ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

Enhancing abrasive grinding performance of Al -7075 alloy through carburizing

A thesis submitted to the graduate school of Addis Ababa University in partial fulfillment of the requirement for the degree of Masters of Science
In

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Addis Ababa University
Addis Ababa Institute of Technology
School of Graduate Studies
School of Mechanical and Industrial Engineering

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Submitted in accordance with the requirements for the degree
MASTER OF SCIENCE(M.Sc.)

Approved by the examining committee members:

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DECLARATION

Addis Ababa University
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I undersigned solemnly declare that the research paper titled **"Enhancing abrasive grinding performance of Al -7075 alloy through carburizing"** is based on my own work to be carried out under the supervision of Dr. Desalegn Wogasso.

The thesis paper has not been formed the basis for the award of any academic certification or any other similar titles. All applicable resources of information used in this thesis have been accordingly acknowledged.

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Abstract

As compared to other metals aluminums are difficult to work on grinding operation because of its ductility and low melting point. This thesis paper deals with the validation and optimization of enhancement of grinding machinability of aluminum alloy by one of precipitation hardening process called carburization, which is mainly about the ingression of carbon molecules to the aluminum alloy for formation of aluminum carbide surface layer. The machinability is measured and characterized by the material removal rate and roughness by considering the influence of machining parameters and material properties such as wheel speed (1800, 2000RPM), work hardness (88, 109, 171VHN), cutting depth (0.02, 0.04,0.06mm) and surface depth (0mm, 1mm, 2mm). The roughness measurement was carried out on digital roughness tester SURFTEST SJ-310 and the material removal rate is calculated. The roughness and material removal rate results are then gathered and analyzed using Minitab 19 commercial software to determine the rank and percentage of the effects and interaction of machining parameters and material properties with the roughness and material removal rate were analyzed. According to the analysis using the signal-to-noise ratio (S/N ratio) to identify the control factor settings that minimize the variability caused by the noise factors on the material removal rate are surface depth, work hardness, wheel speed and cutting depth ranked respectively with highest delta value difference and for surface roughness work hardness, wheel speed and cutting depth and surface depth, ranked respectively. By using grey relational analysis, the optimum machining parameters also set on cutting speed at 2,000RPM, material hardness at 171 VHN, Surface Depth 2mm from surface and depth of cut at 0.04mm to have higher material removal rate and minimum roughness measurement 26.092 mm3/sec and 1.208µm Ra achieved respectively. The experimental and analysis result shows that the properties improved by the solution heat treatment or carburization have a high positive impact on the grindability of aluminum, by recommending identification research of associated mechanical property changes it is evaluated in this research as a better manufacturing process for reduction of clogging on the wheel and frequent dressing requirements.

Keywords: Aluminum Carburization, Aluminum Grinding, Solution Heat Treatment, Material Removal Rate, Surface Roughness

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List of Abbreviations

Abbreviations	**Description**
ANSI	American national standards institute
Al	Aluminum
Al_4C_3	Aluminum carbide
^oC	Degree centigrade (temperature measurement unit)
Si	silicon
CBN	Cubic boron nitride
SHT	Solution Heat Treatment
ASTM	American Society of Testing Materials
VHN	Vickers Hardness Number
RBS	Rutherford backscattering spectroscopy
SEM	Scanning electron microscopy
TEM	Transmission electron microscopy
CD	Continuous dressing
BaCo3	Barium carbonate
NaCo3	Sodium Carbonate
CaCo3	Calcium Carbonate

Chapter 1: Introduction

1.1 Background of the study

Aluminum alloys are flexible material that broadly utilized over numerous applications in household employments and industries from cell phones and household things, such as ladders, utensils, to automotive, manufacturing and development projects. Incorporating lightweight, high strength to weight ratio, malleability and erosion resistance, benefits of utilizing aluminum in manufacturing application is numerous. The applications are somehow limited due to its higher ductility and low melting point properties. These characteristics can lead to stacking, gouging or warm discoloration when material is subjected In any of, cutting and grinding. Grinding of aluminum alloys successfully and effectively can be challenging for several reasons. Aluminum could be a softer metal with a lower melting point than other materials, such as ferro materials[1]. Whereas numerous variables can impact the results including operator skill and work environment, choosing the correct items for the work is also key to accomplishing success.

Aluminum alloys have primary characteristics of having great corrosive resistance in common climate, and have adequately high adaptability. Aluminum in its pure form is much more lighter than steel with specific gravity of 7.8 g/cm3. In automotive industrial world, as metal material, utilization of Aluminum possesses second class after steel, in its both cast and wrought forms [2]. So, because of having good and easy-to-form mechanical properties. In automotive industrial products, automotives driven with fuel power and alternative power sources other than fuel. Use of alternative fuel power is emphasized in this period such as electric power, where, in case applied to vehicles utilizing power of batteries or accumulators. Major stated advantages in utilizing electric cars are: environmentally friendly, minimizing utilize of oil fuel sources; and noiseless. In expansion, use of electric car has also drawbacks such as: low speed and period of car use as result of limited battery or accumulator powers. The advancement in power source consumption is also caused by impact of load received by vehicles movement so utilizing aluminum material can decreases load of the vehicle and result in effective speed and power consumption.

So as to grab the advantages of this metal it is important to improve its machinability whereby it has a good machinability except its adherence property on the wheel during grinding operations

Grinding involves removing material from a work piece with a grinding wheel or abrasive belt. The harder, free cutting aluminum alloys are comparatively easy to grind. The non-free- cutting alloys, particularly in their softer temperature, are likely to clog grinding wheels, and they do not give bright and smooth surface finish as compared to the harder alloys. [3]

A silicon carbide Abrasive wheel is appropriate for grinding aluminum alloys, It is generally preferred in an adaptable base. Aluminum oxide is at times prescribed, but for piston grinding and in cutoff wheels. Wheels of medium hardness, almost 46-grit measure and with a synthetic resin bond, work best for roughing. For finishing, wheels of finer grit measure (to approximately 60) and with a vitrified bond are generally utilized. Recommendations for wheels for a few diverse types of grinding operations are given by the American National Standards Institute (ANSI) system for distinguishing the characteristics of grinding wheels.

If the harder the material can be assumed to be free cutting and comparatively easy to grind, then the surface hardening process expected to result on good grind machinability. By the formation of aluminum carbide on the alloy surface the hardness of the alloy surface can be elevated and tested for its response to the material removal rate and roughness after surface grinding operation.

1.2 Rationale of the study

Beside the industrial requirement of improved aluminum special finishing methods, because of its ductility, and having a relatively low melting temperature resulting to a fusion to the cutting edge due to the heat of grinding friction, on other research's it has been shown that the surface properties of Al can be improved by the formation of a carbide surface layer [4] [5]. The Al_4C_3 compound provides strength to the composite materials also alloys like $Al\text{-}Al_4C_3$, $Al\text{-}SiC\text{-}Al_4C_3$, and $Al\text{-}Al_3Ti\text{-}Al_4C_3$ performs the same [6]. For this reason, different processing advances have been created such as carburizing by plasma which takes place in a glow discharge region. In this process, the aluminum samples are besieged by positive carbon particles. These particles (ions) enter into the surface of aluminum and form the Al4C3 compound which is resistant to chemical erosion. Aluminum has low melting point of almost 660°C, and the carburized layer is formed in temperatures not more than 350°C. Different strategies have been utilized for the formation of a carbide layer such as particle (ion) implantation, carburizing in a plasma environment and in a plasma spot which is utilized for aluminum carburizing, using energetic carbon particles (ions) transmitted from a low-energy (1.5 kJ) Mather type plasma center device operated with methane [4].

1.3 Statement of the problem

Aluminum is soft by nature and can be difficult to work with grinding operations because of its lower melting point and higher ductility, it may form a gummy buildup when cut or machined on grinding operation. This temperature (aluminum's melting point) is low enough that it will often fuse to the cutting edge due to the heat of friction [7].

It can gum up or load on the abrasive during cutting, grinding and finishing. The heat and friction that build up during these processes can quickly melt the aluminum, causing it to stick and accumulate on the tool's surface (aka loading) — making it less effective. To avoid this issue, be deliberate when grinding. For example, always begin with a back stroke to avoid unwanted gouging. In addition, most aluminum products are not painted or coated, which means the surface finish is often exposed. This makes it even more critical to take care of the material's appearance and finish when cutting and grinding it [1].

1.4 Objectives of the study

1.4.1. General objective

It has been shown that the surface properties of Al metal can be improved by the formation of carbide surface layer [6], [8]. The Al_4C_3 compound provides strength to the composite materials and alloys like Al-Al_4C_3, Al-SiC-Al_4C_3, and Al-Al_3Ti-Al_4C_3 so this research mainly focus on Enhancing abrasive grinding performance of Al -7075 alloy through carburizing

1.4.2. Specific objectives

- To assess grindability changes achieved by carburization on aluminum alloy 7075
- To make surface hardness modification of aluminum alloy 7075 using carburizing method
- To examine changes made on the grindability by measuring parameters like material removal rate (MRR) and surface roughness (SR) of carburized aluminum alloy 7075

- To optimize grinding process parameters namely depth of machined surface layer, cutting feed depth, wheel speed and material hardness for carburized Al-7075 alloy using Taguchi method coupled with Grey Relational Analysis (GRA)

1.5 Scope of the research

The main scope of the research was evaluating the enhancement of abrasive grinding performance of Al -7075 alloy by undergoing 400^0C, 450^0C and 500^0C carburization treatment in box furnace and surface grinding experiment followed by the roughness and material removal rate measurement for mean effect and interaction analysis with achieved surface hardness, depth of layer from surface, wheel speed and depth of cut using Tagughi L18 and Relational Analysis (GRA) for parametric optimization

1.6 Significance of the research

However, grinding and surface finishing of aluminum effectively and efficiently can be challenging for several reasons. The benefits of using aluminum in manufacturing applications mainly of its lightweight, strength, malleability and its corrosion resistance is crucial. Aluminum is a soft metal with a lower melting point than other materials, such as other ferro materials (steel). These characteristics can lead to loading, gouging or heat discoloration while cutting and grinding it. While many factors can impact the results including operator experience and work environment, choosing the right products for the job is key to achieving success. Bringing together the right products with some common best practices can also help to get the job done faster, lowering costs and time spent on rework, and produce the best possible surface finish.

The outcomes of this research will provide the importance but not limited for the application areas of

- Light weight sliding members made of Al-7075 like pneumatic valve spool, Automobile connecting rod pins, Engine piston
- Aluminum alloy Al-7075 artillery casing finishing process. This can reduce possible Warfield gun barrel reaming frequency

- Artilleries warhead base bleed unit finishing. This can also reduce the possible gun barrel gauging and reduce special high finish turning machine utilization

1.7 Research questions

1 How does the amount of carburizing can affect surface hardness of aluminum alloy?
2 What is the effect of surface carburization on the grindability ?
3 How much machinability difference will be achieved at the different surface depth of carburized aluminum alloy
4 How much improvement was observed between grinding machined surface texture of carburized aluminum alloy?
5 How much material removal rate was achieved by carburizing?

1.8 Limitation of the study

There were many obstacles while conducting this research work starting from finding the Al-7075 alloy workpiece but the one which resulting on the limitations on the research till the end was the utilizing improved output measurements like on process machining contact temperature measurement, which is mainly applicable for the prediction of the machining contact temperature and its result against machining temperature melting and chips clogging on the grinding wheel surface.

1.9 Motivation statement

The main motivation of conducting this research is mainly because of deep interest in the field and experiencing difficulties of finish machining on artillaries base bleed unit and casing unit manufacturing at HOMICHO ammunition Engineering Industry.

Many of the machinability and other process’s workability properties including material composition, hardness, ductility and melting point has a significant role on production process comprising part machining. Beside those properties, production processes comprising machining operation can be altered by the required shape and size of the part, as well as the accuracy and surface finish, also impact this decision. Also, factors like production volume, cost, and available equipment play a significant role in choosing the most suitable machining operation.

Understanding that, many of headaches of aluminum machining can be eliminated by the development of appropriate machining and pre-machining preparatory process and process parameters development.

1.10 Organization of the thesis

This thesis was focused on the Enhancement of grinding performance of aluminum alloy Al-7075 through carburizing and mainly comprises the pack carburizing or solution heat treatment of the workpiece and grinding on monitored surface grinding machine. This broader content is outlined with five different chapters

Chapter 1: presents the introduction part of this thesis, which mainly includes background, rationale of the study, statement of the problem, objectives, scope, limitations, significance, questions and limitations of the research

Chapter 2: contains review of literatures which includes but not limited to the type, property and functions of aluminum alloys, researches, advancements and trends in metal carburization and grinding and grindability measurements with gaps identified.

Chapter 3: detail presentation of the material and experimental setup preparations, carburization (solution heat treatment), machining measurement on surface grinding machining procedures, process and post surface grinding process, experimental data and statistical analysis using Taguchi on Minitab 19 designed experiment and process parameters optimization using grey relational analysis (GRA)

Chapter 4: mainly includes discussion on result by Taguchi on Minitab 19 and GRA process parameters optimization

Chapter 5: presents the result and discussion on the machinability resultants of carburized Aluminum alloy Al-7075 after carburization and recommendations of related future works.

Chapter 2: Literature review

2.1 Introduction

This chapter presents review works on the available literature including the background of aluminum alloy, grinding process, carburization process and surface response method. It also focus on recent studies or research by authors related to the effect of grinding process parameters on surface roughness, temperature and wear of aluminum alloy or approximately close to the titles of the project.

2.2 Aluminum alloys

Aluminum alloys are alloys in which aluminum is the predominant metal. The ordinary alloying components are copper, magnesium, manganese, silicon, tin and zinc. There are two vital classifications, specifically casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. Approximately 85% of aluminum is utilized for wrought items, such as rolled plate, foils and extrusions. Cast aluminum alloys yield cost-effective items due to the low melting point, in spite of the fact that they for the most part have lower tensile strengths than wrought alloys. The foremost imperative cast aluminum alloy is Al–Si, where the containing levels of silicon is 4% –13%, which contributes to allow great casting characteristics. Aluminum alloys are broadly utilized in building structures and components where light weight or corrosion resistance is required [9].

Alloys composed for the most part out of aluminum have been exceptionally imperative in aviation manufacturing since the presentation of metal-body aircraft. Aluminium-magnesium alloys are both much less flammable than other alloys that contain a really high content of magnesium and lighter than other aluminum alloys [10].

Aluminum alloy surfaces would create a white, protective layer of aluminum oxide, on the off chance that cleared out unprotected by anodizing and/or rectify painting methods. In a wet environment, galvanic erosion can happen when an aluminum alloy is put in electrical contact with other metals with more positive corrosion possibilities than aluminum, and an electrolyte is present that permits particle trade. Alluded to as dissimilar-metal corrosion, this process can happen as exfoliation or as inter-granular erosion. Aluminum alloys can be disgracefully heat treated.

Aluminum alloy compositions are enlisted with The Aluminum Association. Numerous organizations distribute more particular guidelines for the manufacture of aluminum alloy, counting the Society of Automotive Engineers standards organization, particularly its aviation standards subgroups, [11] and ASTM International

Table 1: Composition of aluminum alloys **[11]**.

Alloy designation	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zi**	**Ti**	**Other elements**		**Aluminum**
									Each	**Total**	
1060	0.25	0.35	0.05	0.03	0.03	-	0.05	0.03	0.03	0.15	99.6 min
1100	0.95		0.05-0.2	0.05	-	-	0.1	-	0.05	0.15	99.00 min
1230	0.7		0.1	0.05	0.05	-	0.1	0.03	0.03	0.15	99.3 min
2014	0.5-1.2	0.7	3.9-5	0.4-1.2	0.2-0.8	0.1	0.25	0.15	0.05	0.15	Remainder
Al Clad 2014	2014 Clad with 6003								0.05	0.15	Remainder
2024	0.5	0.5	3.8-4.9	0.3-0.9	1.2-1.8	0.1	0.25	0.15	0.05	0.15	Remainder
Al Clad 2024	2024 Clad with 1230								0.05	0.15	Remainder
2124	0.2	0.3	3.8-4.9	0.3-0.9	1.2-1.8	0.1	0.25	0.15	0.05	0.15	Remainder
2219	0.2	0.3	5.8-6.8	0.2-0.4	0.02	-	0.1	0.02-0.1	0.05	0.15	Remainder
Al Clad 2219	2219 Clad with 7072								0.05	0.15	Remainder
3003	0.3	0.7	0.05-0.2	1-1.5	-	-	0.1	-	0.05	0.15	Remainder
Al Clad 3003	3003 Clad with 7072								0.05	0.15	Remainder
3004	0.3	0.7	0.25	1-1.5	0.8-1.3	-	0.25	-	0.05	0.15	Remainder
Al Clad 3004	3004 Clad with 7072								0.05	0.15	Remainder
3005	0.6	0.7	0.3	1-1.5	0.2-0.6	0.1	0.25	0.1	0.05	0.15	Remainder
3105	0.6	0.7	0.3	0.3-0.8	0.2-0.8	0.2	0.4	0.1	0.05	0.15	Remainder
5005	0.3	0.7	0.2	0.2	0.5-1.1	0.1	0.25	-	0.05	0.15	Remainder
5010	0.4	0.7	0.25	0.1-0.3	0.2-0.6	0.15	0.3	0.1	0.05	0.15	Remainder
5050	0.4	0.7	0.2	0.1	1.1-1.8	0.1	0.25	-	0.05	0.15	Remainder
5052	0.25	0.4	0.1	0.1	2.2-2.8	0.15-0.35	0.1	-	0.03	0.15	Remainder
5083	0.4	0.4	0.1	0.4-1	4-4.9	0.05-0.25	0.25	0.15	0.05	0.15	Remainder
5086	0.4	0.5	0.1	0.2-0.7	3.5-4.5	0.05-0.25	0.25	0.15	0.05	0.15	Remainder
5154	0.25	0.4	0.1	0.1	3.1-3.9	0.15-0.35	0.2	0.2	0.05	0.15	Remainder
5252	0.08	0.1	0.1	0.1	2.2-2.8	-	0.05	-	0.05	0.15	Remainder
5254	0.45		0.05	0.01	3.1-3.9	0.15-0.35	0.2	0.05	0.05	0.15	Remainder
5454	0.25	0.4	0.1	0.5-1	2.4-3	0.05-0.20	0.25	0.2	0.05	0.15	Remainder
5456	0.25	0.4	0.1	0.5-1	4.7-5.5	0.05-0.20	0.25	0.2	0.05	0.15	Remainder
5457	0.06	0.1	0.2	0.15-0.45	0.8-1.2	-	0.05	-	0.03	0.15	Remainder
5652	0.4		0.04	0.01	2.2-2.8	0.15-0.35	0.1	-	0.05	0.15	Remainder
5657	0.08	0.1	0.1	0.03	0.6-1	-	0.05	-	0.02	0.15	Remainder
6003	0.35-1	0.6	0.1	0.8	0.8-1.5	0.35	0.2	0.1	0.05	0.15	Remainder
6061	0.4-0.8	0.7	0.15-0.4	0.15	0.8-1.2	0.04-0.35	0.25	0.15	0.05	0.15	Remainder
Al Clad 6061	6061 Clad with 7072								0.05	0.15	Remainder
7008	0.1	0.1	0.05	0.05	0.7-1.4	0.12-0.25	4.5-5.5	0.05	0.05	0.15	Remainder
7011	0.15	0.2	0.05	0.1-0.3	1-1.6	0.05-0.20	4.0-5.5	0.05	0.05	0.15	Remainder
7072	0.7		0.1	0.1	0.1	-	0.8-1.3	-	0.05	0.15	Remainder
7075		0.5	1.2-2	0.3	2.1-2.9	0.18-0.28	5.1-6.1	0.2	0.05	0.15	Remainder

Alloy designation	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zi**	**Ti**	**Other elements**		**Aluminum**
									Each	**Total**	
Al Clad 7075	7075 Clad with 7072								0.05	0.15	Remainder
7008 Al Clad 7075	7075 Clad with7008								0.05	0.15	Remainder
7011 Al Clad 7075	7075 Clad with 7011								0.05	0.15	Remainder
7178	0.4	0.5	1.6-2.4	0.3	2.4-3.1	0.18-0.28	6.3-7.3	0.2	0.05	0.15	Remainder
Al Clad 7178	7178 Clad with 7072								0.05	0.15	Remainder

2.3 Grinding of aluminum alloys

Grinding includes removing material from a work piece with a grinding wheel or grating belt. The free cutting hard aluminum alloys are comparatively simple to grind. The non-free-cutting alloys, especially in their milder temperature, are likely to clog grinding wheels, and they don't finish to as shinning and smooth to do harder alloys [12].

The grinding is exceptionally imperative operation of finishing strategies. The workpiece has last shape and size with precision. The precision can be required in surface profile, geometrical exactness, hardness or residual stress. Grinding of aluminum alloys don't belong to usual strategies of aluminum alloys machining. Conventional technology for Al alloys machining are turning, milling and drilling [13]. However, conventional advances do not fill extraneous necessities & terms of surface quality. When it is required higher rate accuracy of surface shapes and finish, for example in case one require higher geometrical precision (roundness). The traditional processes of Al alloys are shaping and precision press forming. The grinding of aluminum can be utilized not as it were in post to previously mentioned conventional production forms but also in assembly and repair operations.

Now days, there's an intense utilization of aluminum alloys. The utilizing of Al alloys can be found not as it were in common engineering, but also in dynamic developing sector of engineering, specifically automotive industry, cosmonautics, aeronautics, pharmaceutical and in ranges of protection and security of travelers in plane or vehicles [13]. The necessities of the sales and clients on correspondence between production costs and quality of items lead the manufacturers to the utilizing new type of material. These materials are Al alloys with distinctive chemical compositions (Al with Zinc, Copper, Magnesium and Silicon) with diverse mechanical proprieties (strength, ductility, toughness). The inconstancy of casting of these materials gives us more conceivable in different applications in engineering and production technologies.

Grinding isn't so utilized method of machining Al alloys. Essential of grinding is stock removal all at once due to hundreds or thousands small scale edges (grains). These standards essentially affecting machined surface in sight of heat balance. Aluminum alloys have lower melting point than steels or cast iron. For example, Stress of the surface due to thousands edges in grinding leads to higher heat and rise of conceivable negative impacts. Conventional effect that can be made by higher heat is loss of cutting power of grinding wheels. The loss of cutting power inspires by impact of pores and glue up of grains. This research depicts better approaches in Al alloys grinding with surface quality [13].

Micro mill-grinding in different processing parameters were fulfilled on aluminum alloy 6061 utilizing electroplated cubic boron nitride (CBN) compound apparatuses and compared with micro milling. The results show following conclusions: Abrasive grains on micro mill-grinding compound instruments may cause self-evident grinding grooves or elevates on work material, and even surface burning at low feed rate and high spindle speed. Surface roughness of micro mill-grinding, increases with the increment of cutting depth and feed rate, but decreases to begin with and after that increases with the increment of spindle speed. The turning point is at spindle speed 48000r/min. The variation law is the same as that in micro processing. According to the assessments of surface topography and roughness, the machined surface of micro mill-grinding is way better than that of micro processing within the same processing conditions. For aluminum alloy 6061, the least surface roughness Ra of micro mill-grinding in this experiment is 0.609μm [14].

Abrasive wheels. Are wheels made of minerals of mineral or artificial origins crushed to grains of specified size and rebounded to wheel of specific size. Abrasive wheels are classified based on kind of abrasive, grain size, bond type, hardness, grade, structure, shape and size. Among those various types, for grinding aluminum alloys, a silicon carbide abrasive in an adaptable base is preferred. Aluminum oxide is rarely prescribed, but for piston grinding and in cutoff wheels. Wheels of medium hardness, with around 46 grit measure and with a synthetic resin bond works best for roughing. For finishing, wheels of better grit size to around 60grit and with vitrified bond are for the most part utilized [12].

Wheel suggestions for a few diverse sorts of grinding operations are given in Table 2: Abrasive wheel selection for materials . The ANSI framework for recognizing the characteristics of grinding wheels is clarified within the article [12].

Table 2: Abrasive wheel selection for materials [12].

Type of abrasive	Materials
Silicon Carbide	➢ Gray and chilled iron ➢ Aluminium and copper ➢ Brass and soft bronze ➢ Cemented carbide ➢ Very hard alloys ➢ Others
Aluminium Oxide	➢ Alloy steels ➢ Carbon steels ➢ Wrought iron ➢ Hard bronzes ➢ High speed stells ➢ Annealed malleable iron ➢ Others

2.4 Carburization of aluminum

The research by [8]. was pointed at figuring out the impact of case hardening treatment on aluminum 7075 toward its hardness and tensile quality. Pack carburizing was the strategy utilized as a carburizing process. It was conducted in 2 hours of holding time in different solution heat treatment temperatures (SHT):

350^{0}C, 400^{0}C, 450^{0}C, and 500^{0}C utilizing Smoergen oven, research also evaluated the Hardness rate of aluminum 7075 case hardening from SHT temperature of 350^{0}C to 500^{0}C is appeared in Figure **1**: VHN Graph of Aluminum 7075 Case Hardening with SHT variation ., where ideal hardness rate is found in SHT temperature of 500^{0}C, specifically, 145.9 VHN in 0.25 mm space from side. This hardening rate, in the event that seen from side test space of 0.25 mm to 0.75 mm, has decreased from 145.9 VHN to 137.0 VHN, moreover, in side space of 1.25 mm, there was reduction to 129.1 VHN, and side space of 1.75 has decreased to 126.4 VHN. In case seen from space of 0.25 mm to 1.75 mm, there was reduction from 145.9 VHN to 126.4 VHN of the data hardness of case hardening material in SHT of 500^{0}C, greatest hardness in surface portion, while core portion of surface experienced reduction [8].

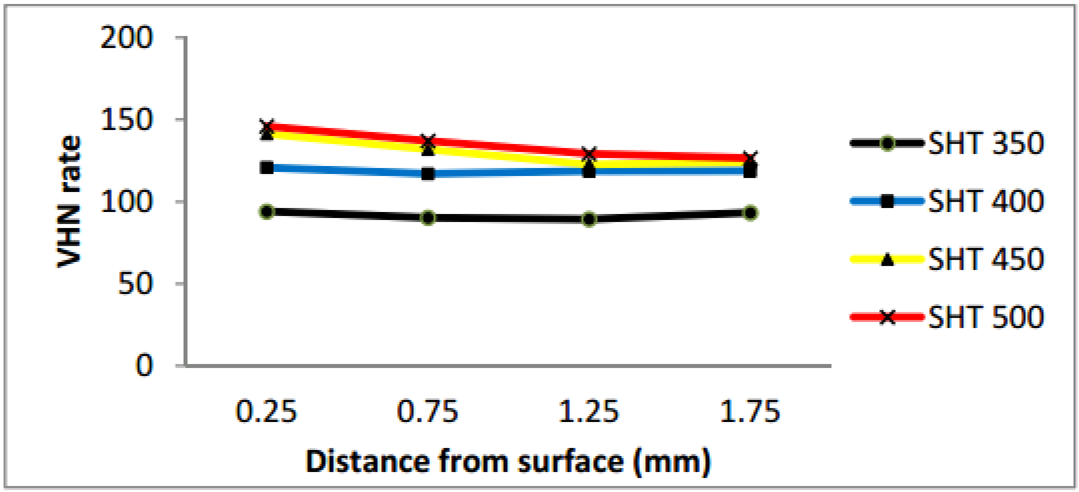


Figure 1: VHN Graph of Aluminum 7075 Case Hardening with SHT variation **[8]**.

Highest hardness of case hardening aluminum is at surface hardness temperature of 500°C with hardness value of 145.9 VHN (test side space of 0.25 mm). The highest tensile strength of aluminum case hardening at SHT temperature of 500°C is 538.3 MPa. The results show that increasing SHT temperature in pack carburizing process can increase tensile strength, cause of increasing hardness values because of Al4C3phase formation in aluminum surface [8].

Research made on the corrosion behavior of carburized aluminum utilizing DC plasma, summarizes that plasma carburizing of aluminum samples was performed in order to elevate their corrosion resistance. Surface examination of altered layer demonstrated that the layer development increases with treatment time and temperature, but the parameter of time is more significant than temperature. In truth, the total surface layer with no defects is formed at higher carburizing time (8 hours), and temperature acts as a promoter. Findings of corrosion tests moreover showed that corrosion behavior of samples depends on the quality of the altered layer, so that, the highest corrosion resistance with no impacts of pitting or localized corrosion was accomplished for samples treated at 700 V, amid 8 h, and at 2 torr, pressure leads to the formation of Al_4C_3 layer with a thickness of 20.06μm; the corrosion current is about 2.519×10^{-7}A/cm2. However, within the case of samples carburized for lower time, localized corrosion was seen at the weak focuses of the layer [15].

The excimer laser cementation process reported is developed to enhance the mechanical and chemical properties of aluminum alloys. It would be interesting to use aluminum alloys in the automotive industry widely because of their low density, corrosion resistance and good workability

[16]. The motor weight can be reduced by replacing usual materials such as iron–steel by light alloys treated to increase their wear resistance. The carbon concentration profiles are decided from Rutherford backscattering spectroscopy (RBS) and scanning electron microscopy (SEM). Crystalline quality is proven by grazing frequency X-ray diffraction (GIXD) procedure. Transmission electron microscopy (TEM) gives the in-depth microstructure. The polycrystalline cemented layer obtained is a few micrometers thick and composed of a unadulterated composition (columnar microstructure) beat layer (200–500-nm thick) standing on a diffusion layer (grains). Fretting test estimations display an advancement of the surface mechanical behavior for a few experimental conditions [16].

By the above researches the researchers find out that the aluminum alloys when carburized forms a hard aluminum carbon refractory composition on the aluminum surface which is assumed and assessed on its value of the surface grinding process.

2.5 Measurement of grind ability

Depending on the application, machinability may be characterized in terms of tool wear rate, total power consumption, achievable surface finish or other benchmarks. Machinability not as it were depending a awesome deal on the perspective of the observer but moreover on the joint influences of a large number of variables, many of which are very complex. For example, machinability is certainly closely connected to the physical and mechanical properties of the workpiece; hard, brittle metals being for the most part more difficult to machine than soft and ductile ones. However, very ductile metals, such as pure copper, stainless steels and a few aluminum alloys tend to create long stringy chips, which makes them difficult to machine. Machinability is additionally emphatically dependent on the type and geometry of tool utilized, the cutting operation, the machine tool, metallurgical structure of the workpiece and tool, the cutting/cooling liquid, and the machinist's skill and experience. It is in this manner not conceivable to describe machinability absolutely which, the term can as it were have meaning in a loose quantitative sense [17].

Although different variables are employed to determine the grindability of aluminum alloy different researchers used and rated the efficiency of the amount they used the research by uses chip thickness as a variable for determination of grindability.

The study of the relationship between chip thickness and the yields of the grinding process has appeared that they are closely connected. Application of distinctive chip thickness models can be utilized to maintain certain key outputs of the process at diverse grinding wheel diameters for a consistent productivity process [7]. However, it has been appeared that both the productivity and chip thickness in grinding have a critical impact on the method each affecting the outputs in several ways. In addition, in spite of the fact that chip thickness includes a relationship with the grinding process outputs, it is best considered as a macro parameter as contradicted to considering the measure of individual chips for an abrasive grain. The conclusions and recommendations illuminate areas of future research inside this subject area. These focus on the application of chip thickness models under diverse process conditions including different grinding setups and material types. In addition, it considers the integration of contact layer hypothesis and cutting fluid convection coefficients to supply improved models for control of the outputs for a grinding process [7].

Tool Life: Tool life may be characterized as the period of time that the cutting tool performs productively. Numerous factors such as material to be machined, cutting tool material, cutting tool geometry, machine condition, cutting tool clamping, cutting speed, feed, and depth of cut, make cutting tool life assurance exceptionally difficult. Metals that can be cut without fast tool wear are generally thought of as being very machinable, and vice versa. A workpiece material with numerous small but hard inclusions may appear to have the same mechanical properties as a less rough metal. It may require no greater power consumption during cutting. However, the machinability of this material would be lower since of its abrasive properties, which will be responsible for fast wear on the cutting tool, coming about in higher machining costs [18].

One issue emerging from the utilize of tool life as a machinability index is its sensitivity to the other machining factors. Of specific significance is the impact of tool material. Machinability ratings based on tool life cannot be compared in case a high-speed steel tool is utilized in one case and a sintered carbide tool in another. The predominant life of the carbide tool would cause the machinability of the metal cut with the steel tool to seem unfavorable [18].

Tool Forces and Power Consumption: The utilization of tool forces or power consumption as a measure of machinability comes about for two reasons. To begin with, the concept of machinability as the ease with which a metal is cut refers that a metal through which a tool is effectively pushed ought to have a good machinability rating. Moment, the more practical concept of machinability in terms of least cost per part machined, relates to forces and power consumption [18].

Surface Finish: The quality of the surface finish on the workpiece amid a cutting operation is some of the time valuable in deciding the machinability rating of a metal. A few workpieces will not yield a good finish as well as others. The elemental reason for surface roughness is the formation and sloughing off of parts of the built-up edge on the tool. Soft, ductile materials tend to create a built-up edge or maybe effortlessly [18].

In numerous cases, surface finish could be a aimless measure of workpiece machinability. In roughing cuts, for example, no consideration to surface finish is required. In many finishing cuts, the conditions creating the desired measurement on the part will intrinsically give a good finish within the engineering determination. Machinability figures based on surface finish measurements don't continuously concur with figures obtained by force or tool life determinations. Stainless steels would have a low rating by any of these measures, whereas aluminum alloys would be rated high. Titanium alloys would have a high rating by finish estimations, low by tool life tests, and halfway by force readings [18].

2.6 *Application of aluminum alloy 7075*

Type 7075 aluminum is one the strongest aluminum alloys. Its high yield strength (>500 MPa) and its low density make the material a fit for applications such as aircraft parts or parts subject to heavy wear [19]. While it is less corrosion resistant than other alloys (such as 5052 aluminum alloy, which is exceptionally resistant to corrosion), some major applications of 7075 aluminum alloy include:

- Aircraft fittings
- Gears and shafts
- Missile parts
- Regulating valve parts
- Worm gears
- Aerospace/defense applications [19]

So as because of its high use in aforementioned application areas, it is crucial to find a solution to ease of manufacturing processes.

2.7 Summary of literature review

As, revised under Table 3: Summary of literature review most research papers and literatures, aluminum alloys have been used in many engineering areas and stayed being a major focus area of researches because of its valuable mechanical properties. meanwhile it has adversely had less response for traditional and cheap metal finishing processes. Although, most researchers tried to cover on aluminum alloy hardening treatment, case hardening, specific application alloy improvement, and laser carburization treatment which is a bit different with this research’s matter in processing methodology.

Table 3: Summary of literature review

S.No	Investigator	Material used	Input parameters considered	Output (response)	Finding of the study
1	Novák, M., Naprstkova, N., & Ruzicka, L. (2011) [13]	• EN AW 2007 (AlCu alloy) • EN AW 6082 (AlMgSi alloy) • EN AW 7075 (AlZn alloy)	grain of grinding wheel, cutting speed and kind of use coolant	Surface roughness evaluation with Ra parameter	suitable selection of cutting conditions, especially grain of grinding wheel, cutting speed and kind of use coolant is fundamental of successfully grinding of Al alloys
2	Gong, Y. D., Wang, C., Cheng, J., Wen, X. L., & Yin, G. Q. (2014) [14]	Aluminium Alloy 6061	radial cutting depth feed rate and spindle speed	surface roughness	Surface roughness of micro mill-grinding increases with the increase of cutting depth and feed rate, but decreases first and then increases with the increase of spindle speed.
3	Darsono, F. B., Triyono, T., & Surojo, E. (2018) [8]	aluminum alloy 7075	Temperature heating of solution heat treatment	tensile strength hardness	Solution heat treatment temperature rise in pack carburizing process increased the tensile strength, while the increase of the hardness value is due to the formation of Al4C3phase on the aluminum surface
4	Pirizadhejrandoost, S., Bakhshzad Mahmoudi, M., Ahmadi, E., & Moradshahi, M. (2012) [15]	Aluminum alloy 1100	DC diode plasma carburizing of aluminum alloy	corrosion behavior	Results of corrosion tests also showed that corrosion behavior of samples depends on the quality of the modified layer
5	Fariaut, F., Boulmer-Leborgne, C., Le Menn, E., Sauvage, T., Andreazza, C., Andreazza, P., & Langlade, C. (2001) [16]	Aluminum alloys	carburization of aluminum alloys by excimer laser	Hardness wear and friction	Results in an increase of the hardness value is due to the formation of Al4C3phase on the aluminum surface

S.No	Investigator	Material used	Input parameters considered	Output (response)	Finding of the study
6	Singleton, R. (2012). Access to Electronic Thesis. Retrieved December 26, 2021 [7]		variation in wheel type and cutting fluid application	chip thickness parameters	Maintenance of the S chip thickness parameter is the optimum method for maintaining Net Power and Specific Grinding Energy for a constant productivity process.

2.8 Gaps identified

In the research's tried to revised in this research paper are considerably observed that the property improvement with hardening or carburizing process is not assessed in the manner to provide preparatory mechanical property improvement for further processes rather to only improve mechanical property. And the reverse is also not assessed in the manner that grindability limitation of the material to be improved by prior treatments. To overcome these limitations and getting additional applicability freedom this research is expected to fill the gaps shown in regard. This research may resolve a gap by which it can combine two promissory not enough assessed research topics in combination (i.e. aluminum carburization and aluminum grinding)

Chapter 3: Methods and Materials

3.1 Methodology

The experimental process of evaluating the improvement of grindability by solution heat treatment or commonly called pack carburization started with process of pack carburizing which has mainly comprises of temperature heating (at 400^0C, 450^0C and 500^0C at each batch) of solution heat treatment for 2 hours using box heater furnace. The process was started by putting the specimen in coal powder and graphite mixtures in closed steel container at rated ratio of coal powder and graphite solution. The solution heat treatment was conducted and followed by quenching process and carried in solution of nitrites and this potentially resulted on the increment of surface hardness of the material followed by surface grind machining test on surface grinder at different surface depth, feed rate and wheel speed.

Particularly this research was used experimental research design method, that establishes a relationship between the cause and effect of a situation. It is a causal design where one observes the impact caused by the independent variable (carburization treatment of aluminum alloys) on the dependent variable or specifically grinding machinability of aluminum alloys. The carburization treatment variables were manipulated to monitor the change it has on the grind machinability.

Experimental data were collected through active intervention to produce and measure change or to create difference when a variable is altered. As experimental data typically allows determining a causal relationship and is typically projectable to a larger population. These types of data are often reproducible, but it often can be expensive to do so. This research can register;

- material removal rate (MRR),
- Surface roughness (SR)
- surface hardness (pre and post to solution heat treatment)

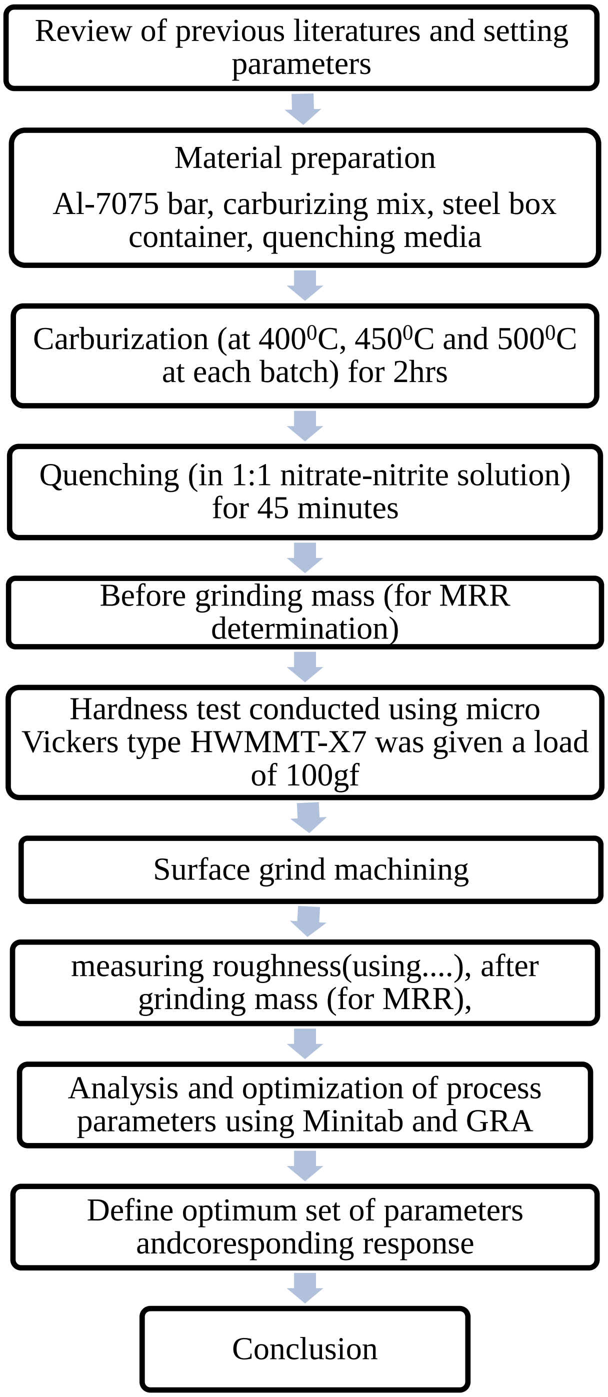


Figure 2: Analysis work flow diagram

3.2 Materials preparation

1. Aluminium alloy 7075 (Al-7075)

7075 aluminium alloy (AA7075) is an aluminium alloy with zinc as the main alloying element. It has excellent mechanical properties and exhibits high strength, good ductility, good resistance to fatigue and toughness [8]

For the research evaluation the researcher [8] used T6 tempered Al-7075 alloy with Table **4**: Chemical composition of Al-7075, an ultimate tensile strength of 530 MPa and yield strength of 450 MPa. For this research experiment this material flat machined to flat bar with: 10mm x 100mm x 250mm (thickness x width x length) size.

Table 4: Chemical composition of Al-7075 (spectrometric tested on the sample)

Alloy designation	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**	**Other elements**		**Aluminium**
								Each	**Total**	
Al-7075	0.5	1.2-2	0.3	2.1-2.9	0.18-0.28	5.1-6.1	0.2	0.05	0.15	Remainder

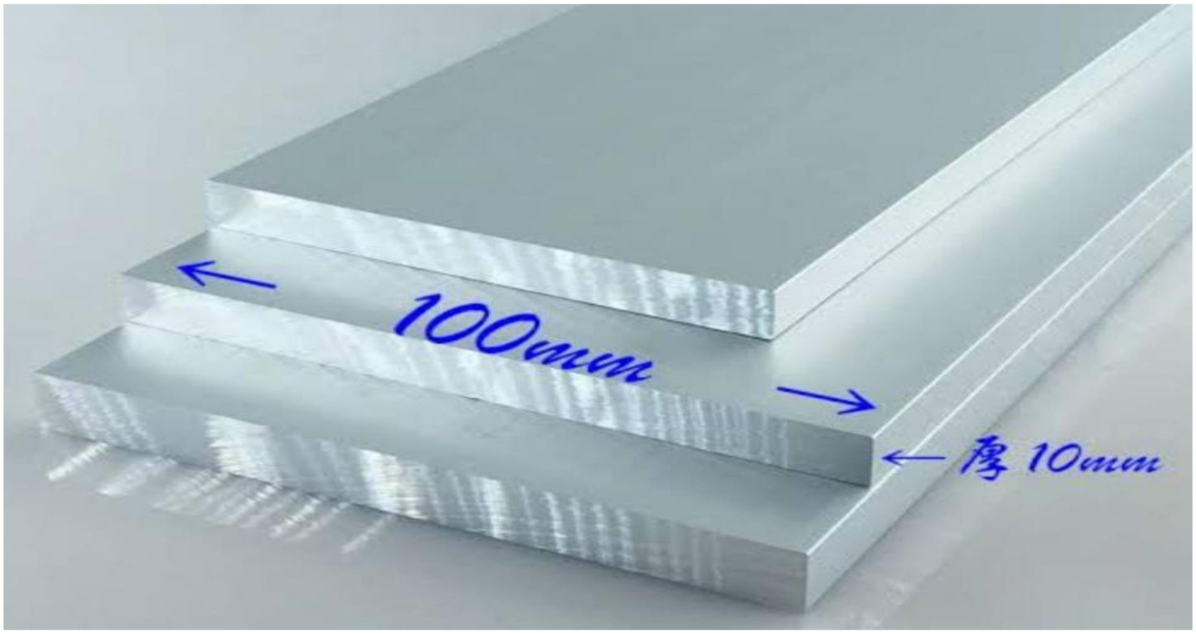


Figure 3: Aluminum alloy bar 7075 for experiment

2. Coal

The coal which was the main solution heat treating component. Which predominantly composed and highest source of carbon that is readily combustible. Coal is black or brownish-black, and has a composition that consists of more than 70 percent by volume of carbonaceous material and some moisture also. It is formed from plant remains that have been compacted, hardened, chemically altered, and metamorphosed by heat and pressure over geologic time.

Apart from that, coal is a natural mineral that forms over the span of millions of years and while charcoal is a manufactured product created from wood and appeared porous and light weight, they have no remarkable difference in the material composition and carburizing effect so the researcher used charcoal by grinding to its powder form

3. Barium carbonate

It is a white salt that is poorly soluble in water. It occurs as the mineral known as witherite. Barium carbonate is widely used in the ceramics industry as an ingredient in glazes. It acts as a flux to remove impurities

Table 5: Properties of barium carbonate **[20]**

Chemical formula	$BaCO_3$
Molar mass	197.34 g/mol
Appearance	white crystals
Odor	odourless
Density	4.286 g/cm^3
Melting point	811 °C (1,492 °F; 1,084 K) polymorphic transformation
Boiling point	1,450 °C (2,640 °F; 1,720 K) decomposes[1] from 1360 °C
Solubility in water	16 mg/L (8.8°C) 22 mg/L (18 °C) 24 mg/L (20 °C) 24 mg/L (24.2 °C)

Figure 4: Barium carbonate powder

Table 6: Barium carbonate product specifications **[20]**

Appearance	White powder
Assay (complexometric; on dried basis)	Min 98.0 %
Substance insoluble in diluted HCL	Max 0.05%
Chloride (Cl)	Max 0.05%
Sulphide (S)	Max 0.001%
Heavy metal (as Pb)	Max0.003%
Iron (Fe)	Max 0.005%
Strontium (Sr)	Max0.8 %

4. Calcium carbonate

Calcium carbonate is also used in the purification of the aluminium like it used in purification of iron from iron ore in a blast furnace. The carbonate is calcined in heating oven to give calcium oxide, which forms a slag with various impurities present, and separates from the aluminium workpiece.

Table 7: Chemical and physical properties of calcium carbonate [21]

Chemical formula	CaCO3
Molar mass	100.0869 g/mol
Appearance	Fine white powder; chalky taste
Odor	odourless
Density	2.711 g/cm3 (calcite) 2.83 g/cm3 (aragonite)
Melting point	1,339 °C (2,442 °F; 1,612 K) (calcite) 825 °C (1,517 °F; 1,098 K) (aragonite)
Boiling point	decomposes
Solubility in water	0.013 g/L (25 °C)

Figure 5: Calcium carbonate powder

Table 8: Calcium carbonate product specifications **[21]**

Appearance	White powder
Assay (complexometric; on dried basis)	98-100.5%
Identification	Pass test
Substance insoluble in acetic acid	Max 0.2%
Chloride (Cl)	Max 0.025%
Sulphate (SO_4)	Max 0.3%
Heavy metal (as Pb)	Max0.002%
Iron (Fe)	Max 0.02%
Barium (Ba)	Pass test
Arsenic (As)	Max0.0004%
Magnesium (as alkali metals)	Max 1.0 %
Loss on drying (200°C; 4hrs)	Max 2.0%

5. Sodium carbonate

Sodium carbonate serves as a flux by lowering the melting point of aluminum alloy and it also used to reduce calcium or magnesium ions and allow replacing them with carbide particles [22]

when such mixtures of sodium carbonate and calcium carbonate are heated, the carbonates release carbon dioxide, which is being extra source of carbon in solution heat treatment process

Table 9: chemical and physical Properties of sodium carbonate [23]

Chemical formula	Na_2CO_3
Molar mass	105.9888 g/mol (anhydrous) 286.1416 g/mol (decahydrate)
Appearance	White solid, hygroscopic
Odor	Odourless
Density	• 2.54 g/cm^3 (25 °C, anhydrous) • 1.92 g/cm^3 (856 °C) • 2.25 g/cm^3 (monohydrate) • 1.51 g/cm^3 (heptahydrate) • 1.46 g/cm^3 (decahydrate)
Melting point	851 °C (1,564 °F; 1,124 K) (Anhydrous) 100 °C (212 °F; 373 K) decomposes (monohydrate) 33.5 °C (92.3 °F; 306.6 K) decomposes (heptahydrate) 34 °C (93 °F; 307 K) (decahydrate)
Solubility in water	Anhydrous, g/100 mL: • 7 (0 °C) • 16.4 (15 °C) • 34.07 (27.8 °C) • 48.69 (34.8 °C) • 48.1 (41.9 °C) • 45.62 (60 °C) • 43.6 (100 °C)

Figure 6: Sodium carbonate powder

Table 10: chemical and physical Properties of sodium carbonate [23]

Appearance	White crystalline or granular powder
Assay (on anhydrous basis)	Min 99.5 %
Moisture (at 300 ^{0}C)	Max 1.5 %
Chloride (Cl)	Max 0.01 %
Silicate (SiO_2)	Max 0.02 %
Sulphate (SO_4)	Max0.02 %
Iron (Fe)	Max 0.005 %
Heavy metal (As Pb)	Max0.003 %

3.3 Experimental preparation

Pre-delivered T6 tempered Al-7075 unpacked and peel off the anti-oxidation protection film cover Figure **7**. It is a sample for the experiment with an ultimate tensile strength of 530 MPa and yield strength of 450 MPa. It has a failure elongation of 10%. flat machined to flat bar with: 10mm x 100mm x 250mm (thickness x width x length) size

Figure 7: Unpacking and peeling of anti-oxidation film cover

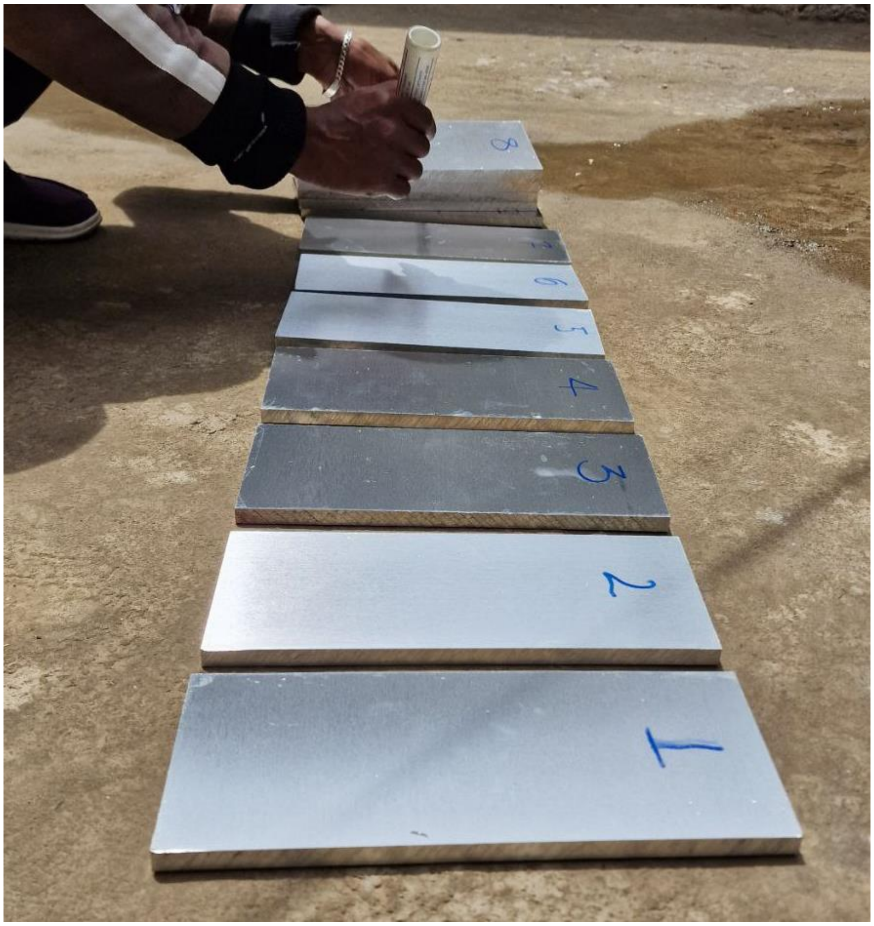


Figure 8: marking on experiment number

3.3.1 Graphite mixture preparation

For pack carburization process the first step was to prepare the carbon source mixture with ratio of coal powder and graphite as (Coal: $BaCO_3$:$NaCO_3$: $CaCO_3$ of 6:3:2:1) [8]

The carburization or solution heat treatment was done with three batches each batch having 6 Al 7075 alloy work pieces of aforementioned size bars and uses 3 kg of pack carburizing mixture because of that the workpiece was needed to get packed in a high carbon medium, so for those three batches of 3Kg mixtures totally required to have 9 kg of mixture.

Table 11: Graphite mixture and chemical requirement

Mixture	**Ratio**	**Mass in Kg = ((9/12) x Ratio of mixtures**	**Requirement per pack (Required Mass in Kg/ unit pack Kg)**
Charcoal	6	4.5 Kg	Available unpacked
$BaCO_3$	3	2.25 Kg	5 packs (each 0.5Kg)
$NaCO_3$	2	1.5 Kg	3 packs (each 0.5Kg)
$CaCO_3$	1	0.75 Kg	2 packs (each 0.5Kg)

Figure 9: Coal, barium carbonate, sodium carbonate and calcium carbonate mixing

3.3.2 Packing work and mixture in steel container

A steel container with lockable top cover of size capable of holding three pieces laterally is prepared and pre-layered with about 5cm depth carburizing mix and the aluminium bar and then applied another layer of mixture then aluminium. Repeating this till last 2 pieces and cover with a layer of carburizing mixture then put on the box cover lock it and prepare to put in furnace

Figure 10: prefilling charcoal carbon mix in lockable steel container

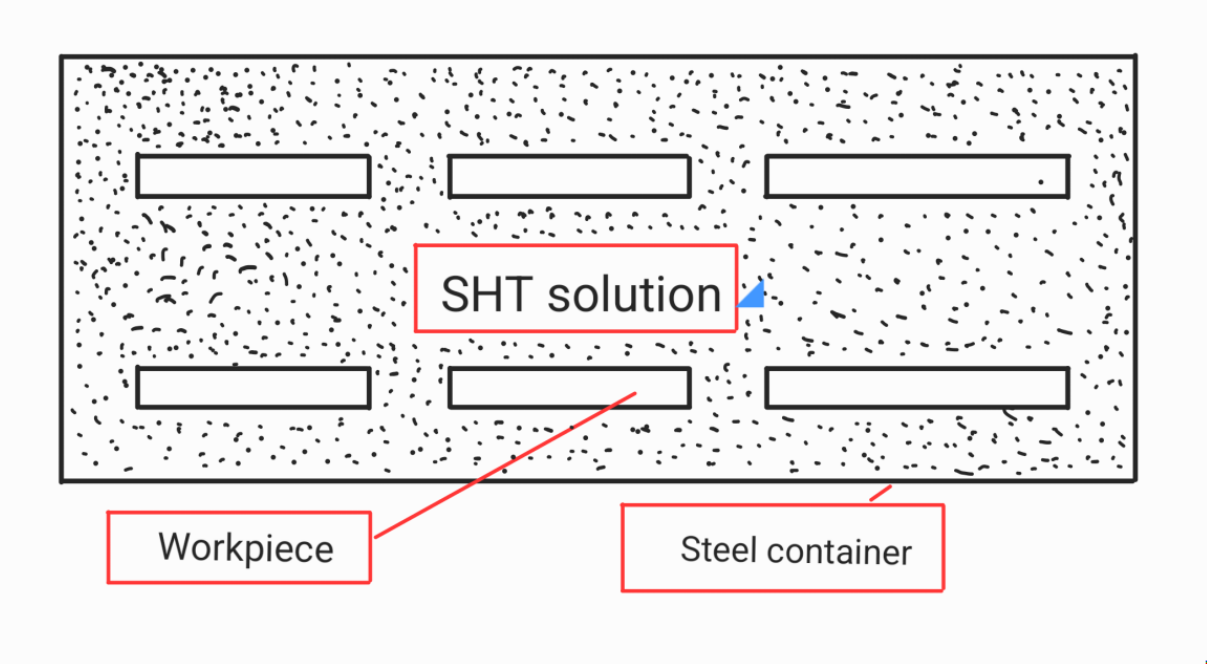


Figure 11: Sample positioning in SHT solution

3.4 Carburization (solution heat treatment)

Treatment process of pack carburizing had the following two stages:

(a) Temperature heating of solution heat treatment (SHT) [8]. SHT temperature heating was conducted for 2 hours using Smit Smoergen heater furnace.

- **1st Batch** – was carried out by backing 6 pieces of pre examined work pieces in a steel box with mixture and put in preheated furnace of 400^{0}C for 2hrs of holding time.
- **2nd Batch** – was conducted by backing 6 pieces of pre examined work pieces in a steel box with mixture and put in preheated furnace of 450^{0}C for 2hrs of holding time.
- **3rd Batch** – was carried out by backing 6 pieces of pre examined work pieces in a steel box with mixture and put in preheated furnace of 500^{0}C for 2hrs of holding time.

(b) Quenching process (in solution of nitrites with ratio 1:1) for 45 minutes [8]. After that, it was polished by autosol.

Further description of the operation is required including the stating its purpose and working requirements (medium, rate, etc)

3.5 Pre machining measurement

1. Hardness measurement

Hardness test was conducted using micro-Vickers type HWMMT-X7 which was given with a load of 100 gf. Dwelling of 10s was carried out on the cross-section surface.

Table 12: Hardness of Al-7075 before carburization

Experiment No	Average hardness measured
1	59.00 VHN
2	59.10 VHN
3	58.69 VHN
4	59.15 VHN
5	59.02 VHN
6	59.06 VHN
7	58.99 VHN
8	59.12 VHN
9	58.99 VHN
10	59.10 VHN
11	59.10 VHN
12	59.06 VHN
13	59.12 VHN
14	59.1 VHN
15	59.1 VHN
16	58.84 VHN
17	59.21 VHN
18	59.19 VHN

The hardness result registered given in Table **12**: Hardness of Al-7075 before carburization it is nearl same that is due to that the Experimental work pieces are cut from one long unit of flat bar to eliminate material factors that can result on result segregation.

2. Mass measurement

The mass of the work piece was measured after the solution heat treatment before the grinding process and after the grinding process to determine the material removal rate by the formula

$$MRR = \frac{\text{Weight (before grinding) Wb} - \text{Weight (after grinding) Wa}}{\text{Time (Sec)}} \text{----------------------------1 [23]}$$

The mass of the workpiece is measured using 0.001g accuracy weighing analytical digital balance

Table 13: Before grind machining weight measurement result

Experiment No	Weight (before grinding) Wb
1	0.758060
2	0.757152
3	0.755790
4	0.758060
5	0.757152
6	0.755790
7	0.753520
8	0.752612
9	0.751250
10	0.753520
11	0.752612
12	0.751250
13	0.758060
14	0.757152
15	0.755790
16	0.753520
17	0.752612
18	0.751250

3. Design of experiments for surface grinding operation

The effect of many different parameters on the performance characteristic in a condensed set of experiments was examined by using the orthogonal array experimental design proposed by Taguchi.

Parameters affecting a process as input variables were:

- Cutting/operation speed,
- Surface depth from carburized end (exposed after machining stages)
- Surface hardness and
- Feed rate (cutting depth)

The levels at which these parameters should be varied was determined. Determining what levels of a variable to test requires an in-depth understanding of the process. Response variables used to describe grindability were;

- Material removal rate (MRR)
- Surface roughness (SR) and

If the difference between the minimum and maximum value of those parameter is large, the values being tested can be further apart or more values can be tested. If the range of a parameter is small, then less value can be tested or the values tested can be closer together.

Knowing the number of parameters and the number of levels, the proper orthogonal array was selected. Using the array selector table **L18** experimental setup was selected.

3.6 Steps used in the implementation of Taguchi method

Step 1: Identification of main purpose and its side effects

The main purpose of this study was surface grinding of pre solution heat treated aluminum 7075 alloy and registering for the response to the grinding operation. The clogging of the aluminum on the grinding wheel was taken as a side effect of the main function if the expected result is not occurring.

Step 2: Identify the control factors, noise factors, testing condition and quality characteristics

Control factors which may have been determined as input variables are: , cutting/operation speed, surface depth from carburized end (exposed after machining stages), surface hardness and feed rate.

Noise factors which are uncontrollable factors during surface grind machining times, and cannot determine their effects on the responses are temperature, operator skill, vibration and raw material type

The quality characters were surface roughness and material removal rate while the test conditions were:

Table 14: Grinding wheel specification

Wheel Type	mid grain Silicon Carbide wheel
Wheel speed:	at 1800 and 2000
Table speed	100mm/sec
Feed/pass:	0.02 mm
Grinding fluid:	Soluble oil: water (1:25)
Time/pass:	20 s

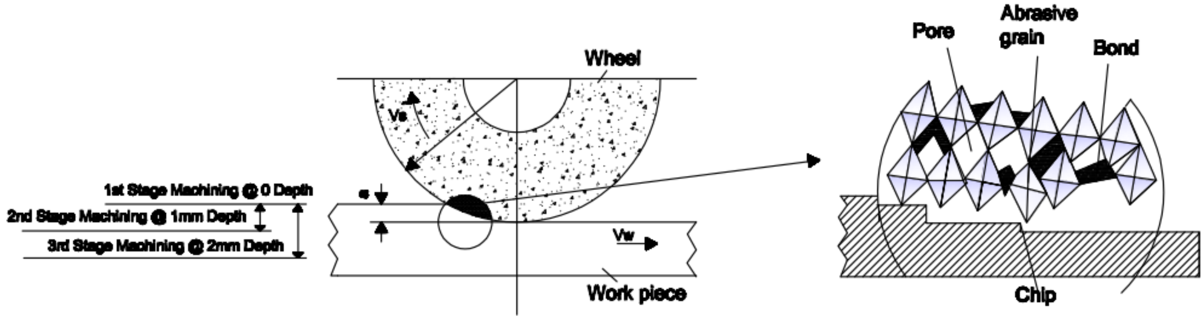


Figure 12: Surface Grinding on different surface depth layers

As shown in the Figure **12**: Surface Grinding on different surface depth layers, the workpiece was subjected to successive machining operations at its depth of 0mm, 1mm and 2mm depth from the surface.

Step 3: Identify the objective function to be optimized

In this study, surface roughness and material removal rates were the output responses to be optimized. Where the prior carburization or solution heat treatment of the alloy was expected to result on that, the surface roughness was best desired to be minimized and material removal rate was to be maximized. So, the signal to noise ratio will be the smaller is the better for surface roughness and the larger is the better for material removal rate analysis.

- The S/N value approach for MRR: the lower – the better

Lower is better S/N = -10 log [1/n (Σ y_i^2)] (n=1) …………………….……2 [24]

- The S/N value approach for MRR: the larger – the better

Larger is better S/N = -10 log [1/n (Σ(1/y_i^2))] (n=1) ………………………3 [24]

Step 4: Identify the levels of machining parameters

The grinding process was carried out and unmounted for the roughness measurement at each predetermined depth of cut (0.02, 0.04 and 0.06mm) at the first surface, at the depth of 1mm and at the depth of 2mm. each levels and corresponding values of surface grinding machining parameters described under Table **15**: Assigned values of machining parameters at different levels and their designated values

Table 15: Assigned values of machining parameters at different levels and their designated values

Factor designation	**Parameters (units)**	**Unit**	**Levels and corresponding values of machining parameters**		
			Level 1	Level 2	Level 3
A	Wheel Speed (RPM)	RPM	1800	1800	2000
B	Average Hardness of the work piece (VHN)	VHN	88	109	171
C	Machined surface at Case Depth	mm	0.00	1.00	2.00
D	DOC (Depth of Cut)	mm	0.02	0.04	0.06

Step 5: Select a suitable Orthogonal Array and construct the Matrix

The Taguchi method involves reducing the variation in a process through robust design of experiments. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources.

Table 16: Taguchi orthogonal array design

Taguchi Array	L18(2^1 3^3)
Factors:	4
Runs:	18

Columns of L18(2^1 3^7) array: 1 2 3 4

Table 17: L18 Taguchi Matrix design

Experiment No	Wheel speed	Work hardness	Surface depth	Depth of cut
1	1800	88	0	0.02
2	1800	88	1	0.04
3	1800	88	2	0.06
4	1800	109	0	0.02
5	1800	109	1	0.04
6	1800	109	2	0.06
7	1800	171	0	0.04
8	1800	171	1	0.06
9	1800	171	2	0.02
10	2000	88	0	0.06
11	2000	88	1	0.02
12	2000	88	2	0.04
13	2000	109	0	0.04
14	2000	109	1	0.06
15	2000	109	2	0.02
16	2000	171	0	0.06
17	2000	171	1	0.02
18	2000	171	2	0.04

3.7 Surface grinding machining procedures

The surface grinding experiment on carburized Al-7075 piece was carried on the surface grinding machine type of surface grinder operating size of 400mm x 250 mm, with automatic in feed electric-cycle control and non-automatic profile dresser with controlled operating conditions

Wheel Type	mid grain Silicon Carbide wheel
Wheel size (outer diameter x width x inner diameter; mm)	Ø500 x 80 x Ø203
Wheel speed:	at 1800 and 2000
Table speed	100mm/sec
Feed/pass:	0.02 mm
Grinding fluid:	Soluble oil: water (1:25)
Time/pass:	20 s

After mounting the work on the machine table, the grinding process was carried out and unmounted for the roughness measurement at each predetermined depth of cut (0.02, 0.04 and 0.06mm) at the first surface, at the depth of 1mm and at the depth of 2mm. in which the carburizing effect is going lower and lower as we going to deeper from the end surface this property's result on the grindability were determined after analyses.

For the determination of material removal rate measurements of radial depth of cut (RDOC), axial depth of cut (ADOC), and inches per minute (IPM) were considered. Further, to evaluate in process melting and clogging of a material, machining temperature measured at contact of tool and work by IR (infrared thermal imaging) imaging camera while the grinding process was going on.

As a post surface grinding process testing the work piece material was measured for its surface roughness to be analyzed as an indicative parameter of grindability.

Table 18: Surface roughness Measurement result

Experiment No	Wheel speed	Work hardness	Surface depth	Depth of cut	Surface roughness (Ra)
1	1800	88	0	0.02	0.356
2	1800	88	1	0.04	0.334
3	1800	88	2	0.06	0.321
4	1800	109	0	0.02	0.518
5	1800	109	1	0.04	0.524
6	1800	109	2	0.06	0.522
7	1800	171	0	0.04	0.724
8	1800	171	1	0.06	0.726
9	1800	171	2	0.02	0.267
10	2000	88	0	0.06	0.265
11	2000	88	1	0.02	0.263
12	2000	88	2	0.04	0.471
13	2000	109	0	0.04	0.469
14	2000	109	1	0.06	0.468
15	2000	109	2	0.02	0.982
16	2000	171	0	0.06	0.980
17	2000	171	1	0.02	0.978
18	2000	171	2	0.04	1.208

Table 19: Material removal rate Measurement result

Experiment No	Wheel Speed (RPM)	Work hardness	Surface depth	Depth of cut	Weight (before grinding) Wb	Weight (after grinding) Wa	Time (Sec)	MRR (kg/sec)	MRR in mm3/sec
1	1800	88	0	0.02	0.758060	0.757152	40.30	2.25E-05	22.531
2	1800	88	1	0.04	0.757152	0.755790	53.17	2.56E-05	25.616
3	1800	88	2	0.06	0.755790	0.753520	94	2.41E-05	24.149
4	1800	109	0	0.02	0.758060	0.757152	71.63	1.27E-05	12.676
5	1800	109	1	0.04	0.757152	0.755790	67.46	2.02E-05	20.190
6	1800	109	2	0.06	0.755790	0.753520	51.34	4.42E-05	44.215

Experiment No	Wheel Speed (RPM)	Work hardness	Surface depth	Depth of cut	Weight (before grinding) Wb	Weight (after grinding) Wa	Time (Sec)	MRR (kg/sec)	MRR in mm3/sec
7	1800	171	0	0.04	0.753520	0.752612	87	1.04E-05	10.437
8	1800	171	1	0.06	0.752612	0.751250	87	1.57E-05	15.655
9	1800	171	2	0.02	0.751250	0.748980	87	2.61E-05	26.092
10	2000	88	0	0.06	0.753520	0.752612	40	2.27E-05	22.700
11	2000	88	1	0.02	0.752612	0.751250	40	3.4E-05	34.050
12	2000	88	2	0.04	0.751250	0.748980	40	5.67E-05	56.750
13	2000	109	0	0.04	0.758060	0.757152	63	1.44E-05	14.413
14	2000	109	1	0.06	0.757152	0.755790	63	2.16E-05	21.619
15	2000	109	2	0.02	0.755790	0.753520	63	3.6E-05	36.032
16	2000	171	0	0.06	0.753520	0.752612	87	1.04E-05	10.437
17	2000	171	1	0.02	0.752612	0.751250	87	1.57E-05	15.655
18	2000	171	2	0.04	0.751250	0.748980	87	2.61E-05	26.092

3.8 Experimental Data and statistical analysis

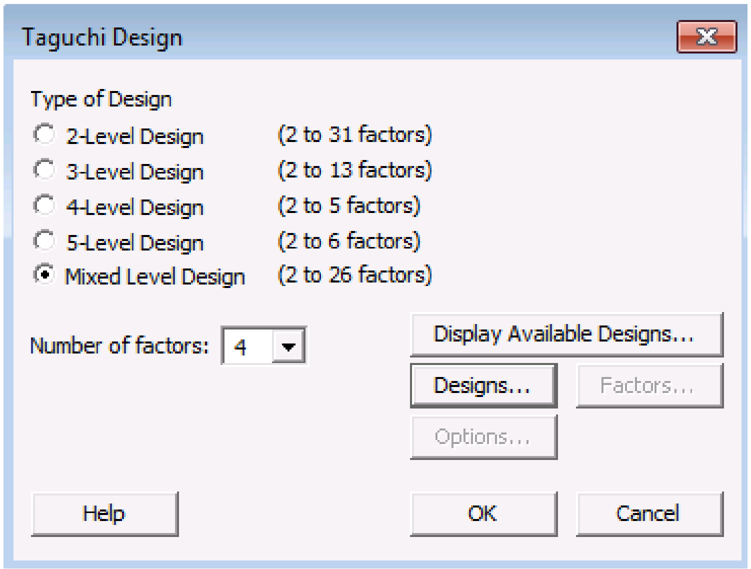
Data for statistical analysis were gotten by conducting carburizing and consequent grinding experiment on the over chosen aluminum alloys by holding factors of interest. One or more of these factors, alluded to as the factors of the study, were controlled so that data may be gotten almost how the variables impact another variable referred to as the response variable, or basically the response. (Particularly, the influence of the carburization on the grinding machinability of aluminum alloy)

A computational strategy as often as possible utilized to analyze the information from an experimental study utilizes a statistical procedure known as the analysis of variance. For experimental designs including different variables, a test for the importance of each individual factor as well as interaction impacts caused by one or more factors acting mutually was conducted. Further discussion of the analysis of variance method is contained within the consequent area.

3.8.1 Conducting a Taguchi on Minitab 19

Steps:

1. Choose **Stat** > **DOE** > **Taguchi** > **Create Taguchi Design** to generate a Taguchi design (orthogonal array). Each column in the orthogonal array represents a specific factor with two or more levels. Each row represents a run; the cell values identify the factor settings for the run.



Taguchi Design

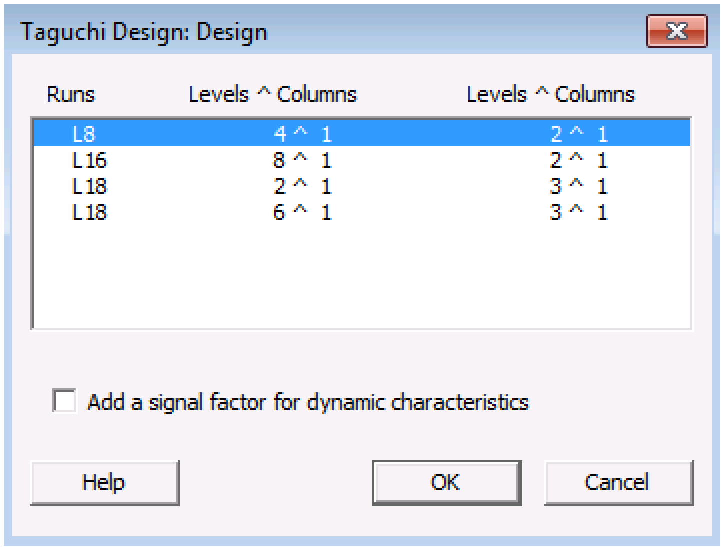
Type of Design

○ 2-Level Design (2 to 31 factors)
○ 3-Level Design (2 to 13 factors)
○ 4-Level Design (2 to 5 factors)
○ 5-Level Design (2 to 6 factors)
● Mixed Level Design (2 to 26 factors)

Number of factors: 4

Figure 13: Taguchi design level selection

2. Select Mixed Level Design > set Number of Factor to 4 > Designs… > then select run L18 with level ^ column: 2^1, 3^3

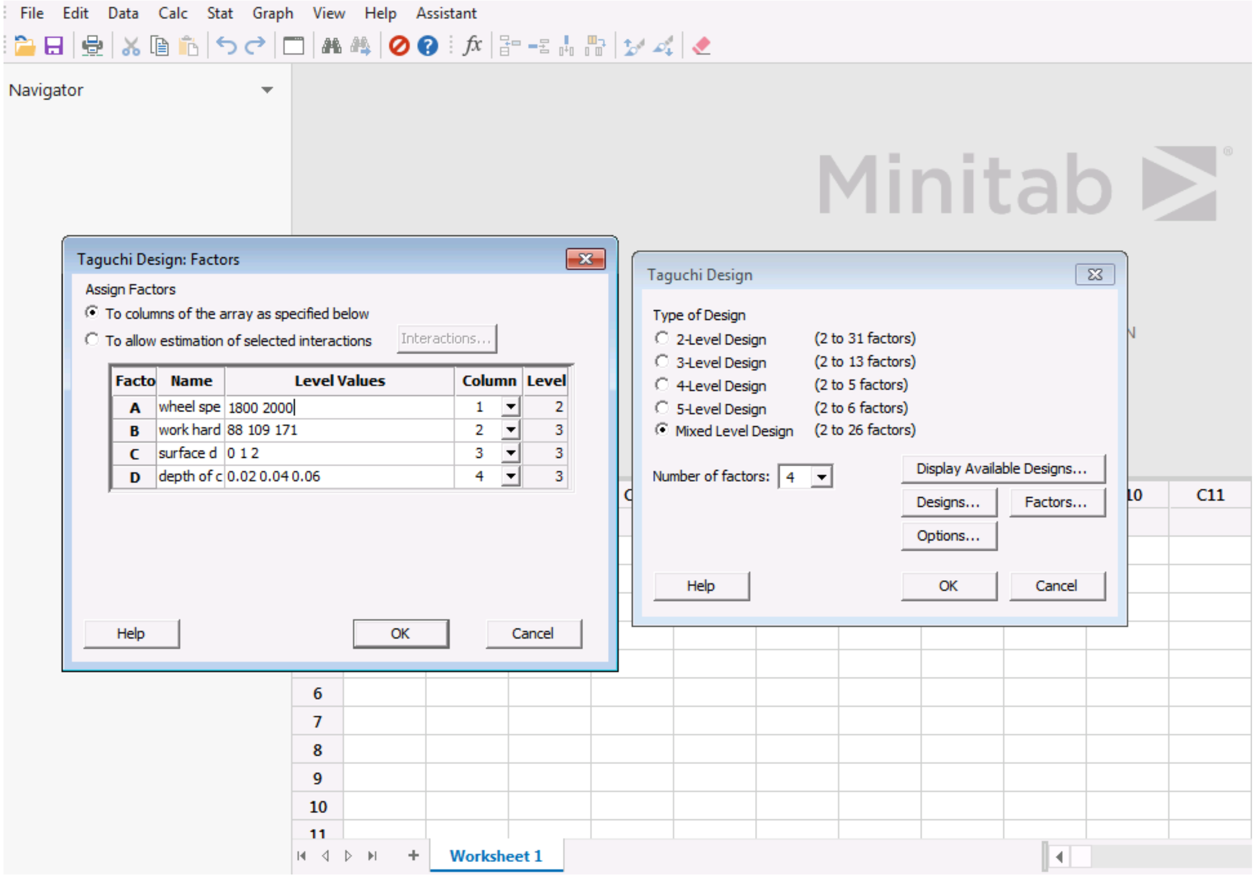


Runs	Levels ^ Columns	Levels ^ Columns
L8	4 ^ 1	2 ^ 1
L16	8 ^ 1	2 ^ 1
L18	2 ^ 1	3 ^ 1
L18	6 ^ 1	3 ^ 1

☐ Add a signal factor for dynamic characteristics

Figure 14: L18 orthogonal array selection

3. Assign level factors and level value



Assign Factors

● To columns of the array as specified below

○ To allow estimation of selected interactions

Facto	Name	Level Values	Column	Level
A	wheel spe	1800 2000	1	2
B	work hard	88 109 171	2	3
C	surface d	0 1 2	3	3
D	depth of c	0.02 0.04 0.06	4	3

Type of Design

○ 2-Level Design (2 to 31 factors)

○ 3-Level Design (2 to 13 factors)

○ 4-Level Design (2 to 5 factors)

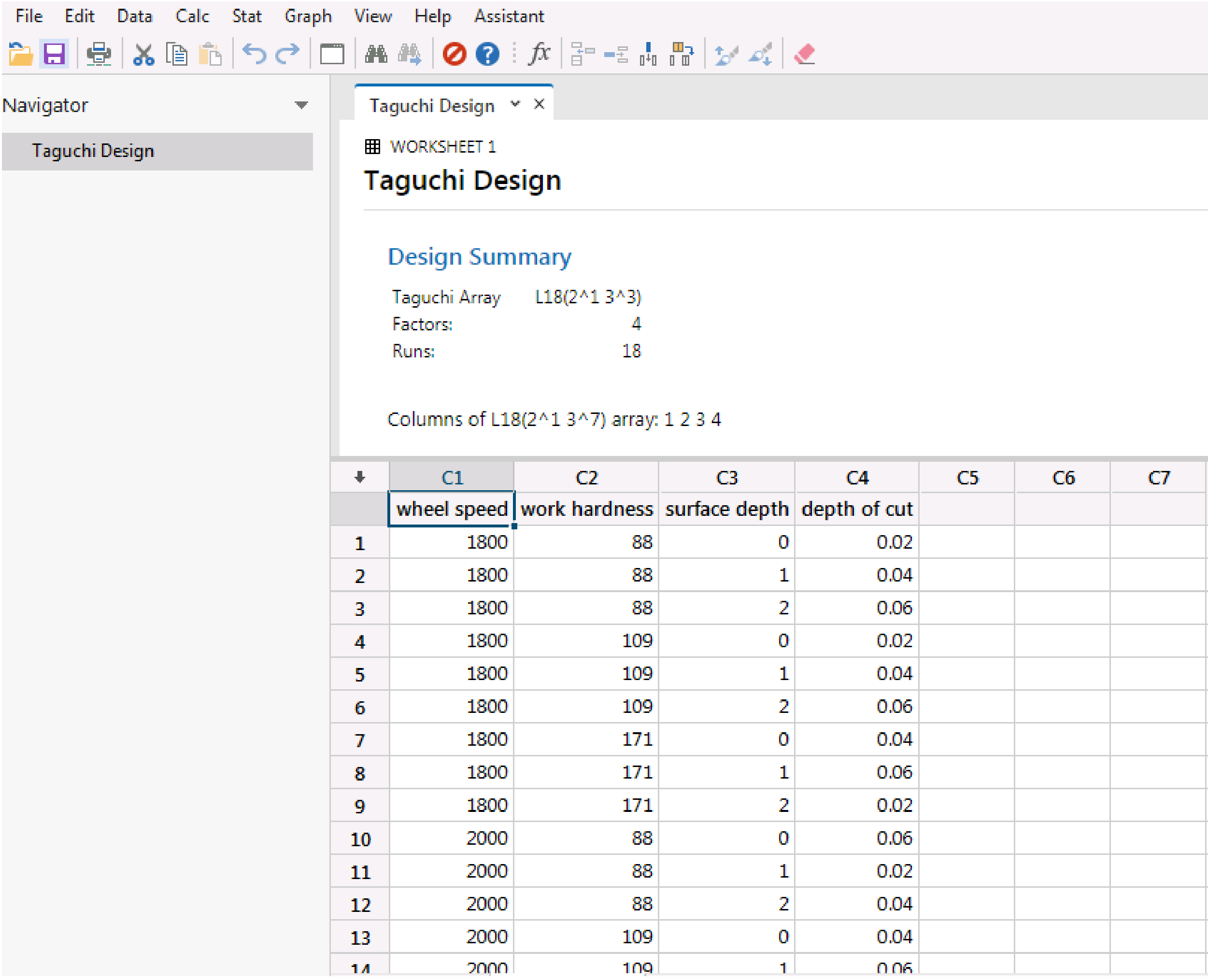
○ 5-Level Design (2 to 6 factors)

● Mixed Level Design (2 to 26 factors)

Number of factors: 4

Figure 15: Assigning level factors

4. Check the generated design summary



Taguchi Design

Design Summary

Taguchi Array	L18(2^1 3^3)
Factors:	4
Runs:	18

Columns of L18(2^1 3^7) array: 1 2 3 4

	C1	C2	C3	C4	C5	C6	C7
	wheel speed	work hardness	surface depth	depth of cut			
1	1800	88	0	0.02			
2	1800	88	1	0.04			
3	1800	88	2	0.06			
4	1800	109	0	0.02			
5	1800	109	1	0.04			
6	1800	109	2	0.06			
7	1800	171	0	0.04			
8	1800	171	1	0.06			
9	1800	171	2	0.02			
10	2000	88	0	0.06			
11	2000	88	1	0.02			
12	2000	88	2	0.04			
13	2000	109	0	0.04			
14	2000	109	1	0.06			

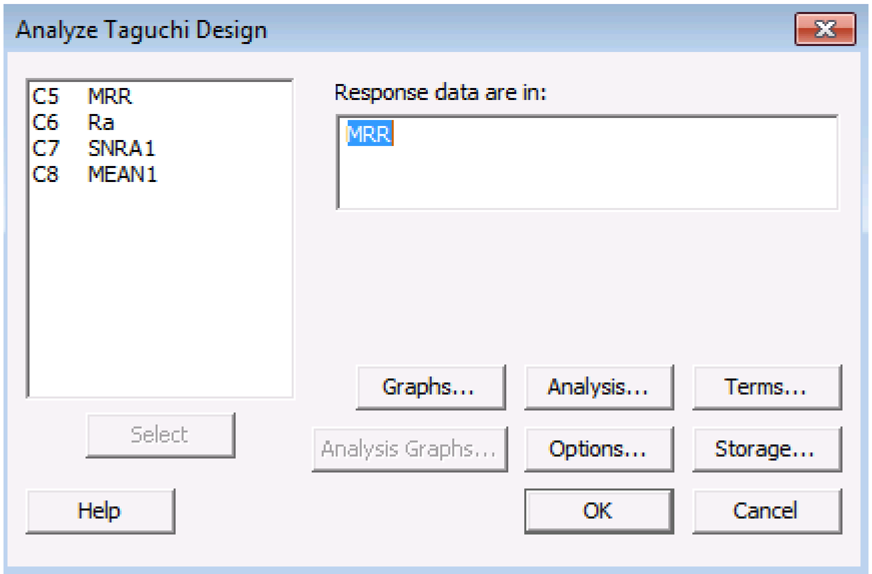
Figure 16: Minitab generated design view

5. Conduct the experiment and collect the response data. The experiment is done by running the complete set of noise factor settings at each combination of control factor settings (at each run). The response data from each run of the noise factors in the outer array are usually aligned in a row, beside the factor settings for that run of the control factors in the inner array.

6. Choose **Stat** > **DOE** > **Taguchi** > **Analyze Taguchi Design** to analyze the experimental data.

For analyzing MRR

Set MRR as response data > Under Graphs**...,** select the desired residual plots of signal to noise ratio and means > under analysis…, select signal to noise ratio and means > select terms > under options, select on larger is better > select data to store


Analyze Taguchi Design

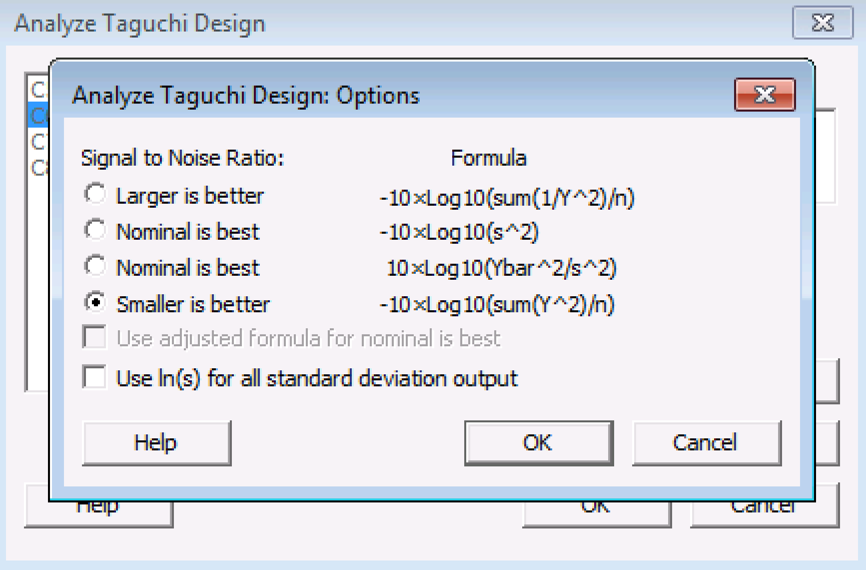
C5 MRR
C6 Ra
C7 SNRA1
C8 MEAN1

Response data are in: MRR

Figure 17: Response data setting for MRR

For analyzing Ra

Set Ra as response data > Under **Graphs**..., select the desired residual plots of signal to noise ratio and means > under analysis…, select signal to noise ratio and means > select terms > under options, select on smaller is better > select data to store



Analyze Taguchi Design: Options

Signal to Noise Ratio:	Formula
○ Larger is better	-10×Log10(sum(1/Y^2)/n)
○ Nominal is best	-10×Log10(s^2)
○ Nominal is best	10×Log10(Ybar^2/s^2)
● Smaller is better	-10×Log10(sum(Y^2)/n)

☐ Use adjusted formula for nominal is best

☐ Use ln(s) for all standard deviation output

Figure 18: Response data setting for Ra

7. Press ok and result be displayed, and interpret the result

3.8.2 Process parameters optimization using Grey relational analysis (GRA)

In Grey relational analysis (GRA), the measured performance characteristics were normalized from zero to one. Then basing on the normalized data, grey relational coefficient (GRC) was calculated. Then Grey relational grade (GRG) was to be generated out by averaging the GRCs. The overall performance response depends on GRG. This process converts a multi response optimizing problem into one response optimizing problem.

When smaller-the-better is a characteristic of the experimental data, then the experimental data can be normalized as follows.

$$\mathbf{Xi(k)} = \frac{\mathbf{max\ xi(k) - xi(k)}}{\mathbf{max\ xi(k) - min\ xi(k)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{4\ [25]}$$

where Xi(k) is the normalized value, xi(k) is the experimental output value. Max xi (k) is the maximum value of the measured experimental value for the kth response. Min xi (k) is the minimum value of the measured experimental value for the kth response.

When the larger-the-better is a characteristic of the experimental data, then the experimental data can be normalized as follows.

$$\mathbf{Xi(k)} = \frac{\mathbf{yi(k) - min\ yi(k)}}{\mathbf{max\ yi(k) - min\ y(k)}} \text{ ………………………………………….. 5 [25]}$$

where Xi(k)= normalized value or grey relational value, yi(k) is the experimental output value. Max yi(k) is the maximum value of the measured experimental value for the kth response. Min yi(k) is the minimum value of the measured experimental value for the kth response.

Then the grey relational coefficient can be calculated as follows.

$$\boldsymbol{\xi}\mathbf{i(k)} = \frac{\boldsymbol{\Delta}\mathbf{min} + \boldsymbol{\Psi\Delta}\mathbf{max}}{\boldsymbol{\Delta}\mathbf{0i(k)} + \boldsymbol{\Psi\Delta}\mathbf{max}} \text{ …………………………………………… 6 [25]}$$

Where ξi(k) is the grey relation coefficient.

Where ***Δ***0i(k)= ǁX0(k)-Xi(k)ǁ is the difference of the absolute value of Xo(k) and Xi(k);

Ψ is the distinguishing coefficient. 0≤ Ψ≤1. Ψ is usually kept as 0.5.

Δmin=the smallest value of Δ0i, and ***Δ***max= the largest value of ***Δ***0i.

After averaging the grey relational coefficient, the grey relational grade was found by the following;

$$\boldsymbol{\gamma i} = \frac{\mathbf{1}}{\boldsymbol{n}} \sum \boldsymbol{\xi}\mathbf{i(k)} \text{ ……………………………………………….. 7 [25]}$$

Where γi is the grey relation grade and n is the number of responses.

The parameter combination with the highest grey relational grade is the optimal condition for combined process parameters.

Chapter 4: Results and discussions

Introduction

Generally, with the aforementioned processes, firstly, treatment process of pack carburizing was carried out. Which mainly comprised of temperature heating of solution heat treatment for 2 hours using box heater furnace, priory by putting the specimen in coal powder and graphite mixtures in closed container. Solution heat treatment temperature was conducted at rated ratio of coal powder and graphite heating and followed by quenching process carried in solution of nitrites and this result on the increment of surface hardness of the material followed by the increment of its grindability. Carburized and polished aluminum alloy 7075 was tested for the response against surface grinding machining for examining material removal rate (MRR) and surface roughness to be optimized by L18 Taguchi method for final result. By considering cutting/operation speed, surface hardness, surface depth and cutting feed depth as an input parameter. The levels at which these parameters varied was determined in-depth experimentation of the process.

4.1 Minitab Taguchi L18 results

4.1.1 Material removal rate of carburized Al-7075 alloy

Table 20: Response Table for Signal to Noise Ratios

Larger is better

Level	wheel speed	work hardness	surface depth	cutting depth
1	26.28	29.29	23.36	27.19
2	27.38	27.01	26.57	26.87
3		24.20	30.57	26.44
Delta	1.10	5.09	7.21	0.74
Rank	3	2	1	4

Table 21: Response Table for Means

Level	wheel speed	work hardness	surface depth	cutting depth
1	22.40	30.97	15.53	24.51
2	26.42	24.86	22.13	25.58
3		17.39	35.55	23.13
Delta	4.02	13.57	20.02	2.45

Rank	3	2	1	4

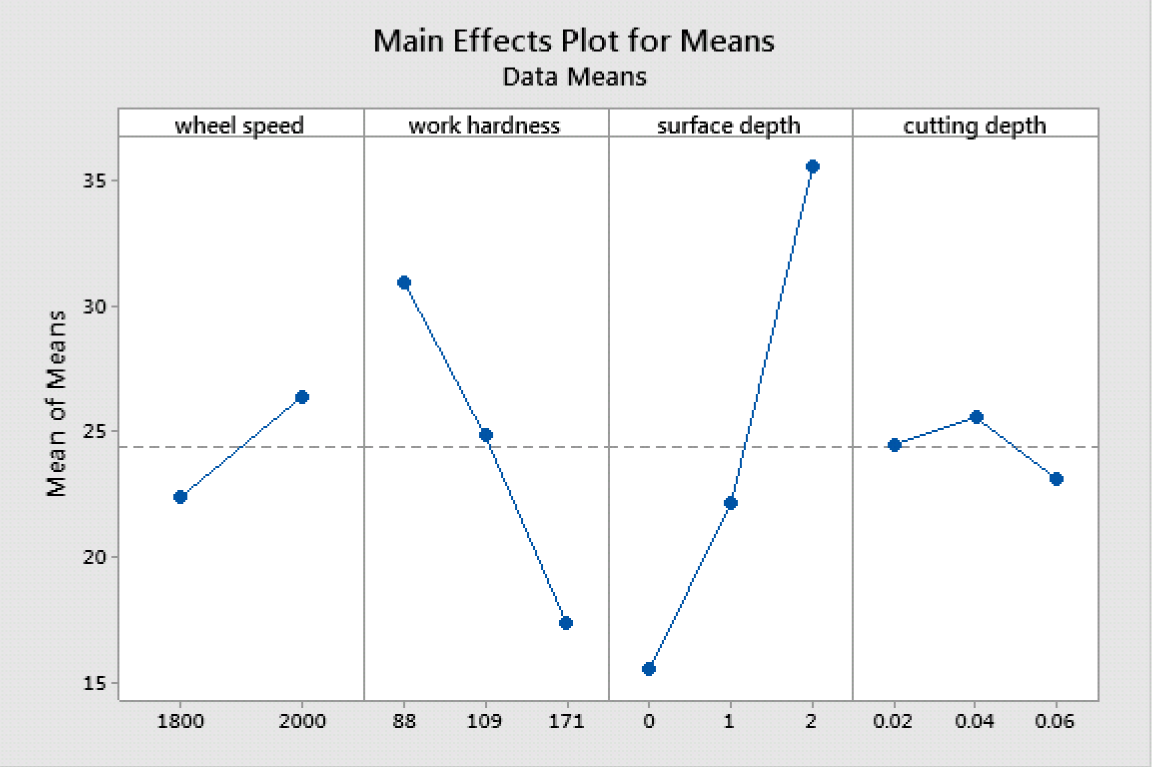


Figure 19: Main effect plot for means (MRR data)

Figure 20: Interaction plot for means (MRR data)

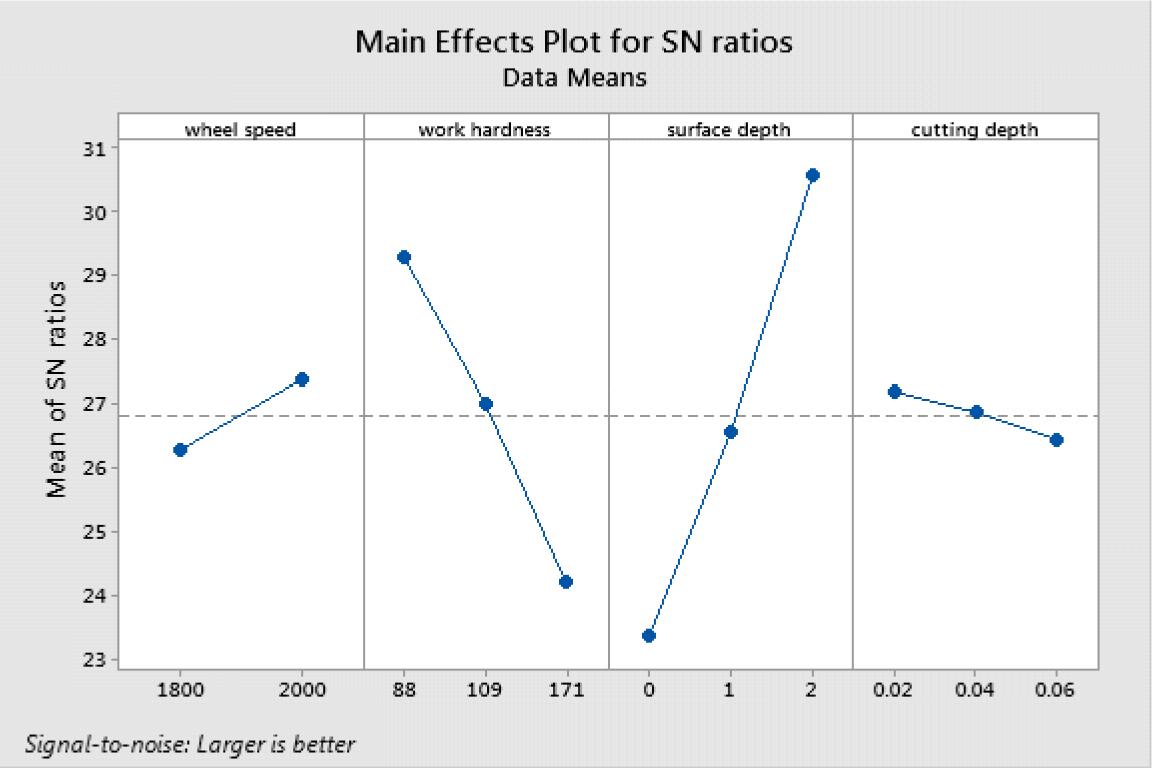


Figure 21: Main effect plot for SN ratios (MRR data)

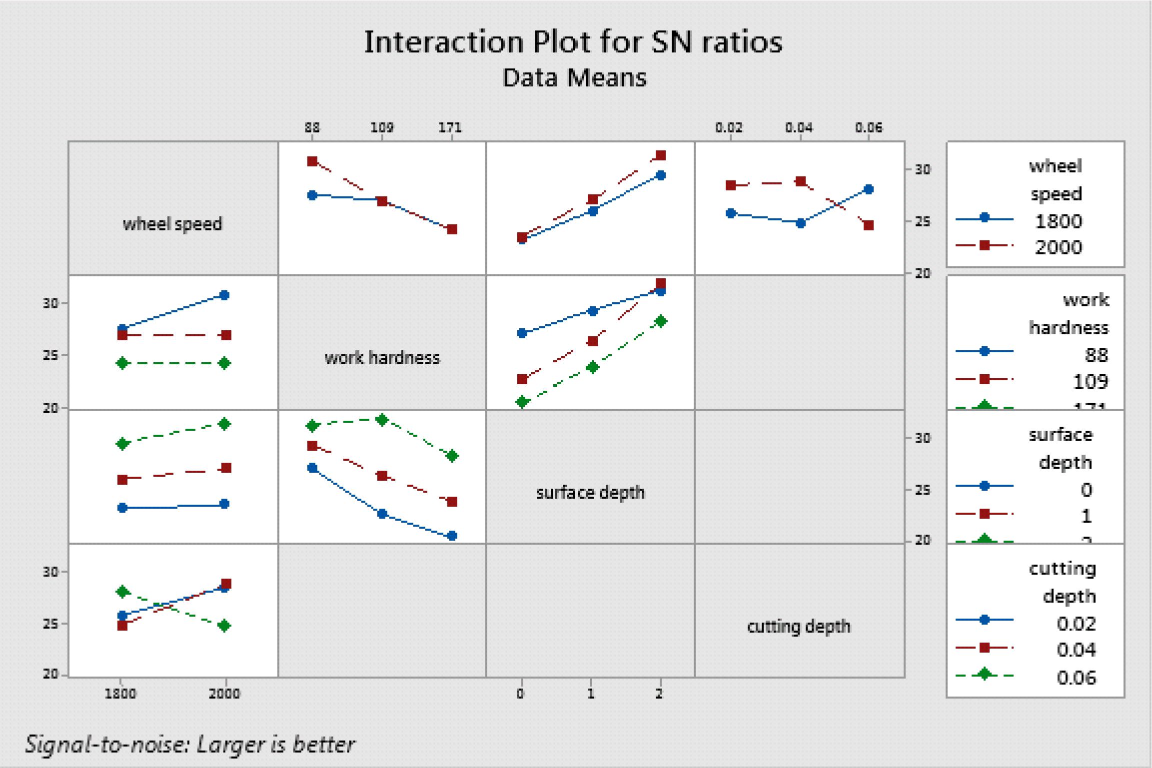


Figure 22: Interaction plot for SN ratios (MRR data)

4.1.2 Surface roughness of carburized Al-7075 alloy

Through solution heat treatment the hardness of the material was increased and expected to increase the surface quality of the surface grinded Al-7075 workpiece. This procedural experiment is then analysed on minitab software with Taguchi L18 experiment to predict the effect-to-effect relation of wheel speed, work hardness, surface depth and cutting depth with surface roughness.

Table 22: Response Table for Signal to Noise Ratios

Level	**wheel speed**	**work hardness**	**surface depth**	**cutting depth**
1	6.933	9.674	5.963	6.351
2	4.637	5.050	6.051	4.903
3		2.631	5.340	6.101
Delta	2.296	7.043	0.711	1.448
Rank	2	1	4	3

Table 23: Response Table for Means

Level	**wheel speed**	**work hardness**	**surface depth**	**cutting depth**
1	0.4769	0.3350	0.5520	0.5607
2	0.6760	0.5805	0.5488	0.6217
3		0.8138	0.6285	0.5470
Delta	0.1991	0.4788	0.0797	0.0747
Rank	2	1	3	4

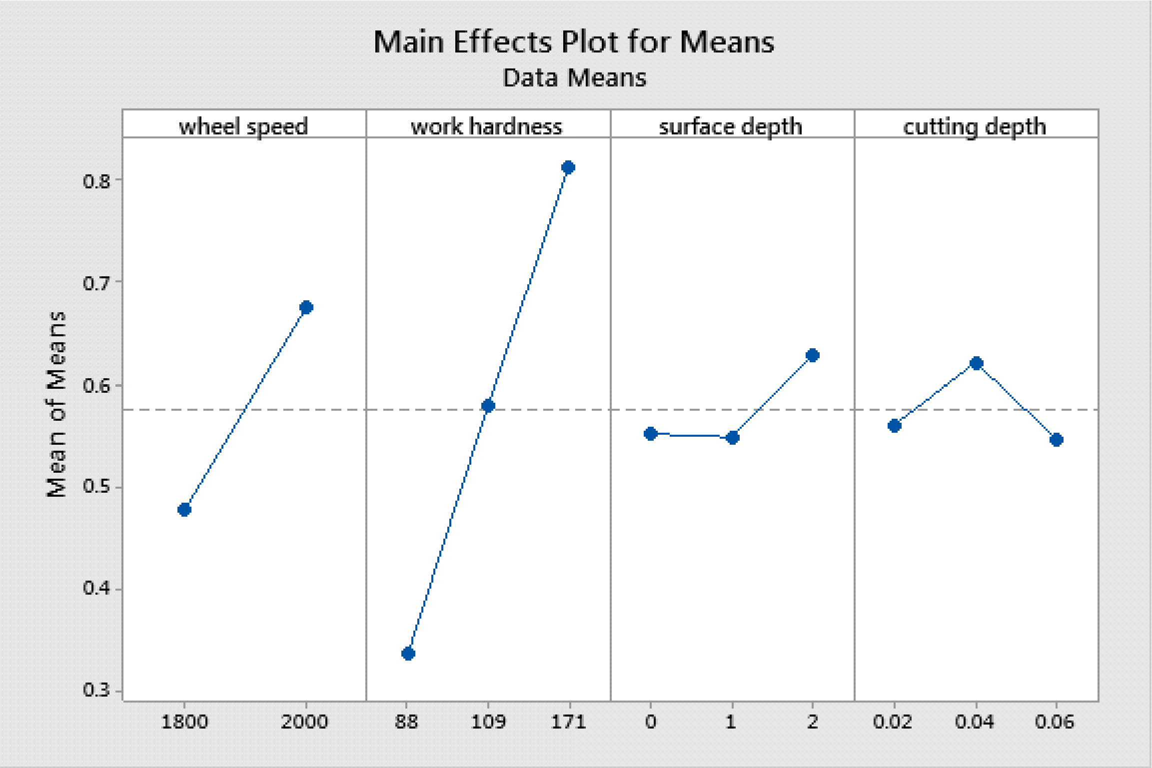
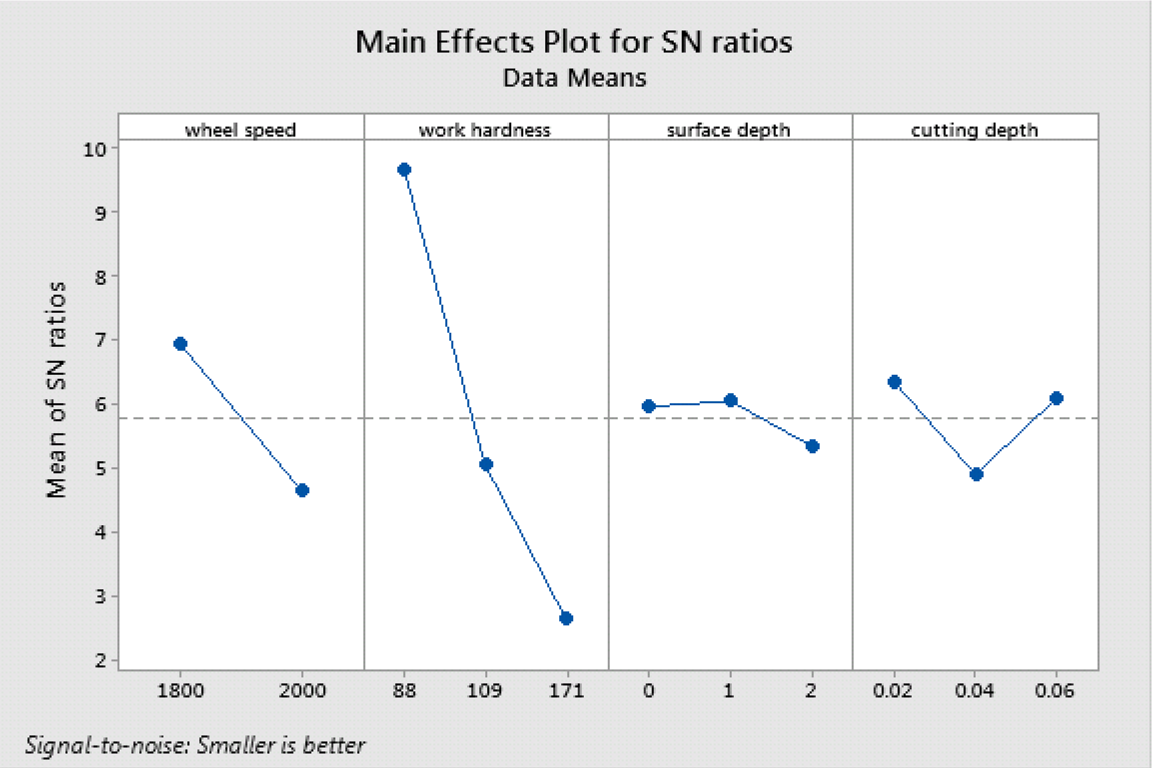


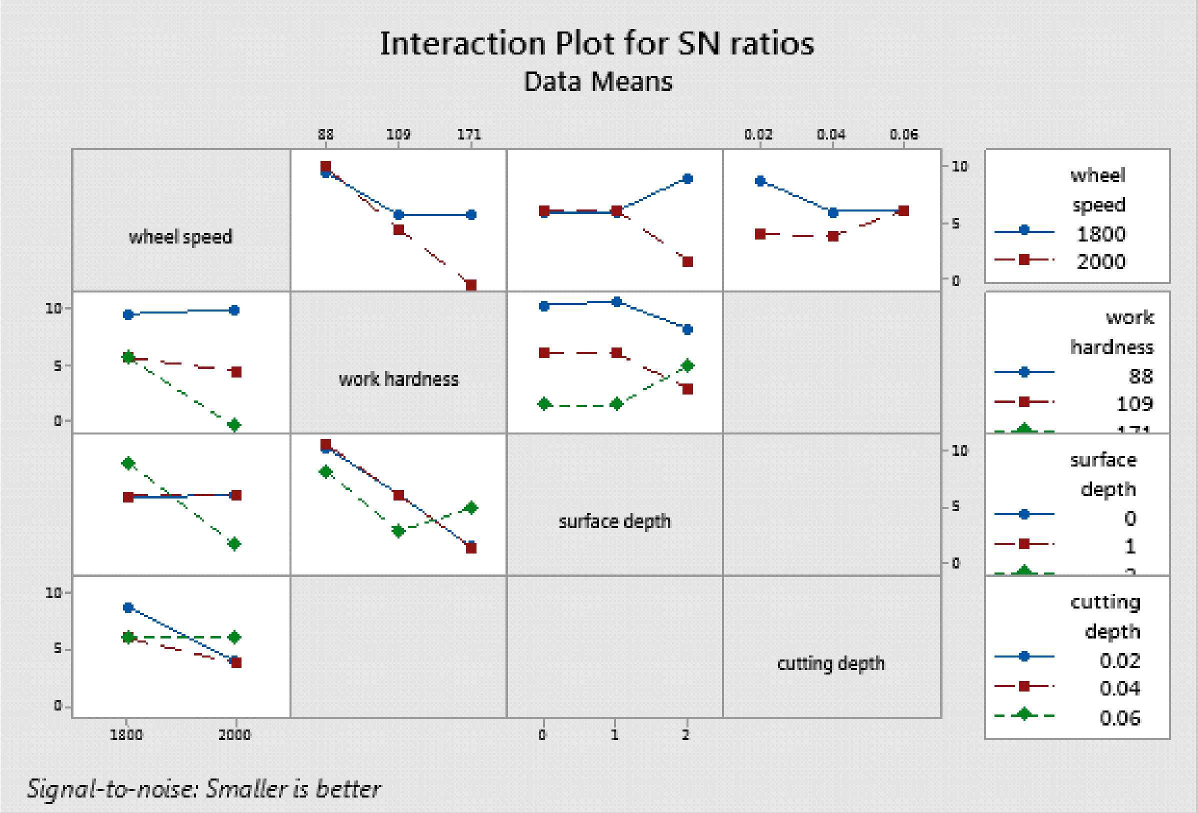
Figure 23: Main effect plot for means (Ra data)

Figure 24: Interaction plot for means (Ra data)


Main Effects Plot for SN ratios
Data Means

Signal-to-noise: Smaller is better

Figure 25: Main Effect plot for SN ratios (Ra data)


Interaction Plot for SN ratios
Data Means

Signal-to-noise: Smaller is better

Figure 26: Interaction plot for SN ratios (Ra data)

4.2 GRA process parameters optimization

In grey relational Analysis, the measured performance characteristics are normalized from zero to one. Then basing on the normalized data, grey relational coefficient calculated. Then Grey relational grade is to be generated out by averaging the grey relational coefficients. The overall performance response depends on grey relational grade. This process converts a multi response optimizing problem into one response optimizing problem.

Table 24: Calculated S/N Ratio

Wheel speed	Work hardness	Surface depth	Depth of cut	MRR	Ra	S/N Ratio	
						MRR	Ra
1800	88	0	0.02	22.531	0.356	27.056	8.971
1800	88	1	0.04	25.616	0.334	28.170	9.525
1800	88	2	0.06	24.149	0.321	27.658	9.870
1800	109	0	0.02	12.676	0.518	22.060	5.713
1800	109	1	0.04	20.190	0.524	26.103	5.613
1800	109	2	0.06	44.215	0.522	32.911	5.647
1800	171	0	0.04	10.437	0.724	20.371	2.805
1800	171	1	0.06	15.655	0.726	23.893	2.781
1800	171	2	0.02	26.092	0.267	28.330	11.470
2000	88	0	0.06	22.700	0.265	27.121	11.535
2000	88	1	0.02	34.050	0.263	30.642	11.601
2000	88	2	0.04	56.750	0.471	35.079	6.540
2000	109	0	0.04	14.413	0.469	23.175	6.577
2000	109	1	0.06	21.619	0.468	26.697	6.595
2000	109	2	0.02	36.032	0.982	31.134	0.158
2000	171	0	0.06	10.437	0.980	20.371	0.175
2000	171	1	0.02	15.655	0.978	23.893	0.193
2000	171	2	0.04	26.092	1.208	28.330	-1.641

Where the maximum and minimum values were

Table 25: Maximum and Minimum S/N Ratios

	MRR	Ra
Min	20.3713	-1.6413
Max	35.0793	11.6009

When smaller-the-better is a characteristic of the experimental data, then the experimental data can be normalized as follows.

$Xi(k) = \frac{\max xi(k) - xi(k)}{\max xi(k) - \min xi(k)}$ ---8 [25]

where Xi(k) is the normalized value, xi(k) is the experimental output value. Max xi (k) is the maximum value of the measured experimental value for the kth response. Min xi (k) is the minimum value of the measured experimental value for the kth response.

Table 26: Normalization result table for Ra

Wheel speed	Work hardness	Surface depth	Depth of cut	MRR	Ra	S/N Ratio		Normalization
						MRR	Ra	Ra
1800	88	0	0.02	22.531	0.356	27.056	8.971	0.199
1800	88	1	0.04	25.616	0.334	28.170	9.525	0.157
1800	88	2	0.06	24.149	0.321	27.658	9.870	0.131
1800	109	0	0.02	12.676	0.518	22.060	5.713	0.445
1800	109	1	0.04	20.190	0.524	26.103	5.613	0.452
1800	109	2	0.06	44.215	0.522	32.911	5.647	0.450
1800	171	0	0.04	10.437	0.724	20.371	2.805	0.664
1800	171	1	0.06	15.655	0.726	23.893	2.781	0.666
1800	171	2	0.02	26.092	0.267	28.330	11.470	0.010
2000	88	0	0.06	22.700	0.265	27.121	11.535	0.005
2000	88	1	0.02	34.050	0.263	30.642	11.601	0.000
2000	88	2	0.04	56.750	0.471	35.079	6.540	0.382
2000	109	0	0.04	14.413	0.469	23.175	6.577	0.379
2000	109	1	0.06	21.619	0.468	26.697	6.595	0.378
2000	109	2	0.02	36.032	0.982	31.134	0.158	0.864
2000	171	0	0.06	10.437	0.980	20.371	0.175	0.863
2000	171	1	0.02	15.655	0.978	23.893	0.193	0.861
2000	171	2	0.04	26.092	1.208	28.330	-1.641	1.000

When the larger-the-better is a characteristic of the experimental data, then the experimental data can be normalized as follows.

$Xi(k) = \frac{yi(k) - \min yi(k)}{\max yi(k) - \min y(k)}$ ---9- [25]

where Xi(k)= normalized value or grey relational value, yi(k) is the experimental output value. Max yi(k) is the maximum value of the measured experimental value for the kth response. Min yi(k) is the minimum value of the measured experimental value for the kth response.

Table 27: Normalization result for MRR

Wheel speed	**Work hardness**	**Surface depth**	**Depth of cut**	**MRR**	**Ra**	**S/N Ratio**		**Normalization**
						MRR	**Ra**	**MRR**
1800	88	0	0.02	22.531	0.356	27.056	8.971	0.454
1800	88	1	0.04	25.616	0.334	28.170	9.525	0.530
1800	88	2	0.06	24.149	0.321	27.658	9.870	0.495
1800	109	0	0.02	12.676	0.518	22.060	5.713	0.115
1800	109	1	0.04	20.190	0.524	26.103	5.613	0.390
1800	109	2	0.06	44.215	0.522	32.911	5.647	0.853
1800	171	0	0.04	10.437	0.724	20.371	2.805	0.000
1800	171	1	0.06	15.655	0.726	23.893	2.781	0.239
1800	171	2	0.02	26.092	0.267	28.330	11.470	0.541
2000	88	0	0.06	22.700	0.265	27.121	11.535	0.459
2000	88	1	0.02	34.050	0.263	30.642	11.601	0.698
2000	88	2	0.04	56.750	0.471	35.079	6.540	1.000
2000	109	0	0.04	14.413	0.469	23.175	6.577	0.191
2000	109	1	0.06	21.619	0.468	26.697	6.595	0.430
2000	109	2	0.02	36.032	0.982	31.134	0.158	0.732
2000	171	0	0.06	10.437	0.980	20.371	0.175	0.000
2000	171	1	0.02	15.655	0.978	23.893	0.193	0.239
2000	171	2	0.04	26.092	1.208	28.330	-1.641	0.541

Then the grey relational coefficient was calculated as follows.

$\xi i(k) = \frac{\Delta min + \Psi\Delta max}{\Delta 0i(k) + \Psi\Delta max}$ ---10 **[25]**

Where ξi(k) is the grey relation coefficient.

Where ***Δ***0i(k)= ‖X0(k)-Xi(k)‖ is the difference of the absolute value of Xo(k) and Xi(k);

Ψ is the distinguishing coefficient. 0≤ Ψ≤1. Ψ is usually kept as 0.5.

Δmin=the smallest value of Δ0i, and ***Δ***max= the largest value of ***Δ***0i.

Table 28: Grey relational coefficient

Experiment No	Grey Relational coefficient	
	MRR	**Ra**
1	0.478	0.384
2	0.516	0.372
3	0.498	0.365
4	0.361	0.474
5	0.450	0.477
6	0.772	0.476
7	0.333	0.598
8	0.397	0.600
9	0.521	0.336
10	0.480	0.334
11	0.624	0.333
12	1.000	0.447
13	0.382	0.446
14	0.467	0.446
15	0.651	0.786
16	0.333	0.785
17	0.397	0.783
18	0.521	1.000

After averaging the grey relational coefficient, the grey relational grade was found by the following;

$\gamma i = \frac{1}{n}\sum \xi \mathrm{i}(\mathrm{k})$ --11 [25]

Where γi is the grey relation grade and n is the number of responses.

Table 29: Grey relation Grade and Rank

Experiment No	Grey Relational coefficient		Grade	Rank
	MRR	**Ra**		
1	0.478	0.384	0.431	14
2	0.516	0.372	0.444	12
3	0.498	0.365	0.431	13
4	0.361	0.474	0.417	16
5	0.450	0.477	0.464	10
6	0.772	0.476	0.624	4
7	0.333	0.598	0.466	9
8	0.397	0.600	0.498	7

Experiment No	**Grey Relational coefficient**		**Grade**	**Rank**
	MRR	**Ra**		
9	0.521	0.336	0.428	15
10	0.480	0.334	0.407	18
11	0.624	0.333	0.479	8
12	1.000	0.447	0.724	2
13	0.382	0.446	0.414	17
14	0.467	0.446	0.456	11
15	0.651	0.786	0.719	3
16	0.333	0.785	0.559	6
17	0.397	0.783	0.590	5
18	0.521	1.000	0.761	1

The parameter combination with the highest grey relational grade is the optimal condition for combined process parameters.

Table 30: Optimum parameter result

GRA	**Multi response**		
	Input parameters stage	**MRR**	**Ra**
	V2, HRC 3, SD 3, FR 2	26.092	1.208

Where V2 (cutting speed) at stage 2 or at 2000RPM

HRC (material hardness) at stage 3 or at 171 VHN

SD (Surface Depth) at stage 3 or at 2mm from surface

FR (Feed Rate depth of cut) at stage 2 or at 0.04mm

Chapter 5: Conclusion and Recommendations

5.1 Conclusion

Generally, with the aforementioned processes, firstly, Treatment process of pack carburizing has mainly comprises of temperature heating at three temperature ranges of 400^{0}C, 450^{0}C and 500^{0}C of solution heat treatment for 2 hours using box heater furnace, priory by putting the specimen in coal powder and graphite mixtures put in closed container at rated ratio of coal powder and graphite solution heat treatment temperature heating can be conducted and followed by quenching process carried in solution of nitrites and this will result on the increment of surface hardness of the material. Then, Carburized and polished aluminum alloy 7075 will be tested for the response against surface grinding machining for the evaluation of material removal rate (MRR), surface roughness and optimized by L18 Taguchi method for final result after wards. By considering wheel speed, Surface hardness and depth of surface from case hardened end surface and cutting depth as an input parameter. The levels at which these parameters varied the result is also evaluated and found that

- According to the analysis Using the signal-to-noise ratio (S/N ratio) to identify the control factor settings that minimize the variability caused by the noise factors on the material removal rate are surface depth, work hardness, wheel speed and cutting depth ranked respectively with highest delta value difference, which implicates that the properties gained by the carburization are surface depth and surface hardness which have a great impact on the grindability material removal rate
- According to the analysis using the signal-to-noise ratio (S/N ratio) to identify the control factor settings that minimize the variability caused by the noise factors on the surface hardness are work hardness, wheel speed and cutting depth and surface depth, ranked respectively. Again, here it implicates that the work hardness which improved from 59.1 VHN to 88, 109 and 171VHN have also a positive change effect on the materials grindability surface roughness improvement
- The parameter combination with the highest grey relational grade is the optimal condition for combined process parameters obtained that the optimal machining parameters was cutting speed at 2000RPM, material hardness 171 VHN, Surface Depth at 2mm from surface and Feed Rate depth of cut should be at 0.04mm

The properties improved by the solution heat treatment and carburization have a high positive impact on the grindability of aluminum, previously due to aluminum grinding has a clogging on the wheel and frequent dressing requirements it perceived to be difficult but prior treating the aluminums case hardness without altering the mechanical properties it is evaluated in this research as a better manufacturing process

5.2 Recommendations

From the research objectives point of view the main problem in aluminum grinding is the clogging of aluminum on the wheel surface due to machining contact temperature which is going above the melting point of the aluminum. In this research the grinding problems are tried to be evaluated with the material removal rate and the roughness due to in process temperature monitoring facility limitation. Here the author wants to recommend that,

- ➢ Enhancement of the grindability of aluminum alloy by carburizing can be also evaluated by the wheel and work piece contact temperature monitoring and chip profile.
- ➢ The alteration of the mechanical property caused by the carburization process should be researched for the implementation

5.3 Future research areas

The recommendations for future work include

- Application of similar experiments under the conditions used in this research utilizing improved output measurements like on process machining contact temperature measurement. The main objective would be assessment of the chip profile against machining temperature melting
- Investigation into deciding specific grinding energy and force requirements for a carburized aluminum alloy grinding process using on process measurements and contact layer theory. This could be further developed to predict and validate the change in force and energy requirements for grinding processes of carburized aluminum alloy.
- Enhancement of crack propagation resistance of carburized aluminum alloy. This would be developed to evaluate the result of aluminum carburization process on the crystallographic property

- Modeling and understanding of the mechanical properties of the carburized aluminum alloy. Aimed to predict if any other negative mechanical properties resultant associated with pack carburization

References

[1] W. Abrasives., "Weiler Abrasives," 25 december 2021. [Online]. Available: https://www.weilerabrasives.com/.

[2] J. Binti Mustafa, "Prediction of grinding machinability when grind aluminium alloy using water based coolant," *Acadamic journal*, 2012.

[3] A. D. S. R. B. M. Á. R. G. R. V. D. A. E. &. D. O. R. F. M. De Mello, " Surface Grinding of Ti-6Al-4V Alloy with SiC Abrasive Wheel at Various Cutting Conditions," *Procedia Manufacturing,* vol. 10, p. 590–600, 2017.

[4] S. S. H. M. S. a. M. Z. G. Murtaza, "“Plasma focus assisted carburizing of aluminium Thin Solid Films," vol. 517, no. 24, pp. pp. 6777–6783,, 2009.

[5] H. (. Arık, "Investigation of influences of pressing pressure and sintering temperature on the mechanical properties of AL-AL4C3 composite materials.," *Turkish Journal of Engineering and Environmental Sciences,* , vol. 27(1), p. 53–58.

[6] 4. P. S. G. a. J. S. Benjamin, "Mechanical alloying," *Annual Review of Materials Science,* vol. 13, p. 279–300, 1983.

[7] R. (. Singleton, "Access to Electronic Thesis.," 2021.

[8] F. B. T. T. &. S. E. Darsono, "The effect of case hardening treatment on aluminum 7075 toward its hardness and tensile strength," *AIP Conference Proceedings,* 2018.

[9] I. J. Polmear, Light Alloys: Metallurgy of the Light Metals., In Google Books. Arnold. , 1995.

[10] E. (. R. 1. D. 2. Hombergsmeier, "Magnesium for aerospace applications," 6 September 2015. [Online].

[11] ATSM, "Aluminum Standard Specification," 27 december 2021. [Online]. Available: https://www.scribd.com/document/480040550/ATSM-B-209-96-Aluminum-standard-specification.

[12] J. R. Davis, Aluminum and Aluminum Alloys, (06610G) (illustrated edition). ed., ASM International., 1993.

[13] M. N. N. &. R. L. Novák, "New Ways in Aluminium Alloys Grinding.," *Key Engineering Materials,* , pp. 496, 132–137. , 2011.

[14] Y. D. W. C. C. J. W. X. L. &. Y. G. Q. Gong, " Influence of Processing Parameters on Surface Roughness in Micro Mill-Grinding Aluminium Alloy 6061.," *Advanced Materials Research,* pp. 1017, 495–499., 2014.

[15] S. B. M. M. A. E. &. M. M. Pirizadhejrandoost, "The Corrosion Behavior of Carburized Aluminum Using DC Plasma.," *Journal of Metallurgy,* 2012.

[16] F. B.-L. C. L. M. E. S. T. A. C. A. P. &. L. C. Fariaut, "Surface carburization of aluminum alloys by excimer laser.," *Surface and Coatings Technology,* , pp. 146-147, 324–330. , 2001.

[17] J. Machine, "Challenges of Aluminum Machining," 13 july 2016. [Online]. Available: https://jbcmachine.com/challenges-of-aluminum-machining.

[18] S. Genculu, "Factors Affecting Machinability of Metals.," *Academic journal.*

[19] C. Cavallo, All about 7075 Aluminum (Properties, Strength and Uses)..

[20] wikipedia, "wikipedia," 27 january 2024. [Online]. Available: https://en.wikipedia.org/wiki/Barium_carbonate.

[21] wikipedia.org, "wikipedia.org," 23 september 2023. [Online]. Available: https://simple.wikipedia.org/wiki/Calcium_carbonate.

[22] wikipedia.org, 13 may 2022. [Online]. Available: https://en.wikipedia.org/wiki/Sodium_carbonate.

[23] Newnes., Comprehensive materials processing, Elsevier Ltd, 2014.

[24] H. M. F. &. S. J. Kaido, Confidence intervals for projections of partially identified parameters., vol. 87(4), Econometrica, 2019, p. 1397–1432..

[25] A. C. W. W. &. R. E. L. Charnes, "Measuring the efficiency of decision making units.," *European Journal of Operational Research,* vol. 2(6), p. 429–444, 1978.

[26] H. Arik and C. Bağci, "Investigation of influences of pressing pressure and sintering temperature on the mechanical properties of Al-Al4C3 composite materials," *Turkish Journal of Engineering and Environmental Sciences,* vol. 27, pp. 53-58, 2003.

[27] S. A. Council, "SAE Aerospace Council," 27 september 2006. [Online]. Available: https://web.archive.org/web/20060927041504/http://www.sae.org/about/board/committees/arsp.htm.

[28] E. Britannica, "Encyclopedia Britannica," 2020. [Online]. Available: https://www.britannica.com/science/statistics/Experimental-design.

[29] R. &. S. Y. Bailey, "Pack carburization of commercially pure titanium with limited oxygen diffusion for improved tribological properties.," *Surface and Coatings Technology,,* pp. 261, 28–34., 2015.

[30] R. Seligman, "Aluminium and its alloys: Their properties, thermal treatment, and industrial application," *Journal of the Society of Chemical Industry,* p. Pp. xxiii + 184., 1923.

[31] M. A. R. J. &. W. G. C. Rabbo, " A study of conversion coating development on aluminium in chromate/fluoride solutions using secondary ion mass spectrometry.," *Corrosion Science,* Vols. 18(2), , p. 117–123., 1978.

[32] G. H. S. S. M. &. Z. M. Murtaza, "Plasma focus assisted carburizing of aluminium thin Solid Films," Vols. 517(24), , p. 6777–6783., 2009.

[33] J. &. K. Y. (. Kwak, "Mechanical properties and grinding performance on aluminum-based metal matrix composites," *Journal of Materials Processing Technology,* Vols. 201(1–3),, p. 596–600., 2008.

[34] N. C. M. K. &. B. R. G. Birbilis, "Electrochemical behavior and localized corrosion associated with Al7Cu2Fe particles in aluminum alloy 7075-T651," *Corrosion Science,* vol. 48(12), p. 4202–4215., 2006.

[35] K. K. P. R. &. J. K. V. Sankaran, "Effects of pitting corrosion on the fatigue behavior of aluminum alloy 7075-T6: modeling and experimental studies," *Materials Science & Engineering. A, Structural Materials: Properties, Microstructure and processing,* pp. 223-229, 2001.

[36] A. &. Y. S. A. Kalkanlı, "Synthesis and characterization of aluminum alloy 7075 reinforced with silicon carbide particulates," *Materials in Engineering,* vol. 29(4), pp. 775-780, 2008.

[37] J. K. &. A. A. Park, "Correlation between microstructure and calorimetric behavior of aluminum alloy 7075 and Al□Zn□Mg alloys in various tempers," *Materials Science & Engineering. A, Structural Materials: Properties, Microstructure and Processing,* pp. 114, 197-203, 1989.

[38] C. W. C. T. &. S. Y. C. Lee, "Intelligent model-based optimization of the surface grinding process for Heat-Treated 4140 steel alloys with aluminum oxide grinding wheels," *Journal of Manufacturing Science and Engineering,* vol. 125(1), pp. 65-76, 2003.

[39] N. V. P. D. Y. G. M. K. N. K. G. K. &. S. S. Syreyshchikova, "Establishing the Relationship between Cutting Speed and Output Parameters in Belt Grinding on Steels, Aluminum and Nickel Alloys," *Development of Recommendations. materials (Basel),* 1974.

[40] H. W. K. L. T. X. Y. &. P. Y. Zhao, "Automatic Aluminum alloy surface grinding trajectory planning of industrial robot based on weld seam recognition and positioning. Actuators," *Academic Journal,* vol. 12(4), p. 170, 2023.

[41] Y. Huang, "Research of grinding force and surface roughness of aluminum alloy based on the abrasive belt grinding. Machine Tool & Hydraulics," *Academic journal,* 2008.

[42] P. F. C. &. G. S. Pao, "Corrosion fatigue crack initiation in aluminum alloys 7075 and 7050," *Corrosion ,* vol. 56(10), p. 1022–1031., 2000.

[43] B. Z. K. G. J. L. Q. &. W. W. Lin, "Influence of grinding parameters on surface temperature and burn behaviors of grinding rail," *Tribology,* pp. 122, 151–162., 2018.

[44] R. D. S. R. B. D. S. L. R. R. M. Á. R. J. M. J. &. H. A. De Souza Ruzzi, " Influence of grinding parameters on Inconel 625 surface grinding," *Journal of Manufacturing Processes,* pp. 55, 174–185, 2020.

[45] X. &. X. F. Zhou, "Modeling and predicting surface roughness of the grinding process," *International Journal of Machine Tools & Manufacture,* vol. 42(8), pp. 969-977, 2002.

[46] D. N. K. P. M. I. D. M. K. S. I. K. G. A. I. M. J. M. I. W. &. P. D. G. R. Negara, "Hardness Distribution and Effective Case Depth of Low Carbon Steel after Pack Carburizing Process under Different Carburizer," *Applied mechanics and materials,* pp. 776, 201-207, 2015.

[47] F. Y. X. Z. Z. S. W. &. X. J. Li, "Optimization of grinding parameters for the workpiece surface and material removal rate in the belt grinding process for polishing and deburring of 45 steel," *Applied Sciences (Basel),* 2020.

[48] D. R. B. M. M. M. S. S. &. M. H. S. Unune, "Fuzzy logic-based model for predicting material removal rate and average surface roughness of machined Nimonic 80A using abrasive-mixed electro-discharge diamond surface grinding," *Neural computing and application,* pp. 647-662, 2016.

[49] R. C. J. W. Q. J. M. F. Z. K. &. X. Z. Zhou, "Effect of EDT surface texturing on tribological behavior of aluminum sheet," *Journal of Materials Processing Technology,* vol. 211(10), p. 1643–1649, 2011.

[50] P. Nayak, "Some aspects of surface roughness measurement," *Wear,* vol. 26(2), p. 165–174, 1973.

[51] P. R.-V. M. A. A. A. &. C.-V. M. A. Ramón-Torregrosa, "Factors affecting the measurement of roughness factor of surfaces and its implications for wetting studies," *Colloids and surfaces. a Physicochemical and engineering aspects,* pp. 83-93, 2008.

[52] F. R. A. H. M. &. A. M. Rabiei, "Performance improvement of minimum quantity lubrication (MQL) technique in surface grinding by modeling and optimization.," *Journal of Cleaner Production,* pp. 86, 447–460, 2015.

[53] N. H. Y. K. A. Y. Y. &. S. H. Nakatsuka, "Effect of Coolant Supplied through Grinding Wheel on Residual Stress of Grinding Surface.," *Advanced Materials Research,* vol. 1017, pp. 33-37, 2014.

[54] C. R. P. &. L. A. Barrientos, "Theoretical study of AlC3: linear or cyclic ground state? Chemical Physics Letters,," vol. 320(5–6), p. 481–486, 2000.

[55] V. &. T. M. Lindroos, "Recent advances in metal matrix composites," *Journal of Materials Processing Technology,* vol. 53(1–2), p. 273–284, 1995.

[56] J. C. D. P. A. J. P. H. N. &. S. A. Lesage, "A model for hardness determination of thin coatings from standard micro-indentation tests," *Surface & Coatings Technology,* vol. 200(1–4), p. 886–889, 2005.

[57] Ş. G. U. &. Ç. H. Karabulut, "Study on the mechanical and drilling properties of AA7039 composites reinforced with Al2O3/B4C/SiC particles.," *Composites Part B: Engineering,* vol. 93, p. 43–55., 2016.

Appendices/Annexes

Annex-A Roughness test report

Sample Description: Exp. No. – 01		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.356	0.417	0.648

Sample Description: Exp. No. – 02		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.334	0.391	0.608

Sample Description: Exp. No. – 03		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.321	0.376	0.584

Sample Description: Exp. No. – 04		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.518	0.606	0.943

Sample Description: Exp. No. – 05		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.524	0.613	0.954

Sample Description: Exp. No. – 06		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.522	0.611	0.950

Sample Description: Exp. No. – 07		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.724	0.847	1.318

Sample Description: Exp. No. – 08		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.726	0.849	1.321

Sample Description: Exp. No. – 09		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.267	0.312	0.486

Sample Description: Exp. No. – 10		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.265	0.310	0.482

Sample Description: Exp. No. – 11		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.263	0.308	0.479

Sample Description: Exp. No. – 12		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.471	0.551	0.857

Sample Description: Exp. No. – 13		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.469	0.549	0.854

Sample Description: Exp. No. – 14		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.468	0.548	0.852

Sample Description: Exp. No. – 15		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.982	1.149	1.787

Sample Description: Exp. No. – 16		
Surftest SJ-310 Series		Date: November 14, 2023
Test condition ISO: 1997 Test Speed: 0.5mm/sec λc 0.8		
Result		
Ra	**Rq**	**Rz**
0.98	1.147	1.784

Sample Description: Exp. No. – 17

Surftest SJ-310 Series Date: November 14, 2023

Test condition

ISO: 1997

Test Speed: 0.5mm/sec

λc 0.8

Result

Ra	**Rq**	**Rz**
0.978	1.144	1.780

Sample Description: Exp. No. – 18

Surftest SJ-310 Series Date: November 14, 2023

Test condition

ISO: 1997

Test Speed: 0.5mm/sec

λc 0.8

Result

Ra	**Rq**	**Rz**
1.208	1.413	2.199

04/03/16