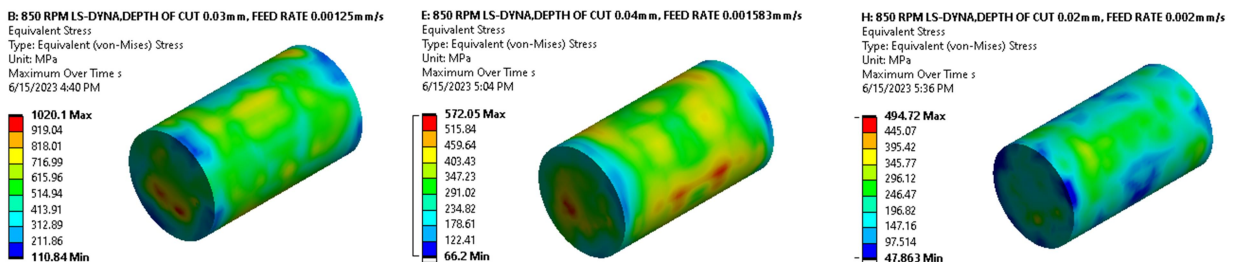
The deformation results obtained from cylindrical grinding simulations are shown in the following figure below, of deformation results according to the input parametrs, speed of workpiece , depth of cut and feed rate of workpiece is maximum 40.86 mm. The second level maximum over time is 38.115 mm and maximum over time is 35.926 mm. The result plote shows that the maximums total deformation is obtained at the first level of work pieces speed 850rpm , feeding rate 0.00125 mm/s and Depth of cut 0.03mm. Supplementary the result shows that, at this 850rpm, when the workpiece increace in the value of both feedrate and

depth of cut , the result of total deformation of the surface slightly decreased. The figure of contour used to tell their results.



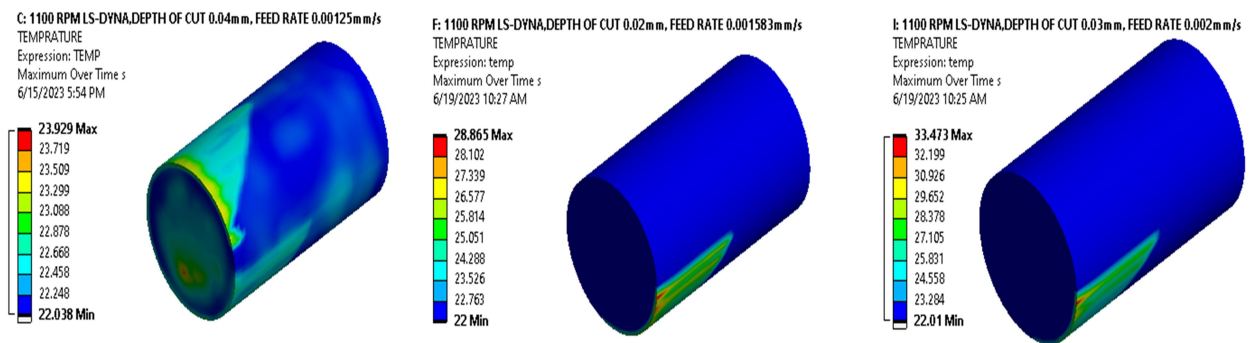
III. Equivalent Stress

The equivalent stress results obtained from cylindrical grinding simulations are shown in the following figure below of equivalent stress results according to the input parametrs, speed of workpiece , depth of cut and feed rate of workpiece is maximum 1020.1 Mpa. The second level maximum over time is 572.05 Mpa maximum over time is 494.72 Mpa. The result plot shows that the maximums equivalent stress is obtained at the first level of work pieces speed 850rpm , feeding rate 0.00125 mm/s and Depth of cut 0.03mm. Supplementary the result shows that, at this 850rpm, when the workpiece increase in the value of both feedrate and depth of cut , the result of equivalent stress of the surface slightly decreased. The figure of contour used to tell their results.



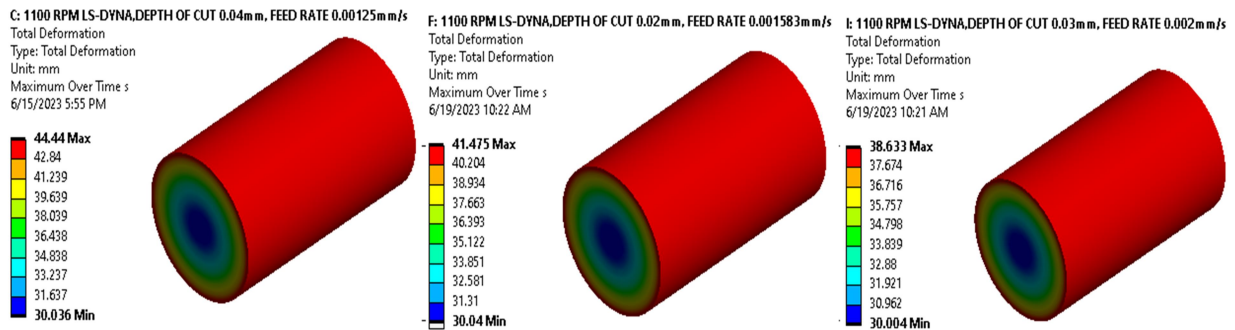
I. Temperature Result

The temperature results obtained from cylindrical grinding simulations were shown in the following of temperature results according to the input parameters, speed of workpiece, depth of cut and feed rate of workpiece is maximum 23.929 °c. The second level maximum over time is 28.865 °c maximum over time is 33.473 °c. The result plot shows that the maximum temperature is obtained at the third level of work pieces speed 1100rpm, feeding rate 0.002 mm/s and Depth of cut 0.03mm. Supplementary the result shows that, at this 1100 Rpm, when the workpiece increases in the value of both feedrate and depth of cut, the result of temperature of the surface slightly increase. The figure of contour used to tell their results.



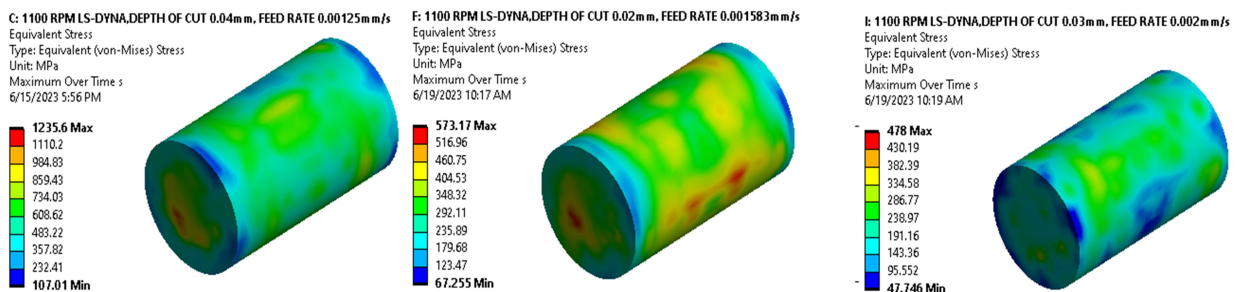
II. Deformation Result

The total deformation results obtained from cylindrical grinding simulations are shown in the following of total deformation results according to the input parameters, speed of workpiece, depth of cut and feed rate of workpiece is maximum 44.44 mm. The second level or figure 2a maximum over time is 41.475 mm maximum over time is 38.633 mm. The result plot shows that the maximum total deformation is obtained at the first level of work pieces speed 1100 rpm, feeding rate 0.00125 mm/s and Depth of cut 0.04mm. Supplementary the result shows that, at this 1100 rpm, when the workpiece increases in the value of both feedrate and depth of cut, the result of total deformation of the surface slightly decreased. The figure of contour used to tell their results.



III. Equivalent Stress

The equivalent stress results obtained from cylindrical grinding simulations are shown in the following figure below of equivalent stress results according to the input parameters, speed of workpiece, depth of cut and feed rate of workpiece was maximum 1235.6 Mpa. The second level maximum over time is 573.17 Mpa maximum over time is 478 Mpa. The result plot shows that the maximum equivalent stress is obtained at the first level of workpieces speed 1100rpm, feeding rate 0.00125 mm/s and Depth of cut 0.04mm. Supplementary the result shows that, at this 1100rpm, when the workpiece increases in the value of feedrate and decrease of depth of cut, the result of equivalent stress of the surface slightly decreased. The figure of contour used to tell their results.



4.5.3 Response Optimization; From LS DYNA Results

By using design expert version 13 optimization of LS Dyna software results were carried out in order to know the best combination of input parameters to produce fine surface roughness of the grinded parts. This optimization was carried out both in numerical and graphical methods based on the goal of the optimization. The output parameters under study were temperature, range deformation, Von-misses stress and equivalent energy (absorbed energy) and the input parameter for simulation were work piece speed, depth of cut and feed rate.

Case I: Optimization of temperature

Target minimization

Optimum value 47.5503°C at combination of the grinding parameters were at work piece speed of 550.01Rpm, feed rate off 0.012004 mm/min and depth of cut were at 0.0399856mm.

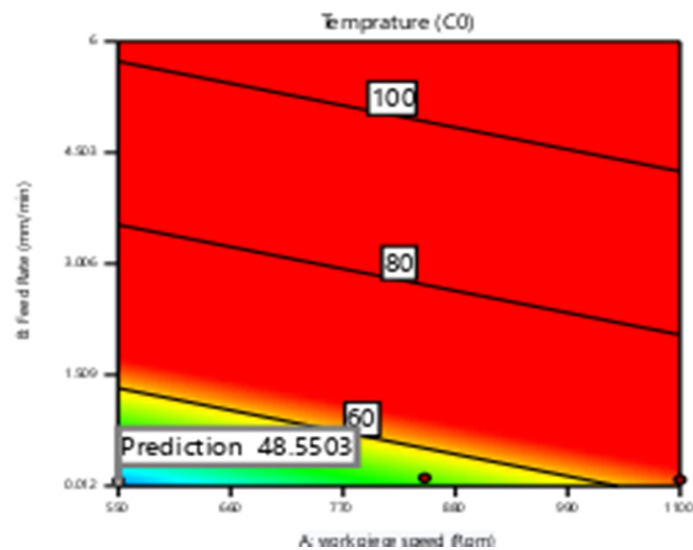


Figure 4-7 Prediction of Temperature

Case II: Optimization of range deformation

Target minimization

Optimum value were 6.40611 mm at combination of grinding parameters were at work piece speed (Rpm) = 550.126Rpm, feed rate = 0.06846mm/min and depth of cut were at 0.02mm.

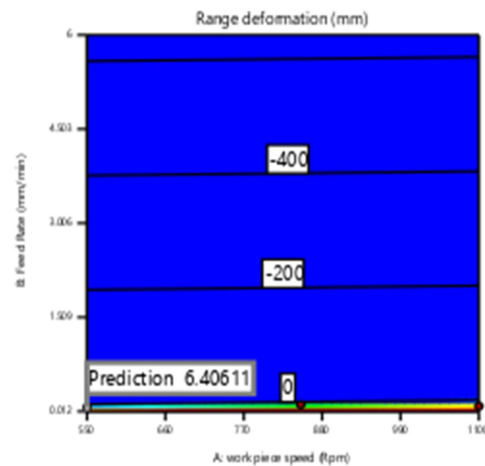


Figure 4-8 prediction of Range Deformation

Case III. Optimization of Equivalent Stress

Target in range

Optimum value were 1068.58 Mpa at combination of grinding parameters were at work piece speed (Rpm) = 550.001Rpm, feed rate = 0.1125mm/min and depth of cut were at 0.0397mm.

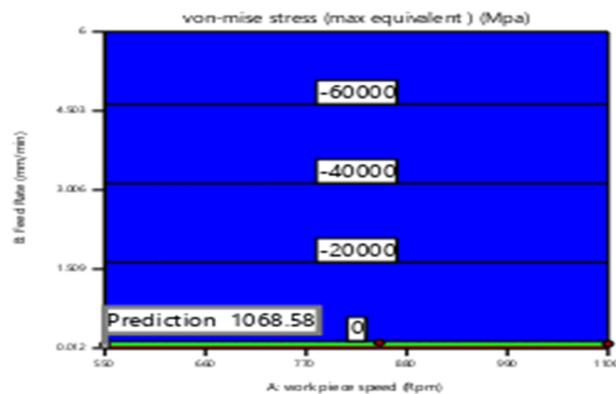


Figure 4-9 Prediction of Equivalent Stress

Case IV. Optimization of Absorbed Energy

Target in range

Optimum value were 11.4301 J at combination of grinding parameters were at work piece speed (Rpm) = 550 Rpm, feed rate = 0.0684mm/min and depth of cut were at 0.02mm.

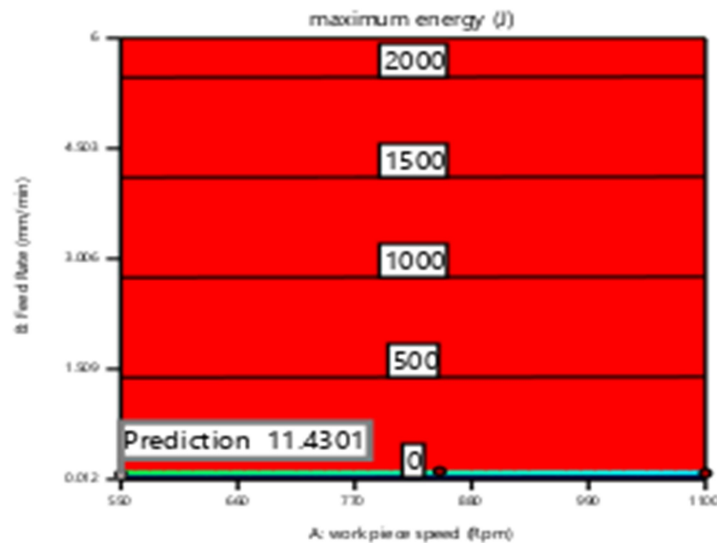


Figure 4-10 Prediction of Absorbed Energy

4.6 Measuring Of Residual Stress Using XRD

There are many methods used for measuring of residual stress. Some of them are listed below

1. Ultrasonic barkhausen eddy current which results only qualitative results
2. Neutron diffraction (sectioning) cannot measure surface residual stress.
3. Hole drilling destructive in nature which cannot quantify high stress levels.
4. X-ray diffraction non-destructive measuring stress level accurately and quantitative results can be obtained and residual at surface and sub-surface

Inter-planer distance (d-spacing)

$$n\lambda = 2d\sin\theta$$

Where n=integer multiple of wavelength

λ =wavelength of x-ray

d=distance between the plane in the crystalline

θ =angle where constructive integer occur

D-spacing & hkl (crystalline planes)

Miller index number

$h=1/x$, $k=1/y$ & $l=1/z$ are intercept

Data observed from XRD

It was confirmed from the ICDD data which corresponds with the Iron Nickel 00-037-0474

The kamacite phase is a mineral that occurs in iron-nickel meteorites and is composed of an alloy of iron and nickel. The crystal structure of kamacite is body-centered cubic (BCC), and its lattice parameters are $a = 0.2866$ nm and $\alpha = 90$ degrees. The typical Miller indices for the kamacite phase are (110), (200), (211), (220), (310), (222), (321), and (400). These Miller indices correspond to the planes of atoms in the crystal lattice that are most commonly observed in X-ray diffraction patterns of kamacite.

The kamacite phase is a mineral that occurs in iron-nickel meteorites and is composed of an alloy of iron and nickel. The crystal structure of kamacite is body-centered cubic (BCC), and its lattice parameters are $a = 0.2866$ nm and $\alpha = 90$ degrees. The typical Miller indices for the kamacite phase are (110) [card no. 04-0836], (200) [card no. 04-0837], (211) [card no. 04-0838], (220) [card no. 04-0839], (310) [card no. 04-0840], (222) [card no. 04-0841], (321) [card no. 04-0842], and (400) [card no. 04-0843]. These Miller indices correspond to the planes of atoms in the crystal lattice that are most commonly observed in X-ray diffraction patterns of kamacite.

Tetrataenite: a nickel-rich iron-nickel alloy with a cubic crystal structure. Its Miller indices are (111), (200), (220), (311), (222), (400), (331), and (420).

Plessite: a mixture of kamacite and taenite that forms lamellar structures. Its Miller indices are the same as those for kamacite and taenite.

Troilite: an iron sulfide mineral that is often associated with iron-nickel meteorites. Its crystal structure is orthorhombic and its Miller indices are (100), (010), and (001).

Schreibersite: a phosphide mineral that is also commonly found in iron-nickel meteorites. Its crystal structure is hexagonal and its Miller indices are (100), (010), (001), (101), (110), and (012).

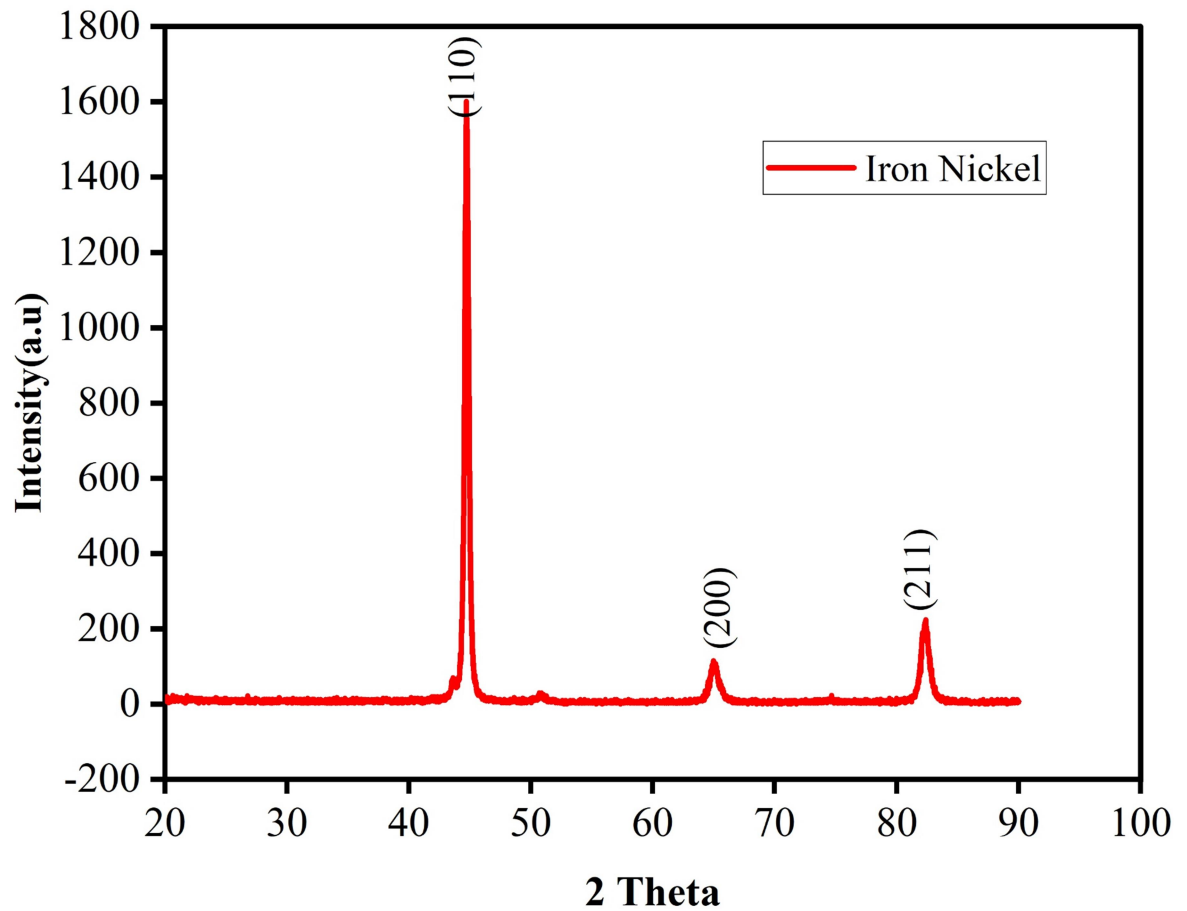


Figure 4-11 Intensity vs 2 Theta

From XRD result for three samples which were grinded at different work-piece speed and constant value of feed rate and depth of cut were presented as follow.

Sample Number	Grinding parameters	Phase type	Lattice parameter(a)nm	Miller index (hkl)
1	Work-piece speed = 550 Rpm Feed Rate = 0.12 mm/min Depth of cut = 0.04 mm	Kamacite	0.2866	h=1 k=1 l=0
2	Work-piece speed = 850 Rpm Feed Rate = 0.12 mm/min Depth of cut = 0.04 mm	Taenite	0.3561	h= 2 k= 2 l= 0
3	Work-piece speed = 1100 Rpm Feed Rate = 0.12 mm/min Depth of cut = 0.04 mm	tetrataenite	0.3465	h=2 k=0 l=0

		d-spacing ($n\lambda=2d\sin\theta$)	β_1	$\Psi(\text{psi})$	$\beta_2(\text{rad})$
2 Theta	Theta				
65.04809	32.524045	0.4141545	0.43048	0.18281	0.0075
82.33937	41.169685	0.5070818	0.88817	0.37717	0.01
44.73741	22.368705	0.2931495	0.844	0.35841	0.01472
50.81196	25.40598	0.3304814	0.61048	0.25925	0.01065

Calculation of micro strain

$$\varepsilon_1 = \left(\frac{\beta_1}{\tan \theta_1} \right) \frac{0.0075}{\tan(32.524045)} = 0.003740$$

$$\varepsilon_2 = \left(\frac{\beta_2}{\tan \theta_2} \right) \frac{0.01}{\tan(41.169685)} = 0.02929$$

$$\varepsilon_3 = \left(\frac{\beta_3}{\tan \theta_3} \right) \frac{0.01472}{\tan(22.368705)} = 0.037117$$

$$\varepsilon_4 = \left(\frac{\beta_4}{\tan \theta_4} \right) \frac{0.01065}{\tan(25.40598)} = 0.03800$$

Calculation of residual stress using hooks law

$$\sigma_1 = \varepsilon_1 * E \quad 0.003740 * 20 * 10^9 = 74.8 * 10^6 \text{ Mpa}$$

$$\sigma_2 = \varepsilon_2 * E \quad 0.02929 * 20 * 10^9 = 585.8 * 10^6 \text{ Mpa}$$

$$\sigma_3 = \varepsilon_3 * E \quad 0.037117 * 20 * 10^9 = 742.34 * 10^6 \text{ Mpa}$$

$$\sigma_4 = \varepsilon_4 * E \quad 0.03800 * 20 * 10^9 = 760 * 10^6 \text{ Mpa}$$

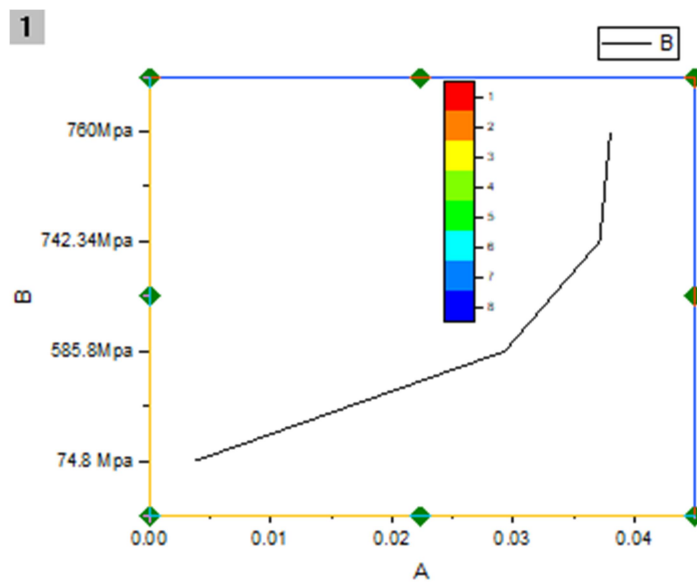


Figure 4-12 Residual Stress vs Micro strain

CHAPTER FIVE

5. Conclusion and Recommendation

5.1 Conclusion

Stainless steel AISI 440c was grinded with aluminum oxide in dry environment. The optimal design ranges of cutting conditions and effect of cutting parameters on output responses were identified based on statistical analysis and graphical interpretations by using design expert 13. The results indicated that cutting parameters influence surface roughness, residual stress and simulation result from LS-DYNA.

For **Ra** based on Whitcomb score model selected to analysis surface roughness where Linear model.

- Predicted R^2 and Adjusted R^2 value was 0.9873 and 0.9936 respectively.
- F-value was 417.82 shows model is significant.
- Work piece speed and feed rate terms are having a significant factor on surface roughness.
- Work piece speed and feed rate having a contribution percentage of 5.59% and 73.13 % respectively.
- From RSM optimization
 $Ra = 0.343285 \mu m$ at $V_w = 550 \text{ Rpm}$, 0.12 mm/min and 0.02 mm

Optimization of result Obtained from LS-DYNA simulation

- **Temperature**
Optimum value $47.5503c^0$ at combination of the grinding parameters were at work piece speed (Rpm) = 550.01Rpm, feed rate = 0.012004 mm/min and depth of cut were at 0.0399856mm.
- **Range deformation**
Optimum value were 6.40611 mm at combination of grinding parameters were at work piece speed (Rpm) = 550.126Rpm, feed rate = 0.06846mm/min and depth of cut were at 0.02mm.

- **Equivalent Stress**

Optimum value were 1068.58 Mpa at combination of grinding parameters were at work piece speed (Rpm) = 550.001Rpm, feed rate = 0.1125mm/min and depth of cut were at 0.0397mm.

- **Absorbed Energy**

Optimum value were 11.4301 J at combination of grinding parameters were at work piece speed (Rpm) = 550 Rpm, feed rate = 0.0684mm/min and depth of cut were at 0.02mm.

From XRD Result

- Kamacite phase, taenite and tetraenite phase was obtained.
- D-spacing calculated by using data from XRD on origin software.
- Micro-strain was calculated
- Residual stress was calculated based on hooks law.

5.2 Recommendation

By adopting the analysis made in this thesis, this research can be extended with increased number of Experiments and different types of wheel materials with increased levels for obtaining comparatively better results.

- This research can be extended for increased numbers of experiments for better analysis and conducting much XRD characterization in order to get different phase changes to obtain comparable value of residual stress.
- This research can be extended to study more about types of grinding forces applied, MQL (minimum quality liquid) and types of residual stress produced during cylindrical grinding.

5.3 Scope for Future Work

- Future researches could be directed toward considering higher number of input process parameters. This will contribute to the optimization of the process considering a higher number of criteria.
- The impact of grinding condition parameter such as work piece speed, feed rate, and depth of cut was investigated in this study. Additional factors such as wheel wear, material composition, and applied force so on could be considered in future research.

6. REFERENCE

- Abhang, L. B., & Hameedullah, M. (2012). Determination of optimum parameters for multi performance characteristics in turning by using grey relational analysis. *The International Journal of Advanced Manufacturing Technology*, 63(1–4), 13–24. <https://doi.org/10.1007/s00170-011-3857-6>
- Alagumurthi, N., Palaniradja, K., & Soundararajan, V. (2008). Optimisation of process parameters in grinding on different dimensions and perspectives. *International Journal of Industrial and Systems Engineering*, 3(4), 447. <https://doi.org/10.1504/ijise.2008.017554>
- Alajmi, M. S., Alfares, F. S., & Alfares, M. S. (2017). Selection of optimal conditions in the surface grinding process using the quantum based optimisation method. *Journal of Intelligent Manufacturing*, 30(3), 1469–1481. <https://doi.org/10.1007/s10845-017-1326-2>
- Chang, L., Burke, M. N., & Scenini, F. (2019). Understanding the effect of surface finish on stress corrosion crack initiation in warm-forged stainless steel 304L in high-temperature water. *Scripta Materialia*, 164, 1–5. <https://doi.org/10.1016/j.scriptamat.2019.01.032>
- Chekole, N., & Deshpande, V. A. (2018). review analysis on optimization of cylindrical grinding process parameters by using taguchi technique. *Industrial Engineering Journal*, 11(5).<https://doi.org/10.26488/iej.11.5.1066>
- Da Silva, L. M., De Farias Moreira, R. T., De Assis Ribeiro Dos Santos, F., & Duarte, F. B. (2018). Study of 3D parameters and residual stress in grinding of AISI 4340 steel hardened using different cutting fluids. *The International Journal of Advanced Manufacturing Technology*, 100(1–4), 895–905. <https://doi.org/10.1007/s00170-018-2763-6>
- Deng, Y., Xiu, S., Shi, X., Sun, C., & Wang, Y. (2016). Study on the effect mechanisms of pre-stress on residual stress and surface roughness in PSHG. *The International*

Journal of Advanced Manufacturing Technology, 88(9–12), 3243–3256.

<https://doi.org/10.1007/s00170-016-9033-2>

Denkena, B., Grove, T., & Lucas, H. (2016). Influences of grinding with Toric CBN grinding tools on surface and subsurface of 1.3344 PM steel. *Journal of Materials Processing Technology*, 229, 541–548. <https://doi.org/10.1016/j.jmatprotec.2015.09.039>

Deresse, N. C., Deshpande, V. A., & Taifa, I. W. R. (2020a). Experimental investigation of the effects of process parameters on material removal rate using Taguchi method in external cylindrical grinding operation. *Engineering Science and Technology, an International Journal*, 23(2), 405–420. <https://doi.org/10.1016/j.jestch.2019.06.001>

Deresse, N. C., Deshpande, V. A., & Taifa, I. W. R. (2020b). Experimental investigation of the effects of process parameters on material removal rate using Taguchi method in external cylindrical grinding operation. *Engineering Science and Technology, an International Journal*, 23(2), 405–420. <https://doi.org/10.1016/j.jestch.2019.06.001>

González-Santander, J. L., & Espinos-Morato, H. (2018). Depth of thermal penetration in straight grinding. *The International Journal of Advanced Manufacturing Technology*. <https://doi.org/10.1007/s00170-018-1766-7>

Gujjar, S. V., Nadar, N. R., Choudhary, K., Hunashyal, A. M., Shahapurkar, K., Kalam, M. A., Asadullah, M., Soudagar, M. E. M., Khan, T. M. Y., Ismail, K. A., & Elfakhany, A. (2022). Investigation of Various Coating Resins for Optimal Anticorrosion and Mechanical Properties of Mild Steel Surface in NaCl Solution. *Advances in Materials Science and Engineering*, 2022, 1–9. <https://doi.org/10.1155/2022/2203717>

Huang, X., Ren, Y., Zheng, B., Deng, Z., & Zhou, Z. (2016). Experiment research on grind-hardening of AISI5140 steel based on thermal compensation. *Journal of Mechanical Science and Technology*, 30(8), 3819–3827. [https://doi.org/10.1007/s12206-016-0745-](https://doi.org/10.1007/s12206-016-0745-x)

x

Huang, X., Ren, Y., Zhou, Z., & McClements, D. J. (2015). Experimental study on white layers in high-speed grinding of AISI52100 hardened steel. *Journal of Mechanical*

- Jamshidi, H., & Budak, E. (2021a). On the prediction of surface burn and its thickness in grinding processes. *CIRP Annals*, 70(1), 285–288. <https://doi.org/10.1016/j.cirp.2021.04.041>
- Jamshidi, H., & Budak, E. (2021b). On the prediction of surface burn and its thickness in grinding processes. *CIRP Annals*, 70(1), 285–288. <https://doi.org/10.1016/j.cirp.2021.04.041>
- Jatti, V. S., Sekhar, R., & Shah, P. (2021). *Machine Learning Based Predictive Modeling of Ball Nose End Milling using Exogeneous Autoregressive Moving Average Approach*. <https://doi.org/10.1109/icmimt52186.2021.9476067>
- Kuang, W., Miao, Q., Ding, W., Zhao, Y., & Zhengcai, Z. (2021a). Residual stresses of turbine blade root produced by creep-feed profile grinding: Three-dimensional simulation based on workpiece–grain interaction and experimental verification. *Journal of Manufacturing Processes*, 62, 67–79. <https://doi.org/10.1016/j.jmapro.2020.11.045>
- Kuang, W., Miao, Q., Ding, W., Zhao, Y., & Zhengcai, Z. (2021b). Residual stresses of turbine blade root produced by creep-feed profile grinding: Three-dimensional simulation based on workpiece–grain interaction and experimental verification. *Journal of Manufacturing Processes*, 62, 67–79. <https://doi.org/10.1016/j.jmapro.2020.11.045>
- Kurt, M., Bagci, E., & Kaynak, Y. (2009). Application of Taguchi methods in the optimization of cutting parameters for surface finish and hole diameter accuracy in dry drilling processes. *The International Journal of Advanced Manufacturing Technology*, 40(5–6), 458–469. <https://doi.org/10.1007/s00170-007-1368-2>
- Kwak, J. (2005). Application of Taguchi and response surface methodologies for geometric error in surface grinding process. *International Journal of Machine Tools & Manufacture*, 45(3), 327–334. <https://doi.org/10.1016/j.ijmachtools.2004.08.007>

- Lv, L., Deng, Z., Liu, T., Li, Z., & Liu, W. (2020). Intelligent technology in grinding process driven by data: A review. *Journal of Manufacturing Processes*, 58, 1039–1051. <https://doi.org/10.1016/j.jmapro.2020.09.018>
- Nayak, S. R., Mohana, K. N., Hegde, M., Rajitha, K., Madhusudhana, A. M., & Naik, S. R. (2021a). Functionalized multi-walled carbon nanotube/polyindole incorporated epoxy: An effective anti-corrosion coating material for mild steel. *Journal of Alloys and Compounds*, 856, 158057. <https://doi.org/10.1016/j.jallcom.2020.158057>
- Nayak, S. R., Mohana, K. N., Hegde, M., Rajitha, K., Madhusudhana, A. M., & Naik, S. R. (2021b). Functionalized multi-walled carbon nanotube/polyindole incorporated epoxy: An effective anti-corrosion coating material for mild steel. *Journal of Alloys and Compounds*, 856, 158057. <https://doi.org/10.1016/j.jallcom.2020.158057>
- Ozay, C., Ballikaya, H., & Savas, V. (2016). Application of the Taguchi method to select the optimum cutting parameters for tangential cylindrical grinding of AISI D3 tool steel. *Materiali in Tehnologije*, 50(1), 81–87. <https://doi.org/10.17222/mit.2014.293>
- Pal, D. S., Bangar, A., Sharma, R., & Yadav, A. (2012). Optimization of Grinding Parameters for Minimum Surface Roughness by Taguchi Parametric Optimization Technique. *International Journal of Mechanical and Industrial Engineering*, 265–269. <https://doi.org/10.47893/ijmie.2012.1051>
- Palanikumar, K. (2006). Cutting Parameters Optimization for Surface Roughness in Machining of GFRP Composites using Taguchi's Method. *Journal of Reinforced Plastics and Composites*, 25(16), 1739–1751. <https://doi.org/10.1177/0731684406068445>
- Pi, V. N., Tung, L. A., Hung, L. X., & Long, B. T. (2016). Cost Optimization of Surface Grinding Process. *Journal of Environmental Science and Engineering*, 5(12). <https://doi.org/10.17265/2162-5298/2016.12a.002>

- Prasad, S. D., Vishai, S., Sai, P. V., Bhargav, K., & Rohith, K. (2021). Cylindrical grinding - experimental investigation and Taguchi study of process parameters on EN31 and mild steel. *IOP Conference Series: Materials Science and Engineering*, 1057, 012066. <https://doi.org/10.1088/1757-899x/1057/1/012066>
- Rabiey, M., & Maerchy, P. (2020). Investigation on Surface Integrity of Steel DIN 100Cr6 by Grinding Using CBN Tool. *Procedia CIRP*, 87, 192–197. <https://doi.org/10.1016/j.procir.2020.03.001>
- Rajaei, A., Hallstedt, B., Broeckmann, C., Barth, S., Trauth, D., & Bergs, T. (2018). Numerical Prediction of the Microstructure and Stress Evolution During Surface Grinding of AISI 52100 (DIN 100Cr6). *Integrating Materials and Manufacturing Innovation*, 7(4), 202–213. <https://doi.org/10.1007/s40192-018-0122-y>
- Ruefer, H. (2019). Living Without Mathematical Statistics. In *Springer eBooks*. <https://doi.org/10.1007/978-3-319-99632-5>
- Sallem, H., & Hamdi, H. (2015). Analysis of Measured and Predicted Residual Stresses Induced by Finish Cylindrical Grinding of High Speed Steel with CBN Wheel. *Procedia CIRP*, 31, 381–386. <https://doi.org/10.1016/j.procir.2015.03.080>
- Sarikaya, M. Z., & Güllü, A. (2015). Multi-response optimization of minimum quantity lubrication parameters using Taguchi-based grey relational analysis in turning of difficult-to-cut alloy Haynes 25. *Journal of Cleaner Production*, 91, 347–357. <https://doi.org/10.1016/j.jclepro.2014.12.020>
- Shaji, S., & Radhakrishnan, V. (2003). Analysis of process parameters in surface grinding with graphite as lubricant based on the Taguchi method. *Journal of Materials Processing Technology*, 141(1), 51–59. [https://doi.org/10.1016/s0924-0136\(02\)01112-3](https://doi.org/10.1016/s0924-0136(02)01112-3)
- Shen, S., Li, B., & Guo, W. (2019a). Surface integrity in grinding of C-250 maraging steel with resin-bonded and electroplated CBN grinding wheels. *The International Journal of Advanced Manufacturing Technology*, 103(1–4), 1079–1094. <https://doi.org/10.1007/s00170-019-03574-9>

- Shen, S., Li, B., & Guo, W. (2019b). Experimental study on grinding-induced residual stress in C-250 maraging steel. *The International Journal of Advanced Manufacturing Technology*, 106(3–4), 953–967. <https://doi.org/10.1007/s00170-019-04655-5>
- Taifa, I. W. R., & Desai, D. A. (2017a). Anthropometric measurements for ergonomic design of students' furniture in India. *Engineering Science and Technology, an International Journal*, 20(1), 232–239. <https://doi.org/10.1016/j.jestch.2016.08.004>
- Taifa, I. W. R., & Desai, D. A. (2017b). User requirements customization and attractive quality creation for design improvement attributes. *International Journal for Quality Research*, 11(1), 131–148. <https://doi.org/10.18421/ijqr11.01-08>
- Taifa, I. W. R., Desai, D. A., & Bulsara, N. M. (2019). The development of an ergonomically designed product through an integrated product team approach. *International Journal of Occupational Safety and Ergonomics*, 27(1), 160–178. <https://doi.org/10.1080/10803548.2018.1557398>
- Usov, A. I., Tonkonogyi, V., Dašić, P., & Rybak, O. (2019). Modelling of Temperature Field and Stress–Strain State of the Workpiece with Plasma Coatings during Surface Grinding. *Machines*, 7(1), 20. <https://doi.org/10.3390/machines7010020>
- Van Nostrand, R. C. (2002). Design of Experiments Using the Taguchi Approach: 16 Steps to Product and Process Improvement. *Technometrics*, 44(3), 289. <https://doi.org/10.1198/004017002320256440>
- Wang, D., Ge, P., Sun, S., Jiang, J., & Liu, X. (2017). Investigation on the heat source profile on the finished surface in grinding based on the inverse heat transfer analysis. *The International Journal of Advanced Manufacturing Technology*, 92(1–4), 1201–1216. <https://doi.org/10.1007/s00170-017-0189-1>
- Wang, D., Sun, S., Jiang, J., & Liu, X. (2017). The profile analysis and selection guide for the heat source on the finished surface in grinding. *Journal of Manufacturing Processes*, 30, 178–186. <https://doi.org/10.1016/j.jmapro.2017.09.023>

- Wegener, K., Hoffmeister, H., Karpuschewski, B., Kuster, F., Hahmann, W., & Rabiey, M. (2011). Conditioning and monitoring of grinding wheels. *CIRP Annals*, 60(2), 757–777. <https://doi.org/10.1016/j.cirp.2011.05.003>
- Weiß, M., Klocke, F., Barth, S., Rasim, M., & Mattfeld, P. (2017). Detailed Analysis and Description of Grinding Wheel Topographies. *Journal of Manufacturing Science and Engineering-transactions of the Asme*, 139(5). <https://doi.org/10.1115/1.4035531>
- Wu, C., Pang, J., Li, B., & Liang, S. Y. (2019). High-speed grinding of HIP-SiC ceramics on transformation of microscopic features. *The International Journal of Advanced Manufacturing Technology*, 102(5–8), 1913–1921. <https://doi.org/10.1007/s00170-018-03226-4>
- Wu, M., Chen, H., Chang, T., & Wu, C. (2019a). Quality evaluation of internal cylindrical grinding process with multiple quality characteristics for gear products. *International Journal of Production Research*, 57(21), 6687–6701. <https://doi.org/10.1080/00207543.2019.1567951>
- Wu, M., Chen, H., Chang, T., & Wu, C. (2019b). Quality evaluation of internal cylindrical grinding process with multiple quality characteristics for gear products. *International Journal of Production Research*, 57(21), 6687–6701. <https://doi.org/10.1080/00207543.2019.1567951>
- Wu, M., Chen, H., Chang, T., & Wu, C. (2019c). Quality evaluation of internal cylindrical grinding process with multiple quality characteristics for gear products. *International Journal of Production Research*, 57(21), 6687–6701. <https://doi.org/10.1080/00207543.2019.1567951>
- Wu, M., Chen, H., Chang, T., & Wu, C. (2019d). Quality evaluation of internal cylindrical grinding process with multiple quality characteristics for gear products. *International Journal of Production Research*, 57(21), 6687–6701. <https://doi.org/10.1080/00207543.2019.1567951>
- Wu, M., Chen, H., Chang, T., & Wu, C. (2019e). Quality evaluation of internal cylindrical grinding process with multiple quality characteristics for gear products. *International*

Journal of Production Research, 57(21), 6687–6701.

<https://doi.org/10.1080/00207543.2019.1567951>

Yao, C. F., Jin, Q. Y., Huang, X. T., Wu, D., Ren, J., & Zhang, D. (2012). Research on surface integrity of grinding Inconel718. *The International Journal of Advanced Manufacturing Technology*, 65(5–8), 1019–1030. <https://doi.org/10.1007/s00170-012-4236-7>

Yerrawar, R. N., & Arakerimath, R. R. (2017). Development of Methodology for Semi Active Suspension System Using MR Damper. *Materials Today: Proceedings*. <https://doi.org/10.1016/j.matpr.2017.07.289>

Zhang, X., & Zhang, M. (2008). *Biologically-Inspired Search Strategy for Locating Odor Source*. <https://doi.org/10.1109/icnc.2008.228>

Zhou, N. H., Peng, R. L., & Pettersson, R. (2016a). Surface integrity of 2304 duplex stainless steel after different grinding operations. *Journal of Materials Processing Technology*, 229, 294–304. <https://doi.org/10.1016/j.jmatprotec.2015.09.031>

Zhou, N. H., Peng, R. L., & Pettersson, R. (2016b). Surface integrity of 2304 duplex stainless steel after different grinding operations. *Journal of Materials Processing Technology*, 229, 294–304. <https://doi.org/10.1016/j.jmatprotec.2015.09.031>

Zhou, N. H., Peng, R. L., & Pettersson, R. (2017a). Surface characterization of austenitic stainless steel 304L after different grinding operations. *International Journal of Mechanical and Materials Engineering*, 12(1). <https://doi.org/10.1186/s40712-017-0074-6>

Zhou, N. H., Peng, R. L., & Pettersson, R. (2017b). Surface characterization of austenitic stainless steel 304L after different grinding operations. *International Journal of Mechanical and Materials Engineering*, 12(1). <https://doi.org/10.1186/s40712-017-0074-6>

Zhou, N. H., Peng, R. L., Schönning, M., & Pettersson, R. (2017). SCC of 2304 Duplex Stainless Steel—Microstructure, Residual Stress and Surface Grinding Effects. *Materials*, 10(3), 221. <https://doi.org/10.3390/ma10030221>

7. Appendix

Response Optimization; From LS DYNA Results

