# OPTIMIZATION OF ABRASIVE MACHINING OF DUCTILE CAST IRON USING WATER BASED $SiO_2$ NANOCOOLANT: A RADIAL BASIS FUNCTION

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**ABSTRACT**

This report presents optimization of abrasives machining of ductile cast iron using water based $SiO_2$ nanocoolant. Conventional and nanocoolant grinding was peerformed using the precision surface grinding machine. Study was made to invetigate the effect of table speed and depth of cut towards the surface roughness and MRR. The best output parameters between conventional and $SiO_2$ nanocoolant are carry out at the end of the experiment. Mathematical modeling is developed using the response surface method. Artificial neural network (ANN) model is developed for predicting the results of the surface roughness and MRR. Multi-Layer Perception (MLP) along with batch back propagation algorithm are used. MLP is a gradient descent technique to minimize the error through a particular training pattern in which it adjusts the weight by a small amount at a time. From the experiment, depth of cut is directly proportional with the surface roughness but for the table speed, it is inversely proportional to the surface roughness. For the MRR, the higher the value of depth of cut, the lower the value of MRR and for the table speed is vice versa. As the conclusion, the optimize value for each parameters are obtain where the value of surface roughness and MRR itself was 0.174 µm and 0.101cm$^3$/s for the conventional- single pass, 0.186 µm and 0.010 cm$^3$/s for $SiO_2$- single pass, 0.191µm and 0.115cm$^3$/s for conventional-multiple pass, and 0.240µm and 0.112 cm$^3$/s for the $SiO_2$- multiple pass.

# ABSTRAK

Laporan ini membincangkan tentang pengoptimuman pemesinan pelelas besi tuang mulur menggunakan $SiO_2$ nanopartikel. Kajian telah dibuat keatas kesan kelajuan meja dan kedalaman pemotongan terhadap kekasaran permukaan dan kadar penyingkiran bahan. Parameter output terbaik antara konvensional dan $SiO_2$ nanopartikel diperolehi pada akhir eksperimen. Pemodelan matematik dibangunkan dengan menggunakan kaedah respons permukaan. Model rangkaian neural tiruan dibangunkan untuk meramalkan keputusan kekasaran permukaan dan kadar penyingkiran bahan. Persepsi pelbagai lapisan bersama-sama dengan kelompok algoritma perambatan belakang digunakan. Persepsi pelbagai lapisan adalah teknik untuk mendapatkan kecerunan untuk meminimumkan kesilapan melalui corak latihan tertentu di mana ia menyesuaikan berat oleh jumlah kecil pada satu-satu masa. Daripada ujikaji tersebut, kedalaman pemotongan adalah berkadar langsung dengan kekasaran permukaan tetapi untuk kelajuan jadual, ia adalah berkadar songsang dengan kekasaran permukaan. Untuk kadar penyingkiran bahan, semakin tinggi nilai kedalaman pemotongan, lebih rendah nilai kadar penyingkiran bahan dan untuk kelajuan jadual adalah sebaliknya. Sebagai kesimpulan, mengoptimumkan nilai bagi setiap parameter adalah mendapatkan di mana nilai kekasaran permukaan dan MRR sendiri adalah 0,174 µm dan 0.101$cm^3$ / s untuk pas konvensional-tunggal, 0,186 µm dan 0,010 $cm^3$ / s untuk pas $SiO_2$-tunggal, 0,191 µm dan 0.115$cm^3$ / s pas konvensional berganda, dan 0.240µm dan 0,112 $cm^3$ / s untuk pas $SiO_2$-pelbagai.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| MRR | Material Removal Rate |
| RSM | Response Surface Methodology |
| UMP | Universiti Malaysia Pahang |
| ANN | Artificial Neural Network |
| RBF | Radial Basis Function |
| $SiO_2$ | Silicon Dioxide |
| h | Centre height |
| $f_d$ | Longitudinal dressing feed-rate |
| $n_r$ | Control wheel speed |
| $v_{fa}$ | In-feed speed |
| $R_a$ | Mean roughness |
| $Al_2O_3$ | Aluminium Oxide |
| SiC | Silicon Carbide |
| SEM | Scanning Electron Microscope |
| ANOVA | Analysis of Variance |
| DOE | Design of Experiment |
| FKM | Fakulti Kejuruteraan Mekanikal |
| CCD | Central Composite Design |
| Eq. | Equation |
| MLP | Multi-Layer Perception |
| BP | Back Propagation |

# LIST OF SYMBOLS

| | |
|---|---|
| $y$ | Predicted response |
| $\beta_0$ | Interception coefficient |
| $\beta_1$ | Linear terms |
| $\beta_2$ | Quadratic terms |
| $\varepsilon$ | Interactions and the coded levels of the independent variables |
| $X_1$ | Independent variable |
| $X_2$ | Independent variable |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

Grinding is a manufacturing process with unsteady process behavior, whose complex characteristic determine the technological output and quality (Krajnik et al., 2005). Grinding is actually a finishing process used to improve surface finish, abrade hard materials, and tighten the tolerance on flat and cylindrical surface by removing a small amount of material. In grinding, an abrasive material rubs against the metal part and removes tiny pieces of material. The abrasive material is typically on the surface of wheel and abrades material in a way similar to sanding. On a microscopic scale, the chip formation in grinding is the same as that found in other machining process. The abrasive action of grinding generates excessive heat so that flooding of the cutting area with fluid is necessary. The selection of appropriate base fluid is very critical in the application of nanoparticles based lubricants in grinding. Grinding may be performed on a surface grinding machine which feeds the workpiece into the cutting tool. A cylindrical grinding machine which rotates the workpiece as the cutting tool feeds into it. Amount of material removal rate (MRR) are depend largely on the amount of the machine current and the spark on time in the cutting process (Newman and Ho, 2004). The speed of the material removal rate is specified on the rate the material that has being removed. The MRR are influenced by the melting temperature of the workpiece, the lower melting temperature will gave faster MRR (Helmi et al., 2010). The quality of machined surface is characterized by the accuracy of its manufacture with respect to the dimension specified by the designer. Every machining operation leaves characteristic evidence on the machined surface. This evidenced in form of finely spaced micro irregularities left by the cutting tool. Each type of cutting tool leaves its own individual pattern which therefore can be identified. This pattern is known as surface roughness. Surface roughness is one of the most important factors for evaluating workpiece quality during the finishing process because the quality of surface affects the functional characteristics of the workpiece such as fatigue and fracture resistance and surface friction (Samhouri and Surgenor, 2005).

Nanofluids have the potential to be the next generation of coolants due to their significantly higher thermal conductivities. Nanofluids are formed by dispersing nanoparticles in base fluids such as water. It has been reported that the thermal conductivities of nanofluids increase dramatically due to the high thermal conductivity of solid particles suspended in the heat transfer fluid (Ding et al., 2009). Nanofluids/nanoparticles are particles that have one dimension that is 100 nanometers or less in size. The properties of many conventional materials change when formed from nanoparticles. This is typically because nanoparticles have a greater surface area per weight than larger particles; this causes them to be more reactive to certain other molecules. Nanoparticles are used, or being evaluated for use in many fields especially in medication and engineering fields.

The machining process is very complex, thus experimental and analytical models that are developed by using conventional approaches such as the statistical regression technique which is combined with the Response surface methodology (RSM) have remained as an alternative in the modeling of the machining process. RSM is practical, economical and relatively easy for used. The experimental data was utilized to build mathematical model for first-and-second order model by regression method. Bradley (2007) stated that when the response can be defined by a linear function of independent variables, then the approximating function is a first order model.

An artificial neural network is a system based on the operation of biological neural networks, in other words, is an emulation of biological neural system. Artificial neural network would be implementation necessary because although computing nowadays is truly advanced, there are certain tasks that a program made for a common microprocessor is unable to perform. Artificial neural network (ANN) has been developed as generalizations of mathematical models of biological nervous systems

(Abraham, 2005). A first wave of interest in neural networks also known as connectionist models or parallel distributed processing emerged after the introduction of simplified neurons by McCulloch and Pitts (1943).

## 1.2 PROBLEM STATEMENT

The environmental issues in machining industry concern mostly the cutting fluids. Coolants are widely used in machining processes to cool the tool and workpiece and to help remove chips from the cutting zone. Despite these benefits, the use of cutting fluids can present potential environmental problems. Coolants also cause harmful effects for the machine operator, as well as in disposal hazardous waste. In addition to the base oil, cutting fluids contain many kinds of additives such as emulsifiers, antioxidants, bactericides, tensides, EP-additives, corrosion inhibitors, agents for preventing foaming and etc. Although the cutting fluids are gradually being developed to be safer for the users and environment, they still have many disadvantages and risks that cannot be eliminated. Cutting fluids are entrained by chips and workpieces, and on the other hand, they contaminated machine tools, floor and workers. The $SiO_2$ nanoparticle as a coolant is used in this project.

## 1.3 PROJECT OBJECTIVES

The objectives of this project are as follows:

(i) To investigate the experimental performance of grinding of ductile cast iron based on response surface method.

(ii) To develop optimization model for grinding parameters using a Radial Basis Function (RBF) technique, and

(iii) To investigate the effect of water based $SiO_2$ nanoparticles to the precision surface grinding.

## 1.4 PROJECT SCOPES

The scopes of this project are to prepare the Design of Experiment, preparation of the $SiO_2$ nanocoolant. The experiment on grinding machine utilizing abrasive grinding wheel have to perform using water based $SiO_2$ of ductile cast iron. The performance will be carried out and also the material removal rate and surface roughness analysis. Statistical analysis using central composite method also will be done. The investigation of the effect of $SiO_2$ nanoparticles and conventional cooling fluid are using ANN.

## 1.5 ORGANIZATION OF REPORT

Chapter 2 presents the literature review that focused on recent studies by the previous researcher about the topic which is the effect of grinding process parameters on surface roughness of the ductile cast iron by using $SiO_2$ nanoparticles as a coolant. Chapter 3 will be discussed about the methodology that will conduct for this project such as the design of experiment, experiment setup, selection of parameters. Chapter 4 is about the analysis the results of surface roughness that obtained from the experiment due to the parameters selected. Chapter 5 will be summarized the overall finding and recommendation for future work.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

Grinding is the most common form of abrasive machining. It is a material cutting process which engages an abrasive tool whose cutting elements are grains of abrasive material known as grit. These grits are characterized by sharp cutting points, high hot hardness, and chemical stability and wear resistance. The grits are held together by a suitable bonding material to give shape of an abrasive tool. Grinding may be classified in to groups as rough or non-precision grinding and precision grinding. Snagging and offhand grinding are the common forms of the rough grinding where the metal is removed without regard to accuracy. In precision grinding, according to type of surface to be ground, it is classified in to external or internal grinding, surface and cylindrical grinding (Malkin, 1984).

Material removal in grinding occurs by the interaction of abrasive grains in the grinding wheel with the workpiece at extremely high speeds and shallow penetration depths (Malkin, 1984). Therefore some practical methods are described for optimization of the grinding and dressing parameters by combining the grinding energy model and thermal analysis together with empirical relationships for surface finish and the influence of dressing parameters on grinding performance. For grinding of steels with aluminium oxide abrasive, it has been postulated that the controlling chemical reaction is the formation of a spindle between the oxidized metal and the aluminium oxide, which act as a transition layer for adhesion. In this case, lubrication effectiveness of grinding fluids might be attributed in part to their ability to reduce metal adhesion by inhibity spindle formation and also the sticking of metal chips to each other.

## 2.2 TYPES OF GRINDING

Grinding machines were originally used almost exclusively for truing tools steel parts, which were distorted by hardening. The great improvements have been made both in grinding machines and abrasive wheels, however, result from the application of the grinding process to the finishing of many unhardened parts. There are various types of grinding including the centerless grinding, cylindrical grinding, surface grinding, centered grinding and contour grinding.

**Centerless Grinding:** Centerless grinding is an abrasive machining process by which small chips of material are removed from the external surface of a cylindrical metallic or nonmetallic workpiece. This process relies on the relative rotations of the grinding wheel and regulating wheel to rotate the workpiece. The process does not require chucking or locating the workpiece between centers for rotation (Todd et al., 1994). Characteristic of this process requires no chucking or mounting of the workpiece. The centerless grinding also produces close tolerances and smooth surfaces. This process is applicable for cylindrical, stepped, formed and crucial workpiece. As other types of grinding, centerless grinding also requires coolant and is a primarily a finishing process (see Figure 2.1).

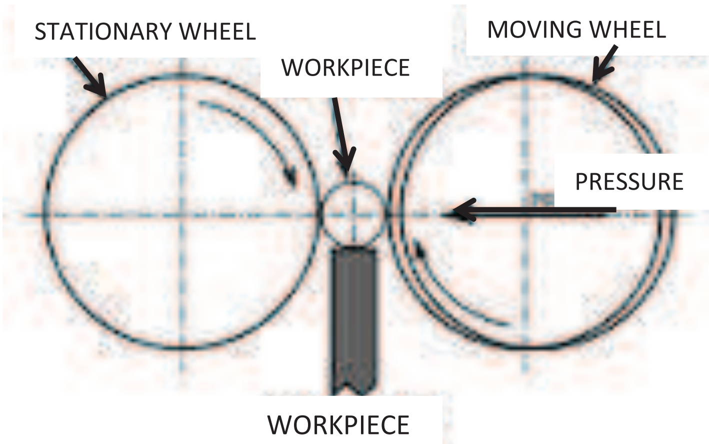
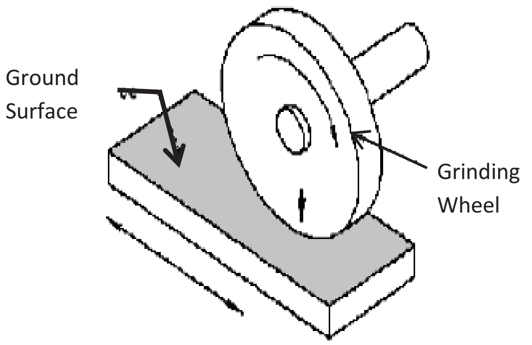



**Figure 2.1**: Centerless Grinding

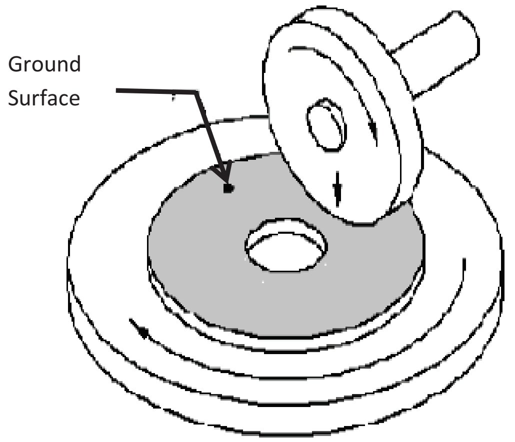
**Cylindrical Grinding:** Cylindrical grinding is an abrasive machining process in which material is removed from the external surface of a metallic or nonmetallic cylindrical workpiece by rotating the grinding wheel and workpiece in opposite directions while they are in contact with one another. The workpiece is mounted between centers and is rotated by means of a workpiece holder (Todd et al., 1994). The characteristic of this process is to produce straight tapered and formed workpiece. It is only used for cylindrical workpiece. Cylindrical grinding produces highly accurate surfaces and smooth finishes and also primarily a final machining process.

**Surface Grinding:** Surface grinders are machine tools used to provide precision regarding the level, size or finish of the surfaces. The longitudinal feed is usually powered by hydraulics or cross feed, and any mixture of hand, electrical or hydraulics operation styles may be used depending on the ultimate usage of the machine. There are a few types of surface grinding which are horizontal-spindle, vertical-spindle, vertical-spindle rotary grinding, horizontal spindle single disk, and vertical swivel head grinding. Figure 2.2 shows the various types of cylindrical grinding (source: Efunda Global).

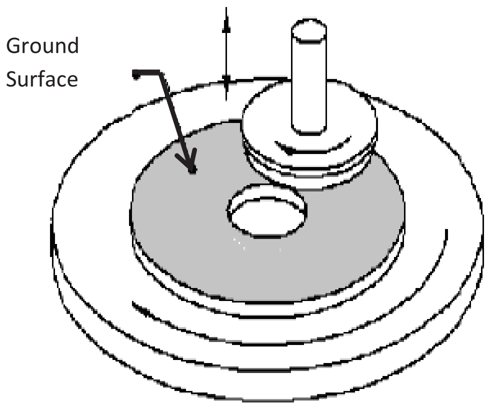
**Centered Grinding:** Grinding for surfaces of rotation (axially symmetric surfaces) can be either centered or centerless. Centered grinding involves fixturing the part on a spindle axis as it is ground as Figure 2.3 (source: Efunda Global). This configuration can be compared to fixturing a part on a lathe with or without a tail stock. The abrasive material is on a grinding wheel that rotates in a direction such that rolling or sliding contact occurs where the wheel and workpiece touch. Centered grinding is accurate and stable, but setup takes time and through put surface.



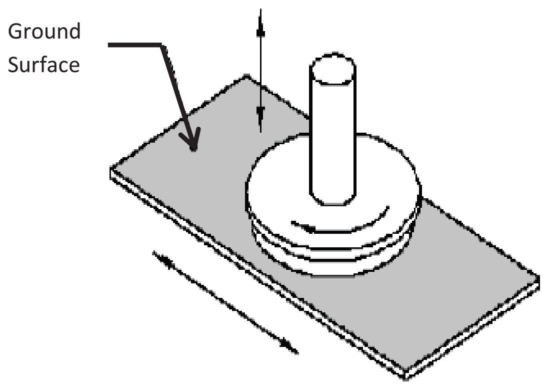

Horizontal-spindle reciprocating table surface grinding




Horizontal-spindle rotary table surface grinding




Vertical-spindle rotary table surface grinding




Vertical-spindle reciprocating table surface grinding

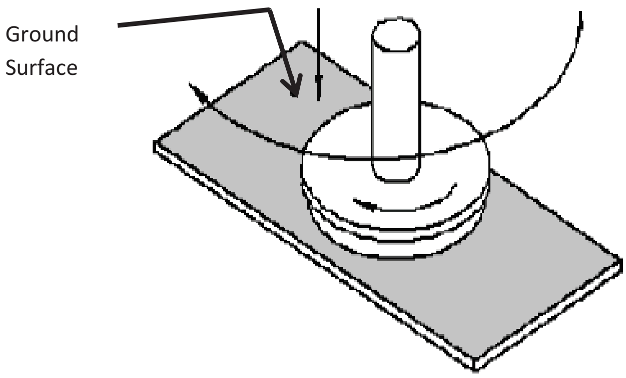



**Figure 2.2:** Surface Grinding

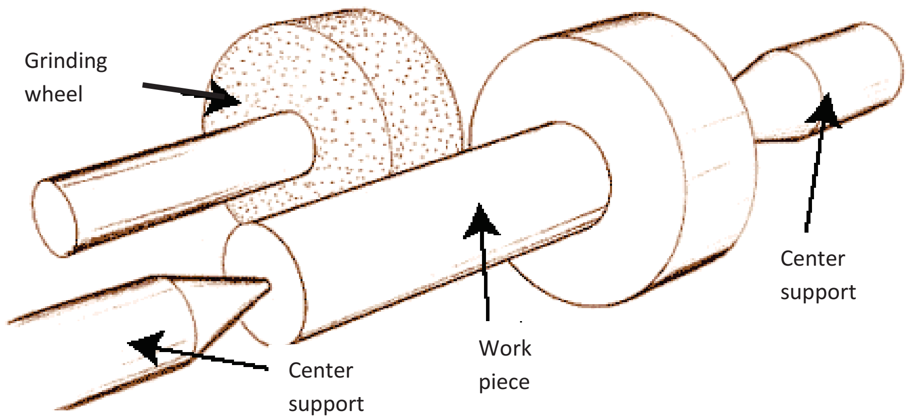



**Figure 2.3:** Centered grinding

## 2.3 THERMAL ANALYSIS

A thermal model of the wet grinding process has been used to predict the temperature at the workpiece surface. The model considers that the heat sources during grinding are from the abrasive grain workpiece interface and the shear plane between the workpiece and chip. During grinding, the power and energy is transmitted as well as heat is generated in the contact zone of the workpiece and grinding wheel. The sliding/friction may raise variety of modes of metal removal, including the plastic grooving which is relatively affect surface roughness. It is sensitive to material properties such as hardness, fatigue strength, toughness the operative values of which being dependent upon the strain, strain rate, and temperature generated in the contact zone. An excessive heat generates affect to the surface roughness (Kalpakjian and Schmid, 2001). In the metal working industry, the grinding process is a very important method of producing a precision part. For ductile materials, the specific energy generated during a grinding process is generally very high, and is mostly dissipated as heat in the wheel-workpiece contact (Liao et al., 1998). The removal rates can be achieved in grinding by the temperature generated. The grinding process required a high level of energy, which is virtually all dissipated as heat over a restricted area. The resulting temperatures can cause various types of surface damage such as burning with steels, softening (tempering) of the surface larger with possible rehardening, unfavorable residual tensile stresses, cracks, and distortions (Malkin, 1984).

## 2.4 GRINDING PARAMETERS

There are a few of parameters need to be considered in order to do grinding process such as the component centre height, h, longitudinal dressing feed-rate, $f_d$, the control wheel speed, $n_r$, the in-feed speed, $v_{fa}$, depth of cut and many more. When the process planner has a prior knowledge about the product quality likely to be produced on a component during grinding, optimum process sequence design and process parameter selection is feasible. A need therefore exists to develop intelligent predictive product quality performance and the process conditions. The qualities of machined parts play a crucial role in the functional capacity of the part and therefore, a great deal of attention should be paid to keep consistent tolerances (Malkin, 1984). The machining process has an important place in the traditional production industry. Cost effectiveness of all machining process has been eagerly investigated. This is mainly affected selection of suitable machining parameters like cutting speed, feed rate and depth of cut according to cutting tool and workpiece material. The selection of optimum machining parameters will result in longer tool life, better surface finish and higher removal rate (Cakir et al., 2007).

**Depth of Cut:** The increase in depth of cut during grinding process increases the surface roughness value and roundness error. Effect of depth of cut is an important aspect on roundness error (Malkin, 1984). This is because of more metal removal at higher depth of cut.

**Grinding Feed Rate:** When feed rate is increased, the arithmetic mean roughness value ($R_a$) also increased and gives poor finish. Because of higher feed rate the metal removal is not uniform and it may not remove the material and also due to high vibration of grinding machine which result in the bad quality product, i.e. - high surface roughness and roundness error (Malkin, 1984).

**Material Removal Rate:** High efficiency deep grinding with its high material removal rate offers the potential to improve cycle times whilst maintaining surface integrity, form and finish requirements (Comley et al., 2006).

**Surface Roughness:** Grinding is used in the metal working industry to produce parts of high quality surface finish and geometry. Surface roughness is one of the most important factors for evaluating workpiece quality during the finishing process because the quality of surface affects the functional characteristics of the workpiece such as fatigue and fracture resistance and surface friction (Samhouri and Surgenor, 2005). Surface roughness is one of the most important factors of workpiece in grinding process. The ground surface is affected by the wheel surface and wheel should be dressed before the ground surface deteriorates beyond a quality limit of surface integrity. The surface roughness of workpiece in grinding process is influenced and determined by the disc dressing conditions due to effects of dressing process on the wheel surface topography. In this way, prediction of the surface roughness helps to optimize the disc dressing conditions to improve surface roughness (Baseri et al., 2008).

## 2.5 SELECTION OF THE GRINDING WHEEL

A successful grinding is based on a qualified operator who has strong knowledge about the shapes, types and the properties of the grinding wheels and people have to know how to use all kinds of wheels in different conditions.

### 2.5.1 Grinding Wheel

The most typical materials for the grinding wheel are aluminium oxide and silicon carbide. The material of aluminium oxide is not as hard and fragile as silicon carbide, it is suitable for grinding the metals with high anti-tensile strength such as softer metal, forge iron and bronze. The crystals of the silicon carbide are very fragile. It is suitable for grinding the metals with high anti-tensile strength such as steel, marble and glass. The grinding wheel is a bonded abrasive body consisting usually of $Al_2O_3$ or SiC abrasive grain in a matrix of ceramic, resinoid, or rubber band. Wheels are available in different grit sizes and type and in different wheel grades and structures that is amounts of bond and porosity, both of which affect the performance and wear characteristics of the wheel (Middle, 2005).

### 2.5.2 Grain Density

The grain density is denominated by the sifting capacity, for example, a grain has the grain density 24 that means it passed a sifter with 24 net-eye/inch. The remaining rough grain density wheels are used for parts that need no fine finishing.

### 2.5.3 Aluminium Oxide Grinding Wheel

Aluminium oxide, the most common industrial mineral in use today, is used either individually or with other materials to form ceramic grains. As an angular, durable blasting abrasive, aluminium oxide can be recycled many times. It is the most widely used abrasive grain in sand blast finishing and surface preparation because of its cost, longevity and hardness. Harder than other commonly used blasting materials, aluminium oxide grit powder penetrates and cuts even the hardest metals and sintered carbide. Aluminium 50% lighter than metallic media, aluminium oxide abrasive grain has twice as many particles per pound. The fast-cutting action minimizes damage to thin materials by eliminating surfaces stresses caused by heavier, slower cutting media. Aluminium oxide grit powder has a wide variety of applications, from cleaning engine heads, valves, pistons and turbines blades in the aircraft industry to lettering in monument and marker inscriptions. It is also commonly used for matte finishing as well as cleaning and preparing parts for metalizing, plating and welding.

### 2.5.4 Silicon Carbide Grinding Wheel

Silicon carbide grinding wheels are tools used in manufacturing industry to form precision components and continue to be used to increased production rates due to their ability to remove high volumes of material at high speeds (Jackson, 2010). Silicon carbide is the hardest blasting media available. High-quality silicon carbide media is manufactured to a blocky grain shape that splinters. The resulting silicon carbides abrasive has sharp edges for blasting. Silicon carbide has a very fast cutting speed and can be recycled and reused many more times than sand. The hardness of silicon carbide allows for much shorter blast times relative to softer media. Silicon carbide grit is the ideal media for use on glass and stone in both suction or siphon and direct pressure blast