Surface roughness analyses of engineering polymers

Marouane Nadir
Mechanical engineering

Gödöllő
2023

Hungarian University of Agriculture and Life Science

Szent István Campus

Mechanical Engineering Course

THESIS TITLE:

Surface Roughness Analyses of Engineering Polymers

Primary Supervisor:	Name : Dr. Kálacska Gábor
	Position: Professor
Independent Consultant:	Name: Sarankó Ádám
	Position: Associate professor
Author:	Name : Marouane Nadir
	Neptun ID : X02THO

Institute/Department: Institute of Technology

HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

INSTITUTE OF TECHNOLOGY

INSTITUTE OF TECHNOLOGY MECHANICAL ENGINEERING (BSC)
Mechanical engineering specialization

THESIS

worksheet for

Marouane Nadir
X02THO

(BSc) student

Entitled:
Surface roughness analyses of engineering polymers

Task description:

In this thesis, I will talk about the surface roughness of engineering polymers. We will analyze the surface roughness during the machining of 3 materials which are PA6, POMC, and UHMW-PE. We will do the machining of these materials in 2 parts: roughing and finishing. We will have 90 datas since we are calcultating the surface roughness for each machined material 3 times.

Department: Mechanical engineering technology

Consultant:

Supervisor: *Dr. Kalácska Gábor Professor,* MATE, Institute of Technology

Submission deadline: 03. May 2023

Gödöllő, 20. January 2023

Approved		Received
(head of department)	(host course leader)	(student)

As an independent consultant of the author of this thesis I hereby declare that the student took part in the planned consultations.

Gödöllő, 02day 05 month 2023.

(Consultant)

TABLE OF CONTENTS

LIST OF FIGURES:

LIST OF TABLES:

1-INTRODUCTION

Plastics has been appearing like a symbol of modernity back in the 20th century. Most of our products back then were made from plastics. Its popularity was in majority due to its characteristics mostly its weight (plastic products happen to be very light) and its adaptation to every kind of product.

Plastics are considered as a specific type of polymer. Polymers can be either created synthetically or found in nature.

During these last few years, polymers has been taking a growing interest in the field of manifacturing and production. The object is to put in the production and in the market some materials having some advanced thermomechanical properties.

Nowadays, polymeric materials are known for their easier transformation and so they are largely used in all industrial sectors. However, the level of exigence in quality and performance of materials based on polymers has been growing and it is still growing in an enormous level. That means that those materials will require more and more development in the future so they can replace metals in a big part of the industry.

The surface roughness in polymers is one of their most important characteristics. Manufacturers aim to go for materials that are not affected by some machining problems. Those materials help the manufacturers offer better quality for the customer and also prevent them from some economical problems.

There is several reasons why I did chose this subject as my thesis work. The main reason is that polymers are now part of our daily life, and more importanlty part of all manifacturing processes. Manufacturers seemed to be more into using polymers than other materials lately. And as a mechanical engineer, it is important to understand the functioning of polymers during the manufacturing and how does the surface roughness affect its machinability. It is also very important to differetiate the polymers and to understand which polymer is suitable for each kind of manifacutirng and each kind of industry.

The main objective of this study work is to study the difference between the surface roughness during the machining of some polymers. Many parameters will be changed during this process, mainly the spindle’s speed and feed.

The engineering polymers that will be used during this research work are PA6, POMC, and UHMW-PEHD1000.

1.1- Aim of the research work:

The present work in this project is aimed to:

-Provide an understanding of the difference between surface roughness characterizations during the machining of polymers with the change of some important parameters during the work especially the spindle's speed and the spindle's feed.

-Study the difference between three kinds of engineering polymers and how the change of the parameters cited before will affect their surface roughness.

2-LITERATURE REVIEW

2.1- Engineering polymers for machined parts:

2.1.1- Polyamide 6:

A thermoplastic polymer belonging to the nylon family, Polyamide 6 was created to mimic the properties of Polyamide 6.6 without violating a patent. While having a chemical composition and set of characteristics that are extremely similar to Polyamide 6.6, Polyamide 6 manufacturing is fundamentally different. Whereas most Nylon polymers (like PA66) are created by condensation reactions, Polyamide 6 is created through ring-opening polymerization.

Only a few applications differ between Polyamide 6 and Polyamide 6.6 due to their high similarity. When compared to PA 66, Polyamide 6 is used in applications where a lowermelting point and improved dyeability are necessary. The characteristics of polyamides 6 and 6.6 can also be combined by the means of a copolymer or bicomponent.

Polyamide is an industrial polymer. One way of making it is to begin with one monomer that contains both an amino group and carboxylic acid group. (Teergarden, 2004)

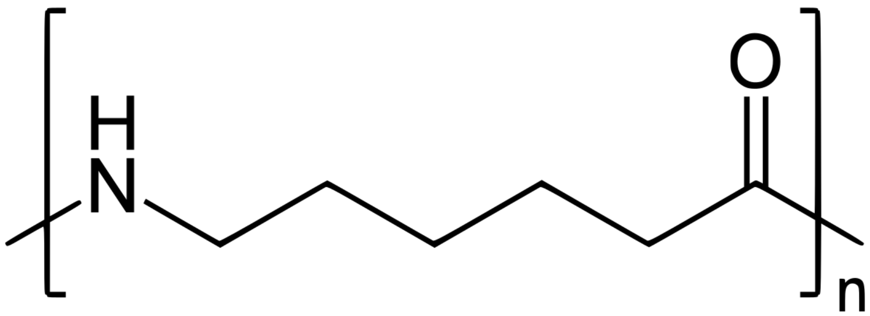


Figure 1: Polyamide 6 chemical structure (Intratec, 2019)

2.1.2- Polyoximethylene:

Polyoxymethylene (also known as POM and Polyacetal Resin) can be considered a high performance fiber, it is one of the strongest of all engineering thermoplastics. Polyacetal is suitable for a range of applications, from high-performance engineering to milk pumps and coffee spigots due to its resistance to chemicals, excellent dimensional stability, and high strength and stiffness.POM-C can be used in a lot of industries, such as industrial and automative applications (e.g: Gears, cams, bushing, door handles, windows ..) and food applications such as food Conveyors.Polyoxymethylene is a synthetic engineering polymers, it is produced on commercial scale by co-polymerization of purified formaldehyde, and contains stabilizers and filters.

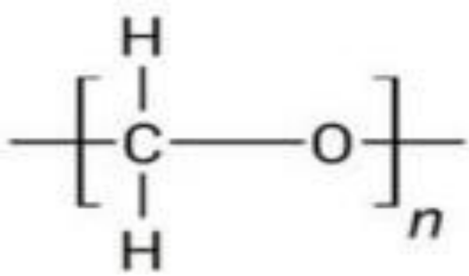


Figure 2: Polyoxymethylene chemical structure (Intratect, 2016)

Polyacetal Resins, supplied in a granulated form, are available in different viscosity ranged, According to the intended application. Lower viscosity POM are suitable for injection molding, and higher viscosity POM are used for extrusions and for molded parts requiring toughness. (Intratect, 2016)

Polyoxymethylene was discovered by Hermann Staudinger, a German chemist who received the 1953 Nobel Prize in Chemistry. He characterized POM as polymers after studying the polymerization and structure of POM in the 1920s while researching macromolecules. POM was not commercialized at that time due to its problems with thermal stability.

POM is normally opaque white, due to its high crystalline composition, but it is available in all colors. (Cheremisinoff, 2001)POM can be made into the following parts through injection molding:

-Mechanical gears, sliding and guiding elements, housing parts, springs, chains, srewas, nuts fan wheels, pump parts, and valve bodies.

-Electrical engineering: insulators, bobbins, connectors, parts for electronic devices such as televisions, telephones, etc.

-Vehicle: fuel sender unit, light/control stalk/combination switch (including shifter for light and turn signal), power windows, door lock systems, and articulated shells.

-Model: model railway parts, such as trucks (bogies) and handrails (handlebars)

POM is either machined with manual methods or CNC methods. It should not be painted. It can be reinforced with fibers for increased strength and mechanical properties. (Cheremisinoff, 2001)

2.1.3- UHMW polyethylene:

For nearly sixty years, medical ultra-high molecular weight polyethylene (UHMWPE) has been the longstanding material of choice for use as a bearing surface in total joint arthroplasty. In in tenure an as orthopedic biomaterial, UHMPWE has been an undergone numerous in its processing in order to address ongoing clinical challenges faced in total joint replacements.

Ultra-high molecular weight polyethylene, or UHMWP, is a very durable plastic with exceptional wear and abrasion resistance. Due to its adaptability, polyethylene is a well-liked plastic for numerous industrial applications that call for toughness, minimal friction, and chemical resistance. Exploited since the 1950s, these characteristics of UHMWPE have been used in a lot of industrial applications, including pickers for textile machinery, lining for coal chutes and dump trucks, runners for bottling machinery.

Polyethylene is a polymer formed from ethylene (C_2H_4). Polyethylene's generic chemical formula is $–(C_2H_4)_n$-, where n is the degree of polymerization. UHMWPE comes from a family of polymers with a really simple chemical composition, it is only consisting of only Hydrogen and Carbon.

UHMWPE differs from other polymers and from other materials (e.g: metals and ceramics).

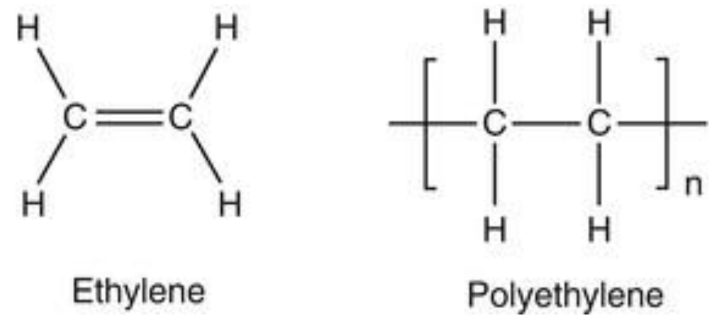


Figure 3: UHMWPE chemical structure (Kurtz, 2004)

As we can see in the figure 3, Ethylene and Polyethylene are based on the same molecular components (Hydrogen and Carbon). Polyethylene is the degree of polymerization of Ethylene. (Kurtz, 2004)

2.2- Machining features of engineering polymers:

The mechanical characteristics of polymer materials are exceptional. Polymer materials are lighter and less expensive. As a result, metals are being replaced by polymer in numerous applications. Molding is the primary method for processing polymers. Injection molding, blow molding, compression molding, transfer molding, etc. are some examples of molding processes. Molding is chosen to produce polymer products in big quantities.

Molding is not recommended when only modest quantities of polymer products are needed since the expense of creating the mold, the time it takes for the process to set, and the material waste do not justify the cost of the finished product. Hence, in this situation, plastics can be machined. Turning, drilling, and milling are the three main machining techniques.

These machining techniques can be applied to the production of polymer goods like as gears, cams, bearings, bushes, and valve seats. High dimensional accuracy and superior surface quality are desired when producing precise machinery, electronics, and optics. a situation where precision machining is preferred. Precision cutting is now being done using modern non-conventional machining techniques like laser cutting. Cutting speed, feed rate, and depth of cut have the most impact on quality measures such as surface roughness during turning operations. The physical and mechanical characteristics of the material being cut, the cutting angles, and all of the aforementioned factors have a significant impact on the creation of chips and the material's surface polish.

The behavior of polymers in machining is affected by multiple parameters such as tool material, rake angle, cutting-edge radius, depth of cut, and cutting speed. The rate of application of the load is also important for the ultimate strength and elongation to fracture the polymers. That is due to polymer’s viscous behavior. The increase in cutting speed can affect the process in two opposing ways. The material will fail at a lower strain or in a brittle manner due to to the high strain rate that it will experience. The opposite way is that the long-range mobility of the material’s molecular chains will increase due to the temperature in the cutting zone.

Chip formation is also an important thing to take into consideration. Several types of chips can be formed during the machining of polymers. Those can differ depending on the polymer type, tool geometry, and cutting conditions (e.g: spindle’s feed, cutting speed). One type of chip can be formed by elastic deformation and the chip thickness is equal to the depth of cut.

This type of chip is not produced in metal cutting. The shear-flow type chip is obtained when cutting thermoplastics and it is caused by the plastic deformation of the material as it passes through a shear plane. This type of chip is similar to the chip produced when machining ductile metals. Its thickness is greater than the depth of cut.

The heat generated during the machining of polymers is usually greater than that of metals. Therefore, the temperature rise in the polymer will be larger when a given quantity of heat is applied to equal volumes of a polymer and metal. Heat is generated in the primary deformation zone during the machining, and by friction between the chip and tool face and between the workpiece and the tool clearance side. Most of this heat is removed from the cutting area by the chip during the machining of metals. Therefore, during the machining of plastics, the heat generated in the primary shear zone does not quickly conduct to the tool and only the heat at a thin interfacial layer could play a role in heat removal. (Ahmad, 2009)

Mechanical properties (like toughness, rigidity, abrasion resistance, and heat resistance) of polymers are like metals, so polymers can replace metals. Polymer’s price and weight are less compared to metals.

We can have a lot of processes for polymer machining such as turning, drilling, milling..

Here is some pictures of those processes in the figures below (Figure 4,5, and 6):

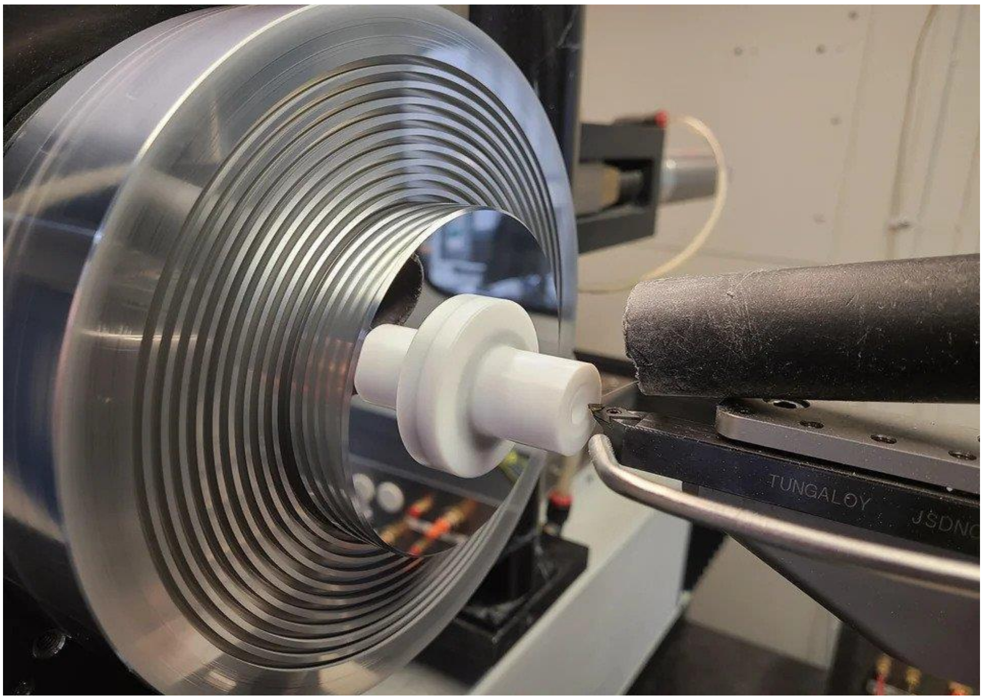


Figure 4: Turning process for polymers (Lie, 2019)

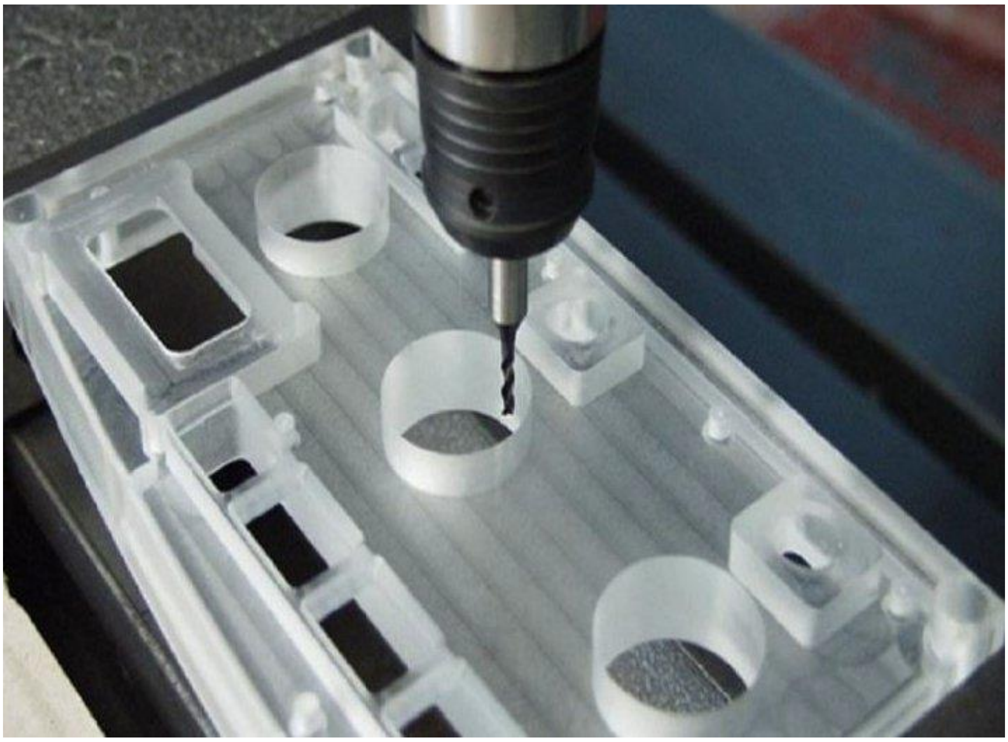


Figure 5: Drilling process for polymers (Lie, 2019)

Figure 6: Milling process for polymers (Lie, 2019)

As we can see, polymers do not differ from metals in anything when we are talking about machining. Although many industries prefer metals for now, but we can see that a lot of them started to take polymers into consideration due to its advantages and its cheap price compared to metals.

Polymers are used in a wide range of engineering applications. That is because of their unique properties such as lightweight, durability, flexibility, and resistance to corrosion, heat,and chemicals.

Polymers such as Polyethylene are widely used in packaging applications due to their excellent barrier properties and low cost. These polymers are used to manufacture producs such as bottles, containers, bags, and films. Construction is also one of the industries where polymers are extensively used. They are used for various applications such as insulation, roofing, flooring, and piping. The automotive industry uses polymers in various applicationslike interior and exterior parts, electrical components, and tires. Polymers are also widely used in the electronics industry for various applications such as circuit boards, insulation, and packaging. (Crawford, 2001)

2.3- Importance of surface roughness:

Surface texture includes surface roughness, which has a significant impact on how an object will interact with its surroundings. A mechanical component's potential performance can be predicted by how rough it is, as surface imperfections can serve as the starting point for corrosion or cracks. In tribology, rough surfaces often have greater friction coefficients and wear more quickly than smooth surfaces.

Roughness may be needed for some applications to encourage adhesion for decorative finish coatings like painting, powder coating, or plating. Calculating the relative roughness of a surface profile using a single numerical parameter is called surface roughness, also known as surface texture. Ra. The arithmetic mean of surface heights recorded across a surface is known as Ra. Just take the height of all of the tiny peaks and valleys. A surface profile measurement tool called a profilometer can quantify surface roughness. It basically indicates the deviation of a mean line's mean height of imperfections from the roughness component. Ra offers a straightforward value for decisions to accept or reject. (In more important applications, when a more in-depth understanding of the whole surface texture in three dimensions is required for scanning white light optical interferometers or scanning electron microscopes may also be utilized for surface texture mapping. For engineers and manufacturers to create consistent and dependable production procedures for each product, maintaining surface control is essential. Surface measuring may be a crucial component of maintaining control of the manufacturing when precision surface engineering is necessary. This is done by monitoring the process to make sure it complies with predetermined standards. Several pieces can be mechanically finished concurrently thanks to mass finishing. Parts can be deburred, descaled, brightened, and polished via mass finishing. In a process known as "loose-abrasive" mass deburring, batches of parts are tumbled or vibrated in barrels or tubs that are specially made for the purpose. Finishing media can be made from organic, prefabricated metallic, ceramic, or plastics that have been resin-bonded. To produce a surface finish of the highest caliber, various finishing procedures are applied. In order to consistently produce outcomes, ISO Finishing has created and documented methods to guarantee that every completed product fulfills the strictest specifications.

Surface roughness has a huge influence on many important physical phenomena such as contact mechanics, sealing, adhesion and friction. Experiments have shown that a substratewith a root-mean-square roughness can remove the adhesion completely between a rubber ball and a substrate, while nanoscale roughness will remove the adhesion between most hard solids (e.g: metals and minerals)In the same context, rubber friction on most surfaces or practical interest (e.g: road surfaces)

is mainly due to the pulsating forces that act on the rubber surface as it slides over the substrate asperities. (Yang, 2008)

Surface roughness plays an important role in the satisfactory operation of elastohydrodynamic lubrication of rolling/sliding contacts. Although machined surfaces appear smooth to the naked eye, they are quite rough at the microscopic level. In the past few decades, a number of different devices have been designed and developed in order to characterize the surface features of machine components.

If we are speaking about polymers, surface roughness plays a crucial role in determining their wear resistance and friction behaviour. It is found in some research that the wear resistance of the polymers increased with increasing surface roughness due to the enhanced ability of the rougher surfaces to trap and retain wear debris. However, the friction coefficient of the polymers decreased with increasing surface roughness due to the reduction in the contact area. Surface roughness should be carefully controlled to optimize their wear resistance and friction behaviour in different applications. (Zadorecki, 2019)

2.4- 2D surface roughness characterization Ra, Rz, Rq, Ry :

2.4.1- Arithmetical mean roughness (Ra):

Average roughness, or Ra, is the most commonly specified surface structure parameter. It offers a broad measurement of the texture's height on a surface. Ra is actually the average of the height deviations from the mean of all the points on the surface. An accurate first-pass indicator of the overall height of the surface texture is average roughness. It has proven helpful for tracking manufacturing processes in industries ranging from the auto to the medical device for decades. It is a useful tool for shop floor quality control because it can be measured rapidly with only cheap instruments.Ra, however, is blind to several critical aspects of surface texture, and relies solely on Ra to control surfaces can lead to quality issues.

Ra is unable to determine where surface characteristics are located across a profile. The Ra of a surface with peaks distributed erratically is equal to the Ra of a surface with the same peaks concentrated at one end of the portion. A concentration of high peaks on a mating surface may cause uneven loading, scratching, gouging, early wear, etc. Furthermore, it's very likely that a single stylus measurement won't even cross that peak material, leaving it completely unnoticed. Ra equalizes peaks and valleys and measures absolute deviations from the mean height. A variety of quite different surfaces, some with uniform roughness and others with deep valleys or high peaks, can all have the exact same Ra value, as the graphic below demonstrates. This flaw in Ra is the root of many of the quality and warranty problems we encounter: while all of the parts adhere to the Ra specification, some of them squeak, leak, or wear out too quickly. How is that possible when the Ra is acceptable? The peaks and troughs frequently contain the solution.

The value of Ra is expressed in micrometer.

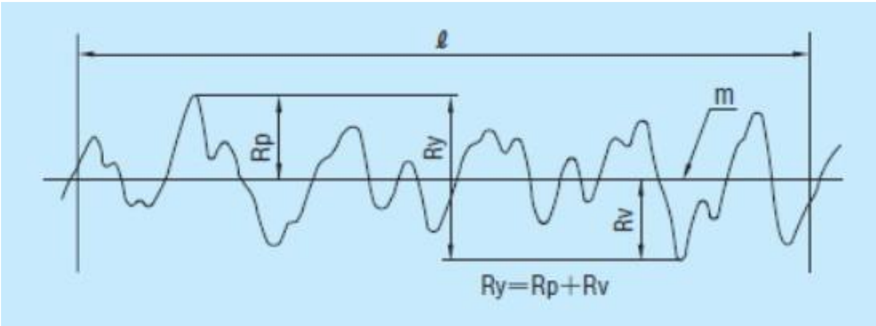


Figure 7: Arithmetical mean roughness (Ra) (Crawford, 2001)

2.4.2- Maximum peak (Ry):

Maximum peak (Ry) is a surface roughness parameter that measures the maximum height of surface irregularities on a surface relative to the mean line within a specified sampling length. In very simplified words, it is the highest point above the mean line within a sampling length.The maximum peak (Ry) is one of the parameters defined by international standards such as ISO 4287:1997(E) and ASME B46.1-2002 for characterizing surface texture. It is commonly used in quality control and assurance to ensure that the surface roughness of a product or a component meets the required specifications. The maximum peak (Ry) is expressed in micrometers. (Whitehouse, 2013)

According to ISO 4287:1997(E), maximum peak (Ry) is defined as the maximum height of the roughness profile within the sampling length. (ISO 4287:1997(E), 1997)

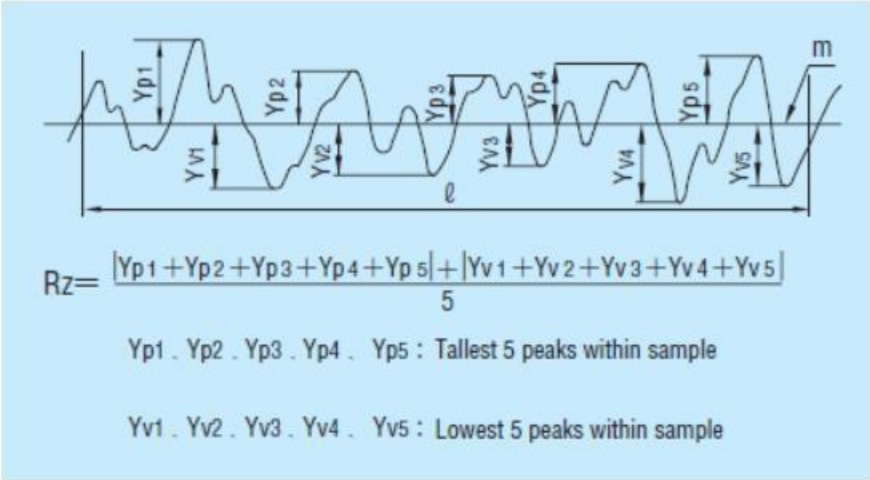


Figure 8: Maximum peak (Ry) (Crawford, 2001)

2.4.3- Ten-point mean roughness (Rz):

Ten-point mean roughness (Rz) is a surface roughness parameter that measures the average distance between the highest and lowest points on a surface within a sampling length. It is defined as the arithmetic mean of the five highest peak-to-valley measurements and the five lowest peak-to-valley measurements within the sampling length

The Rz parameter is commonly used in quality control and assurance to ensure that the surface roughness of a product or component meets the required specifications. It is expressed in micrometers. (Whitehouse, 2013)

According to ISO 4287:1997(E), Rz is defined as the average of the sums of the five largest peak-to-valley heights and the five smallest valley-to-peak heights. (ISO 4287:1997(E), 1997)

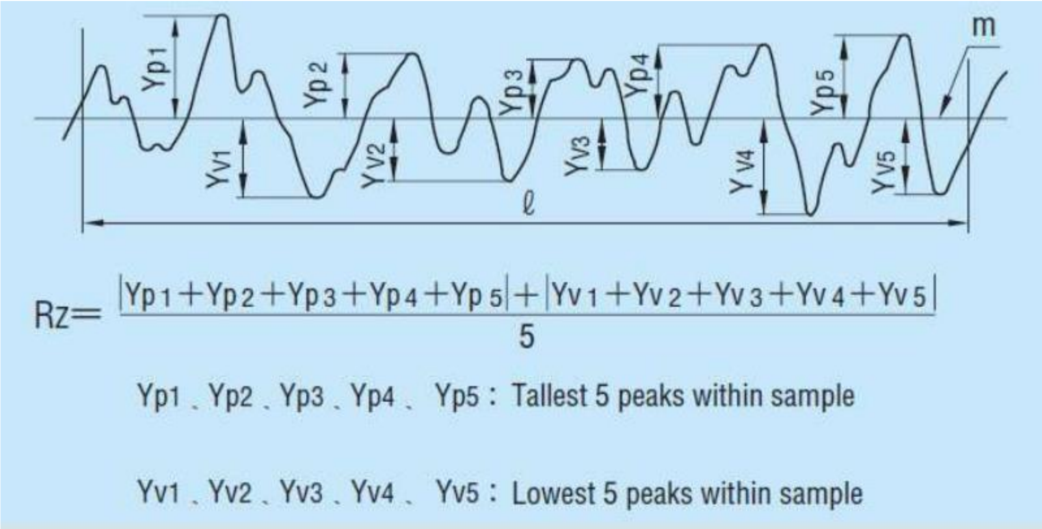


Figure 9: Ten-point mean roughness (Rz) (Crawford, 2001)

2.4.4- Root mean square roughness (Rq):

Root mean sqaure roughness (Rq) is a commonly used parameter in the field of surface metrology to quantify the roughness of a surface. Rq is calculated as the square root of the average of the sqaured height deviations from the mean line over a specified evaluation length. Is it expressed in the same units as the surface heght measurements and is a measure of the average height variation of the surface over the evaluation length.

Rq is a widely used roughness parameter because it provides a good balance between the measurement sensitivity and the ability to filter out unwanted noise in the surface profile. It is also useful because it is relatively insensitive to the skeweness and kurtosis of the surface profile, making it a more robust parameter than others, such as Ra (arithmetic mean roughness)

The standard for calculationg Rq is defined in ISO 4287:1997(E), it provides guideness on the use of Rq. (ISO 4287:1997(E), 1997)

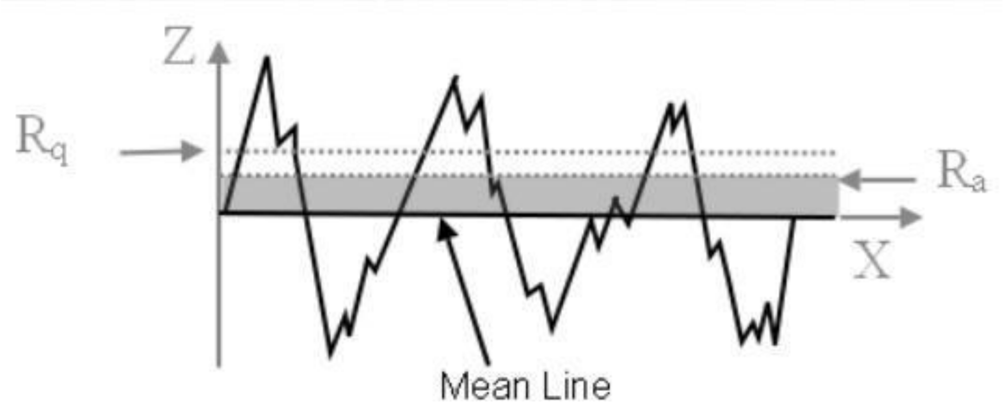


Figure 10: Root mean square roughness (Rq) (Crawford, 2001)

3- OWN RESEARCH WORK:

3.1- Applied materials:

3.1.1- PA6:

Polyamide 6 is the most common extruded polyamide and offers a balanced combination of all typical characteristics of this group of materials. The damping properties and impact strength of the material deserve to be emphasized as much as high toughness even at low temperatures. Good abrasion resistance, particularly against mating with rough surfaces, completes the typical performance package.

PA6 has a lot of main features that make it one of the most polymers to be used in the industry. One of its main features is:

-High toughness

-Resistant to many oils, greases, and fuels

-Electrically insulating

-Good wear properties

-Good weldable and bondable

-High strength

-Good slide and wear properties

-Good machinability.

We can also talk about the mechanical properties of Polyamide 6, this material has a tensile modulus of 2746.5 Mpa, a tensile strength of 68.38, and an elongation at break of 2.45%.The physical properties of PA6 are an important feature in understanding the material correctly. This figure summarizes all the physical features of Polyamide 6:

Property	Unit	Castamide
Density	gr/cm^3	1,10
Water absorption	%	7
Tensile strength	MPa	80
Modulus of elasticity	GPa	4
Tensile elongation	%	>20
Compression strength	Kg/cm^2	950
Compression modulus	MPa	2,700
Impact strength (Izod, notched)	kJ/m^2	5.6
Hardness (Shore D)	Shore D	84
Wear rate	mg/km	0,44
Melting temperature	°C	220
Coefficient of heat expansion	$°C^{-1}$	8×10^{-5}

Figure 11: PA6 properties

3.1.2- POM-C:

Polyoxymethylene (POM) is an engineering thermoplastic that can be used in precision parts requiring high stiffness, low friction, and excellent dimensional stability. It is produced by different chemical forms, just like many other polymers. It is characterized by its high strength, hardness, and rigidity to -40°C.

POM is frequently used as a direct replacement for metals due to its stiffness, dimensional stability, and corrosion resistance. Copolymers including ethylene oxide are quite common, primarily because they reduce the propensity for depolymerization at normal processing temperatures.

Some typical properties of POM-C are:

-Glass transition temperature, Tg=-30°C

-Melting temperature, Tm=183°C

-Amorphous density at 25°C =1.25g/cc

-Crystalline density at 25°C = 1.54g/cc

-Molecular weight of repeat unit = 30.03 g/mole

-Tensile strength = 5000-9000 psi

-Tensile modulus = 447 K psi

-Tensile elongation = 10-76 %

3.1.3- UHMWPE-HD1000:

UHMWPE is a semi-creystalline, whitish, and efficiently opaque engineering which, chemically, is an extremely high molecular weight (3-6 Million) HDPE. As a result, it has a very high melt viscosity and can usually be processed only by powder sintering methods. It also has excellent cut and wear resistance and toughness and extremely good chemical resistance.

Some typical properties of UHMWPE can be described in this figure:

table 1: UHMWPE properties

Property	**Value**
Density (g/cm^3)	0.945
Tensile strength (MPa)	35
Strain at yield (%)	25
Flexural modulus (GPa)	0.5
Elongation at break (%)	500
Max operating tempeture (C)	55

3.2- Applied instruments:

3.2.1- Lathe machine:

Used back to 1300 BC in Egypt, the lathe machine is probably the oldest machine tool known to humanity.

It is a machine tool that removes the undesired material from a rotating workpiece in the form of chips with the help of a tool that is traversed across the work and can be fed deep into the work. It is one of the most versatile and widely used machine tools all over the world.The lathe machine consists of a lot of main parts that can be shown in the figure below (Figure 11):

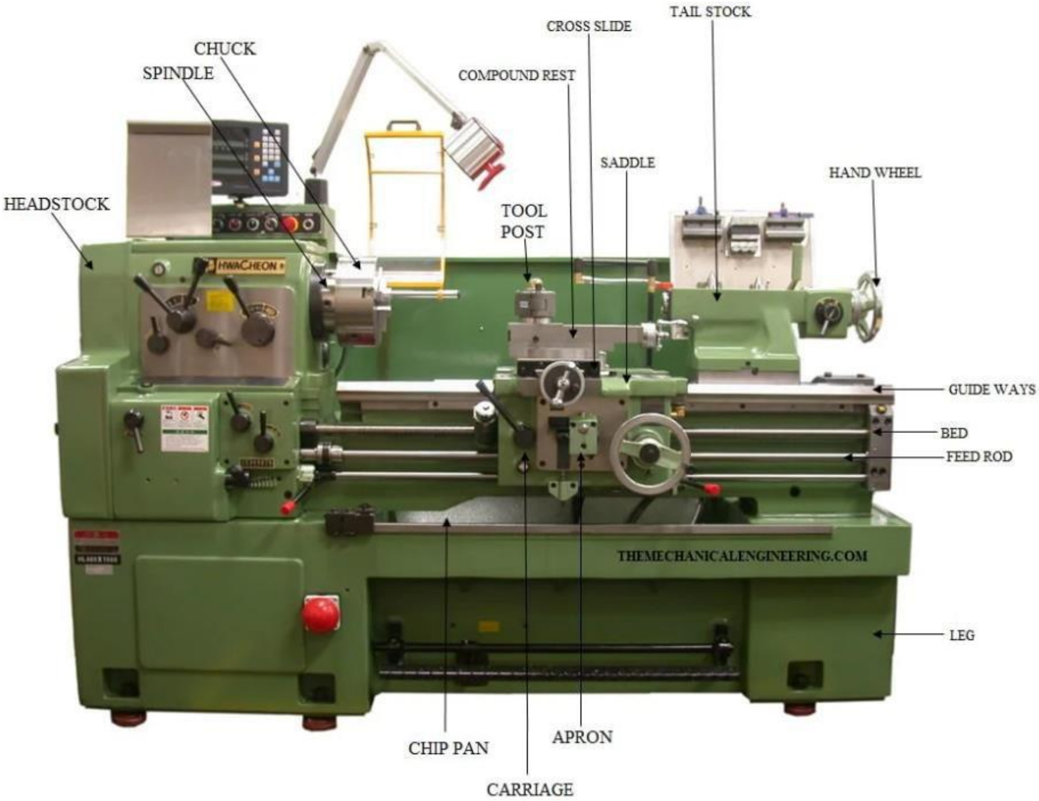


Figure 12: Lathe machine (Kumar, 2019)

One of the most important of the lathe machine is the bed. It is made from cast iron or nickel cast iron alloy, and it is the base on which all the other parts of the machine are mounted.The headstock is present on the left end of the bed. Its main function is to transmit power to the different parts of the lathe. It supports the main spindle in the bearing and aligns it properly.

We can also talk about the tailstock and the carriage; both of those parts are very important in the function of the machine. First, the tailstock's main function is to support the other end of the work when being machined and the carriage's workpiece is to support, guide, and feed the tool against the job during operation.

A lathe works on the principle of rotating the workpiece and a fixed cutting tool. The workpiece is held between two rigid and strong supports called a center in a chuck or in a faceplate that revolved. The main function of the lathe is to remove the metal or polymer material from a workpiece to give it the required shape and size. The normal cutting operations are performed with the cutting tool fed either parallel or at right angles to the axisof the work.

The cutting tool can be fed at an angle relative to the axis of the work for machining tapers and angles.The lathe machine can produce a lot of products such as train parts, electric motor parts, aircraft parts, gun barrels...

It can also perform a lot of operations that are very important during manufacturing. The main operation that it can perform is the turning operation; it is a machining operation in which the diameter of the workpiece is reduced by removing the excess material from the outer diameter of the workpiece which is mostly cylindrical or conical in shape.

The lathe machine could also be helpful for the chamfering operation, the drilling operation, the boring operation, and the reaming operation.

It can be useful in a lot of industries such as textile, defense, medical, aerospace, automotive..The lathe machine has many advantages such as it provides high-quality product, it has high speed, and can also saves time and money. Therefore, it can have a lot of disadvantages such as the initial cost that can be very high. Also, a highly skilled worker is required for the initial setup, and the CNC machines can not be used for small productions.The CNC-lathe, type E400, was used for tests.

The equipment can be found in the laboratory of the Insitute for mechanical engineering technology of the Hungarian University of Agriculture and Life sciences. The photograph of the turning process can be seen in the figure below. (Figure 12)

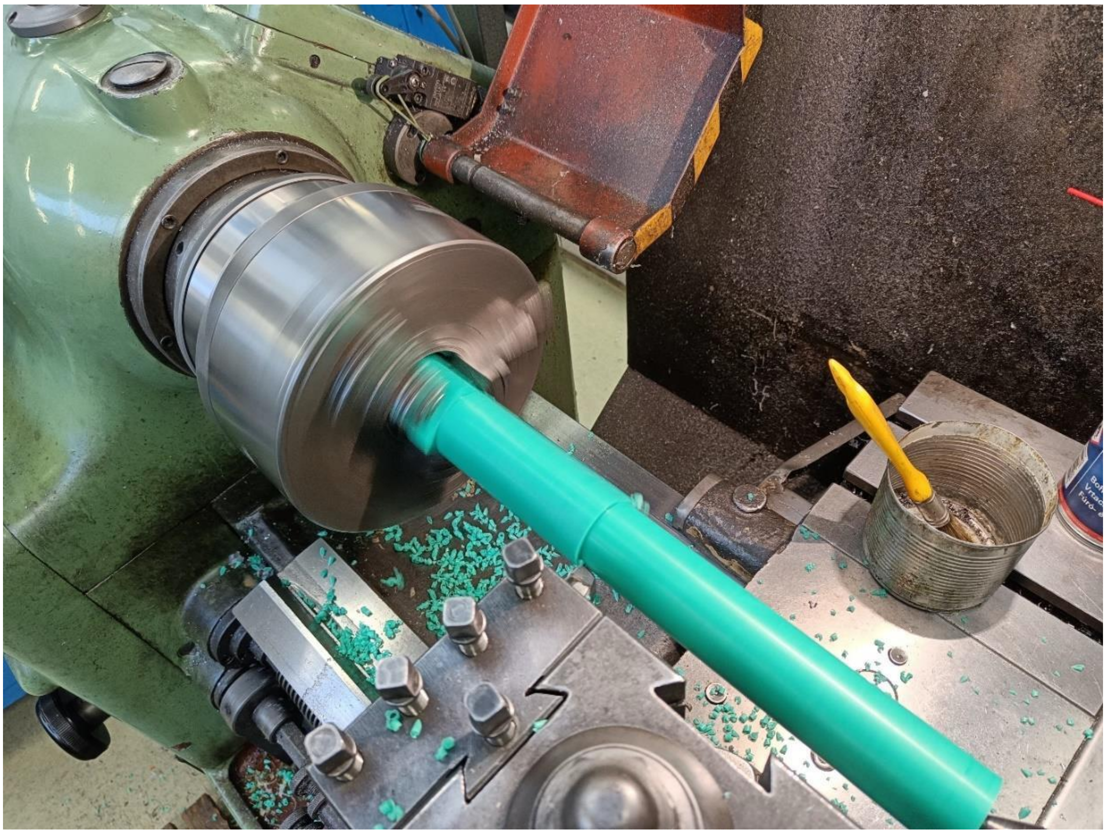


Figure 13: Turning process of the research work

3.2.2- Cutting tool:

3.2.2.1-Overview :

For CNC lathe machine cutting tools, there are three major classification categories: material, uses, and method of applying feed.

Let’s first talk about material classification. First, there is a high-speed steel tool that is ideal for rough machining and semi-finish machining. There is the carbide tool which is ideal for difficult materials such as plastic, steel, and glass.. We can also state the diamond blade which is perfect for precision machining of brittle, wear-resistant, conforming and hard materials such as graphite.

Cutting tools can also be classified by use. There are three main tools which are turning tools, chamfering tools, and thread-cutting tools.

3.2.2.2-Cutting tool used during the research work :

The cutting tool and the head of the spindle used can be seen on the figures below (Figure 13 and 14) :

Figure 14: Cutting tool

Figure 15: Head of the spindle

The equipment can be found in the Insititute of mechanical engineering technology of the hungarian Univeristy university of Agriculture and life sciences.

3.2.3-Mitutoyo roughness:

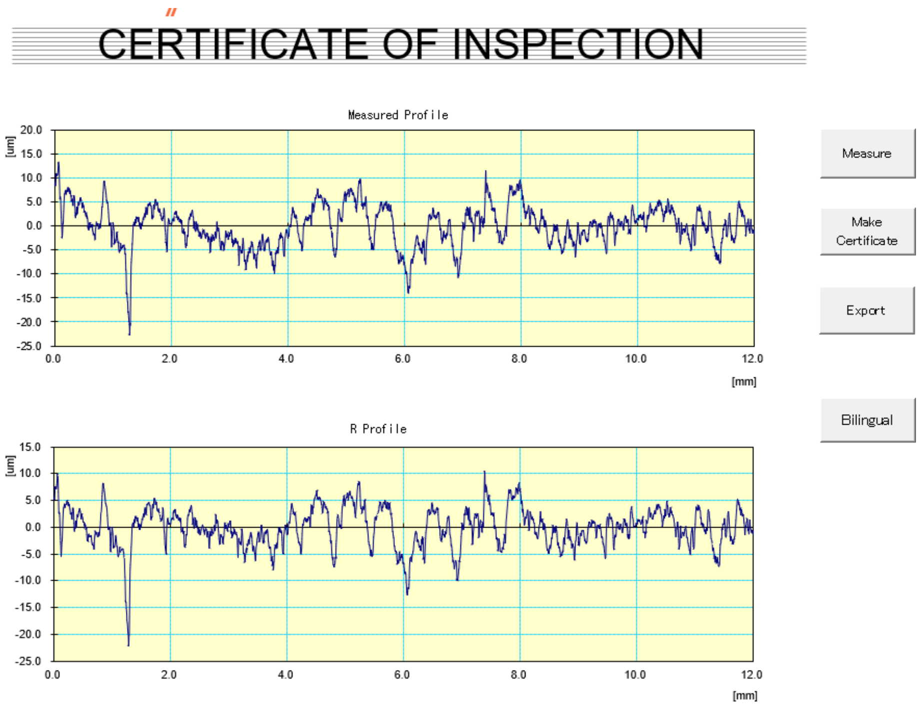
The surface roughness tester used during our research work is Mitutoyo Surftest SJ-201. The surftest SJ-201 is a user-friendly surface roughness measurement instrument designed as a handheld tool. It is easy to use with a simple key layout which means it can be easily used using the keys on the front of the unit.

The surtest is connected to a computer for a data analysis system. A lot of parameters can be shown on the computer such as the measurement result, the measurement conditions, and the analysis graph.

An example of Mitutoyo roughness tester is be shown in the figure below (Figure 15):

Figure 16: Mitutoyo roughness tester

An example of the result analysis that can be seen on the computer is shown in the figure



below (Figure 16):

Figure 17: Mitutoyo certificate of inspection

Also, this is how the results are shown in a computer in the Mitutoyo roughness tester (Figure 17) :

Work Name	Sample	Operator	Mitutoyo
Measuring Tool	SurfTest SJ-201	Comment	Ver4.00

Standard	ISO 1997	Evaluation length	12.0 mm
Profile	R	Cut-Off	2.5 mm
Range	AUTO	Filter	PC75

Ra	2.80 um	
Ry	32.55 um	
Rz	32.55 um	
Rq	3.68 um	

Figure 18: Mitutoyo results sheet

3.3- Results:

3.3.1-Overview:

We divided the research work into 3 parts :

-Machining (Roughing and Finishing) of the applied materials using different feeds.

-Calculating the surface roughness after each machining three times means we calculate the surface roughness for each machined workpiece three times with a rotation angle of approximately 120°.

-Comparing the different surface roughness using Excel, and Word. This comparison is either related to the feed rate, the applied material, or the surface roughness.

3.3.2-Average of the calculated surface roughness:

In this research work, we are calculating the surface roughness for 3 materials with different feeds. We have 90 data since we are calculating the surface roughness 3 times after the machining of each material.

To summarize all the data, this figure will show us the average of all the surface roughness for the machined materials (Table 2):

table 2: Average of all surface roughness for the machined materials

Average	PA6		POMC		UHMW-PEHD1000	
	Roughing	**Finishing**	**Roughing**	**Finishing**	**Roughing**	**Finishing**
Ra	**8.45**	**4.05**	**7.17**	**1.36**	**11.49**	**9.75**
Rz	**46.31**	**33.06**	**37.92**	**10.65**	**65.69**	**57.84**
Rq	**9.7**	**5.28**	**12.86**	**1.72**	**13.54**	**11.9**
Ry	**46.31**	**33.06**	**37.92**	**10.65**	**65.69**	**57.84**

3.3.3-Surface roughness difference between finishing and roughing:

Let's now talk about the surface roughness difference in both roughing and finishing for all three materials. We have calculated the surface roughness after each machining 3 times with a rotation angle of 120° using the Mitutoyo roughness tester. The parameters changing duringthis experience are the feed rate and the spindle's speed.

The figure below will show us a diagram of the change in the surface roughness of PA6 during roughing and finishing in micrometer (Figure 18,19, and 20):

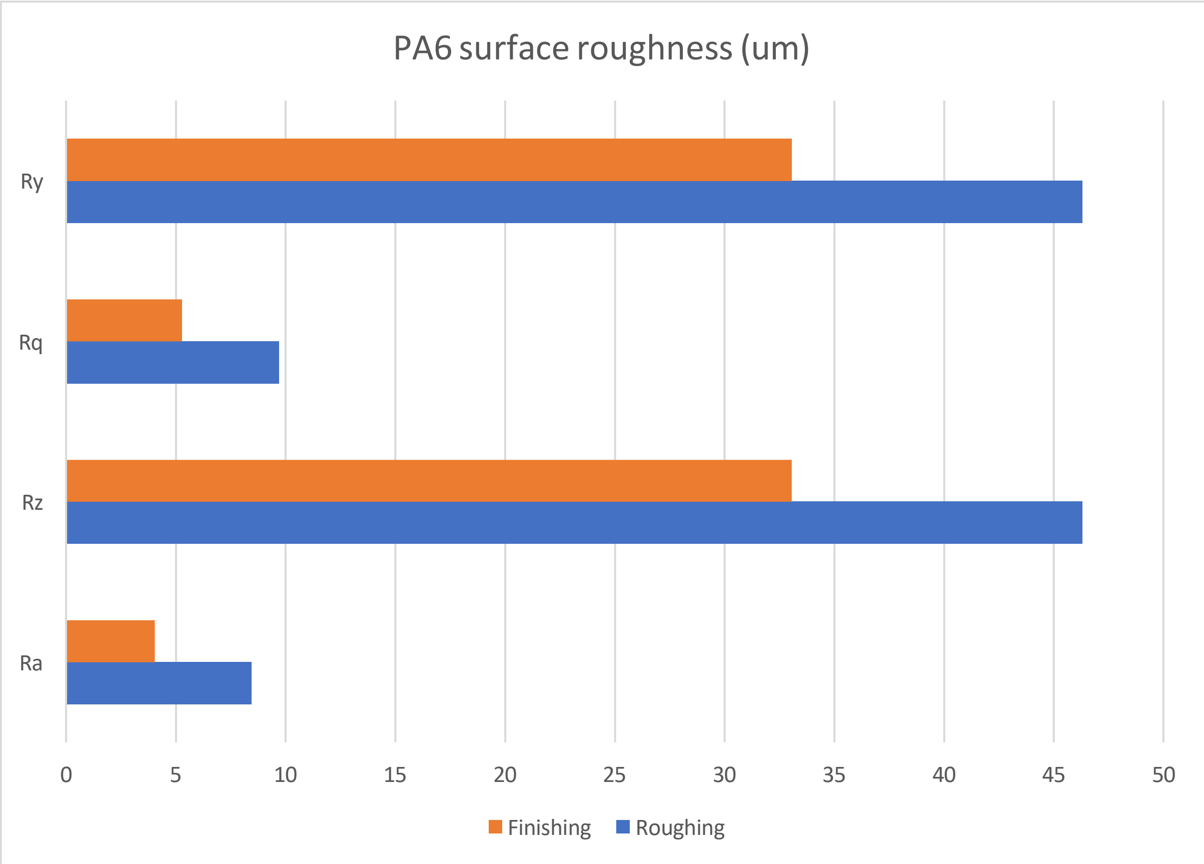


Figure 19: PA6 surface roughness

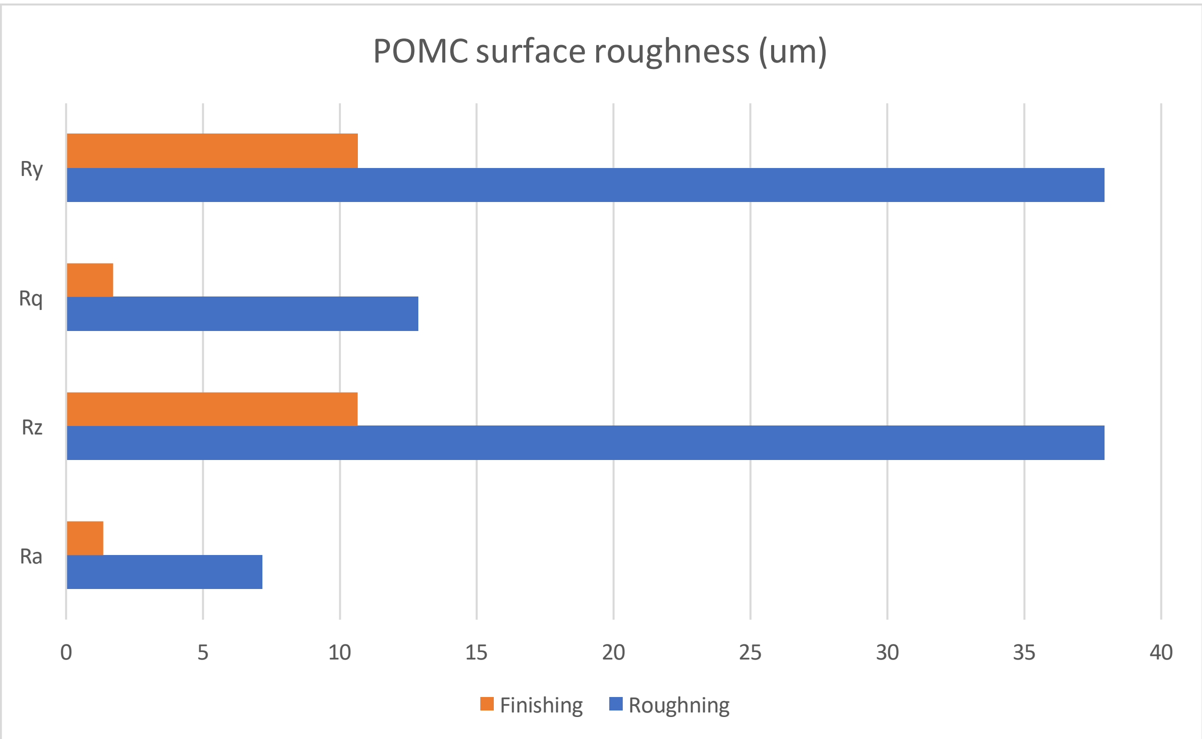


Figure 20: POMC surface roughness

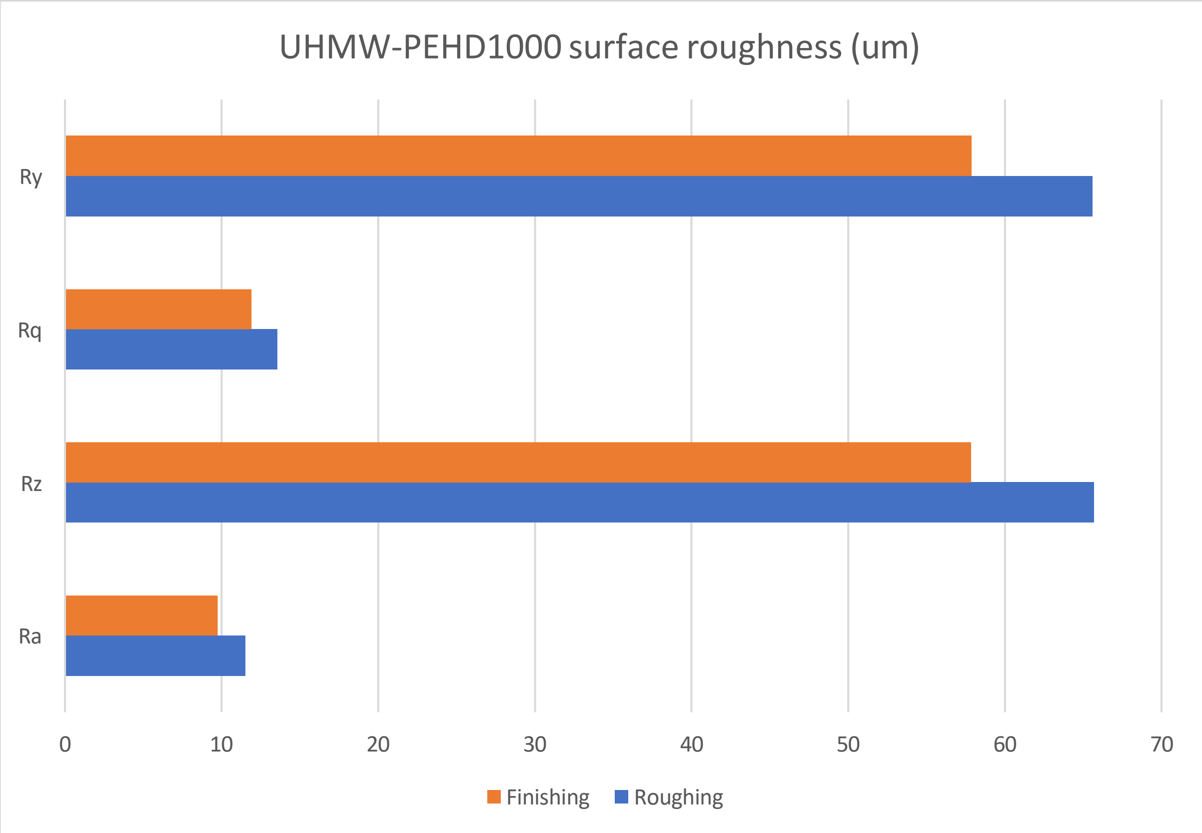


Figure 21: UHMW-PE surface roughness

We can see that the surface roughness differs between roughing and finishing. Roughing has always a higher surface roughness than finishing. That is due to the difference in feed. For roughing, the feed rate is always higher. We can also see that the values of Ry and Rz are approximately the same and both of them are way higher than Ra and Rq. This difference is visible for all three materials. Even though the results can differ frommaterial to another, the difference between the two machining processes is obvious, and as we said previously, this is due to the feed rate. For roughing, we used a feed rate between 0.2 and 0.5, which is theoretically a big number for feed rates. Instead, for finishing, we used a feed rate between 0.025 and 0.1.

It is also very important to compare the percentage of change for the surface roughness parameters during the machining. For this comparison, we will show the difference in %. We will mainly focus on the difference between the parameters for roughing and finishing. The conditions of machining will not change and we will have 3 diagrams for each materials.The diagrams can be seen on figures 22, 23, and 24:

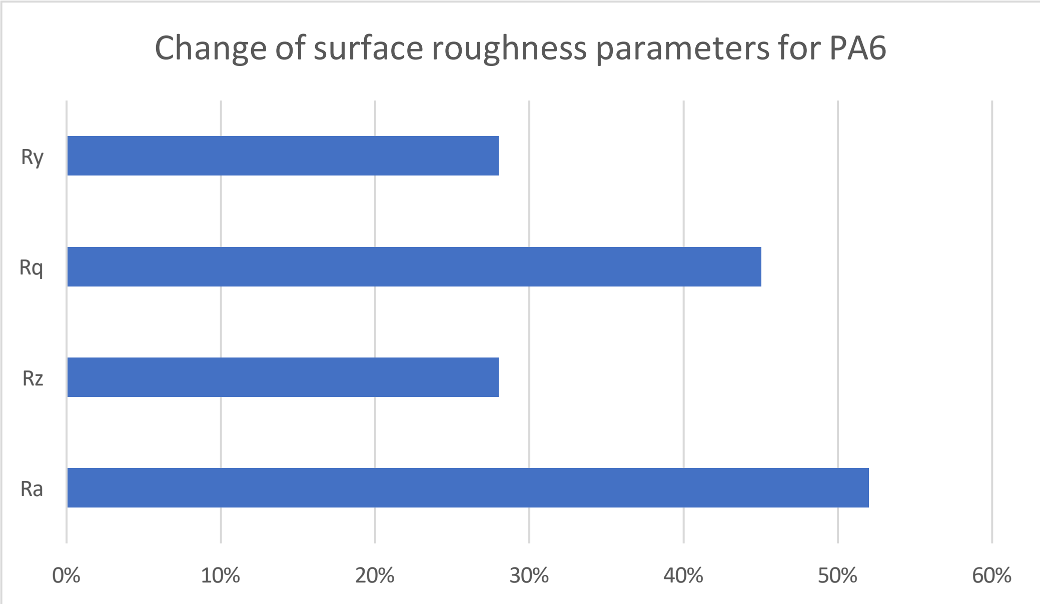


Figure 22: Change of surface roughness parameters for PA6 between roughing and finishing

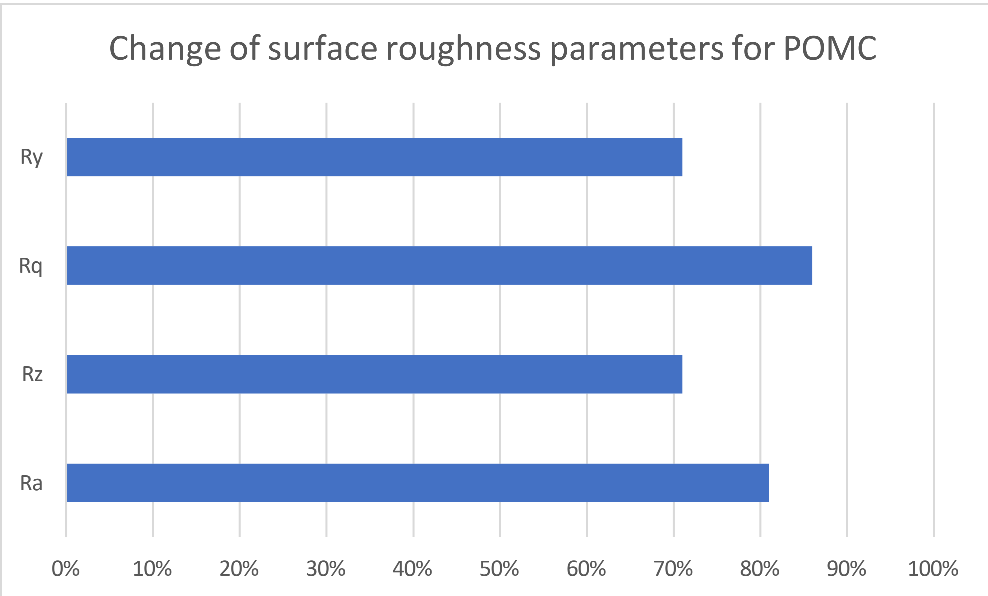


Figure 23: Change of surface roughness parameters for POMC
between roughing and finishing

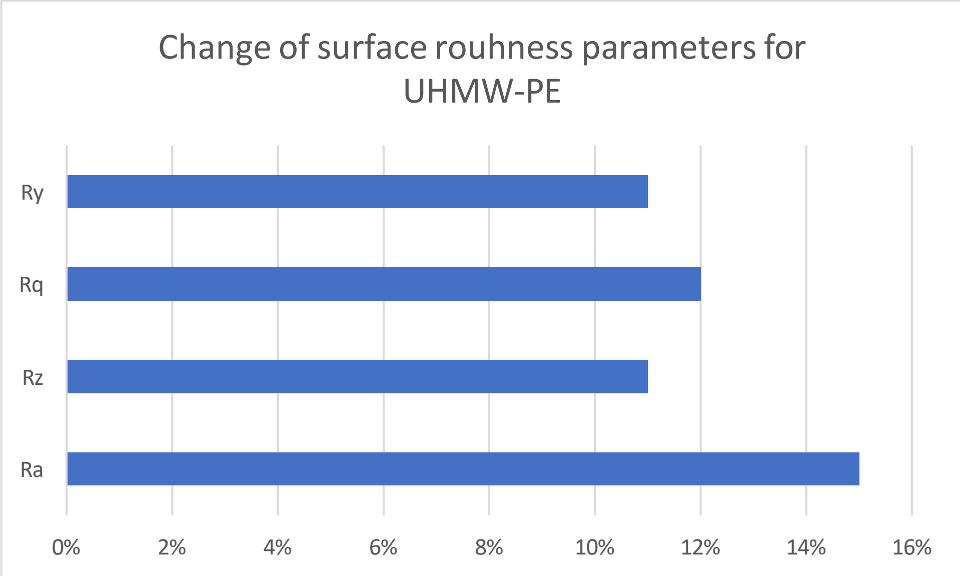


Figure 24: Change of surface roughness parameters for UMHW-PE between roughing and finishing

The reason why we choose to compare the change of surface roughness in percentage is because if the percentage of difference is high; it means that the material is really affected by the change from a high feed rate (roughing) to a smaller feed rate (finishing). And if the the percentage of difference is not that big; that means that the material is not really affected by the feed rate's value and can be usen under any feed rate.

The difference in percentage is proving our point. As we could see in the figures above, the change between roughing and finishing is nearly the same for PA6 and POMC. For all the parameters, the difference between roughing and finishing is near to or higher than 50% for those 2 materials., but for UHMW-PE, the same parameters do not go above 20%. We could also from the figures that there is quite a big difference between the two machining features. Roughing is always higher than finishing. This is due to the feed's rate which is always higher.

If we take into consideration all the parameters above, mainly for the surface roughness parameters and their difference, we could have an idea of the morphology and the characteristics of each material.

We could say, that from the parameters above, PA6 and POMC represent a lot of similarities in their structure.

3.3.4-Change of Ra during the machining of materials:

First, let's talk about the change of Ra during roughing. As we previously stated, the conditions of machining did not change. We will only change the feed rate and the spindle's speed. In this part of the research work, we will only compare in the function of the feed rate.

The feed rates used are: 0.2, 0.275, 0.325, 0.4, and 0.5. All in mm/rev.

The figure below will show us the change of Ra during the roughing of those materials in function of the feed rate (Figure 21):

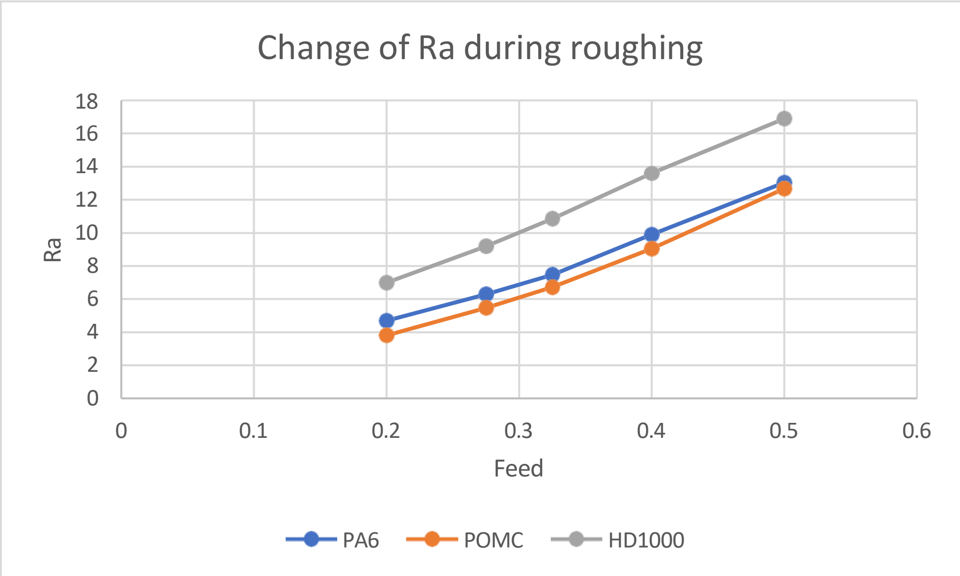


Figure 25: Change of Ra during roughing

As we can see in the figure, UHMWPE-HD1000 has a more important arithmetical mean roughness than the other materials. Even though the difference is not that important, the characteristics of each material make its surface roughness different. We can say, from these results, that PA6 and POMC have the same characteristic in terms of structure and morphology. We have reached this conclusion because as we can see in the figure, their arithmetical mean roughness was approximately the same during the whole process of roughing. These conclusions can either be confirmed or not in the next chapter after comparing the other parameters during roughing, or during the finishing of those materials.

Now, we will see the same roughness parameter, but during the finishing.

The feed rates that are used are 0.025, 0.0375, 0.05, 0.0755, 0.1.

The figure below will show us the change of Ra during the finishing of the materials in function of the feed rate (Figure 22):

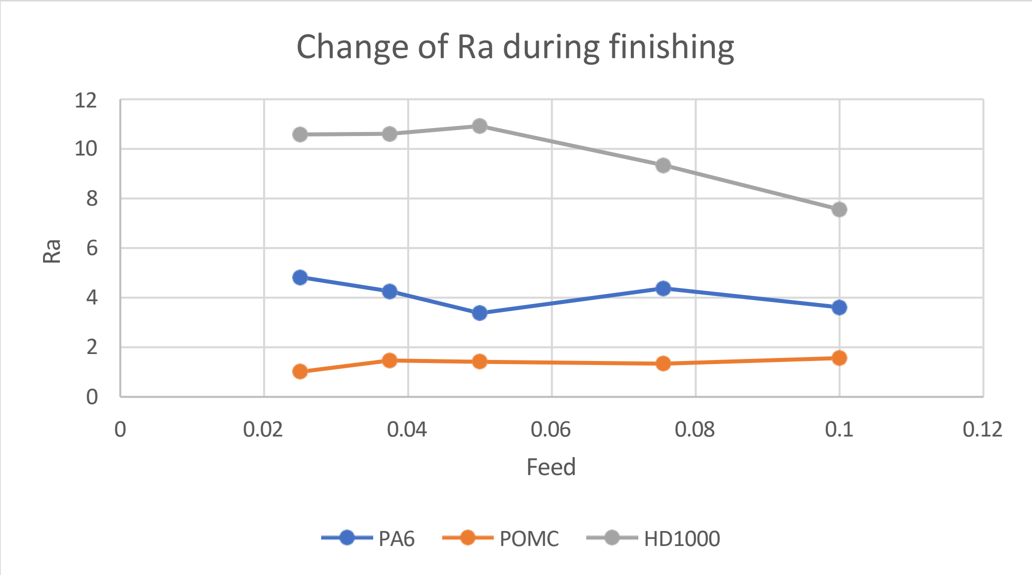


Figure 26: Change of Ra during finishing

The figure above confirmed our theory that UHMW-HD1000 has different characteristics than PA6 and POMC. We can that the arithmetic mean of UHMW is higher than the others, this is due to the difference in terms of structure and morphology.

We can also see from the figure that the arithmetic mean is not stable for all 3 materials, it is either increasing or decreasing at some point. This is due to the fact that during finishing, the cutting tool is designed to make precise cuts. It is also due to the spindle's feed rate which is very small for finishing.

3.3.5-Change of Ry and Rz during the machining of materials:

If we look at paragraph 3.3.2- where we calculated the average of the surface roughness measured during the research work, we could conclude that Ry and Rz have the same value for all the 3 materials. This is due to the fact that both parameters measure the average deviation of the roughness profile from the mean line.

Although both parameters are calculated differently, they have (in most cases) the same or approximately the same value. In our case, we see that they both the same value. This is due to the smoothness of the calculated surfaces.

Now, let's compare these parameters during the machining of the 3 materials. We will start with the roughing. (Figure 23)

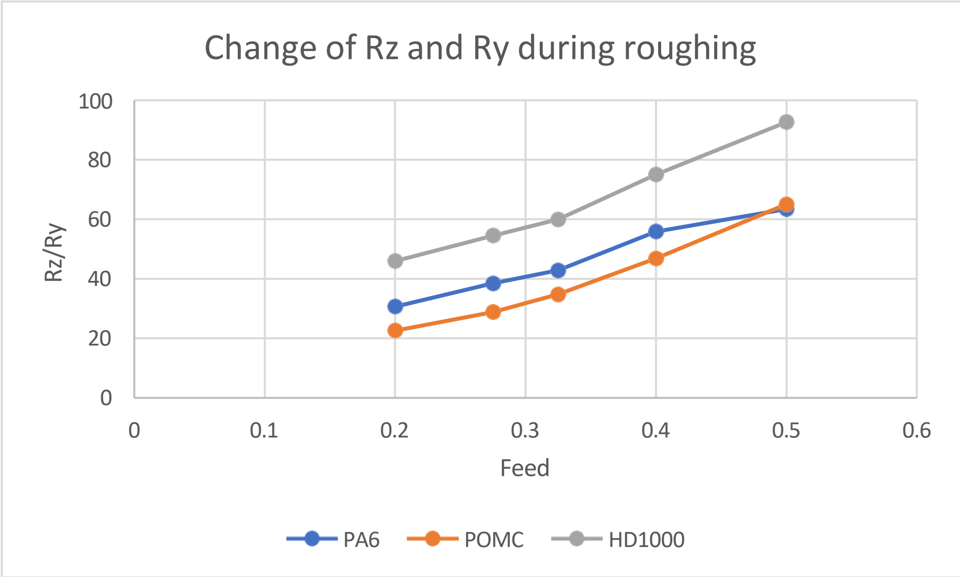


Figure 27: Change of Rz and Ry during roughing

We can see in figure that PA6 and POMC has approximately the same change for all the feed rates, and that UHMW-PE values are higher than those for the other materials. The values of z and Ry are quite big, the biggest value is 92.68 um. This is due to the fact that the feed rates for roughing are big as well, since the biggest is 0.5. We can also support the idea that we had in the previous paragraph in which we said that PA6 and POMC have approximately the same characteristics and the same morphology.

Now, let's compare the same parameters, but during the finishing of the same parameters.

The feed rates that are used are the same used during the previous paragraph which are :

0.025, 0.0375, 0.05, 0.0755, 0.1.

The figure below will show us the change of Rz and Ry during the finishing of the 3 materials. (Figure 24)

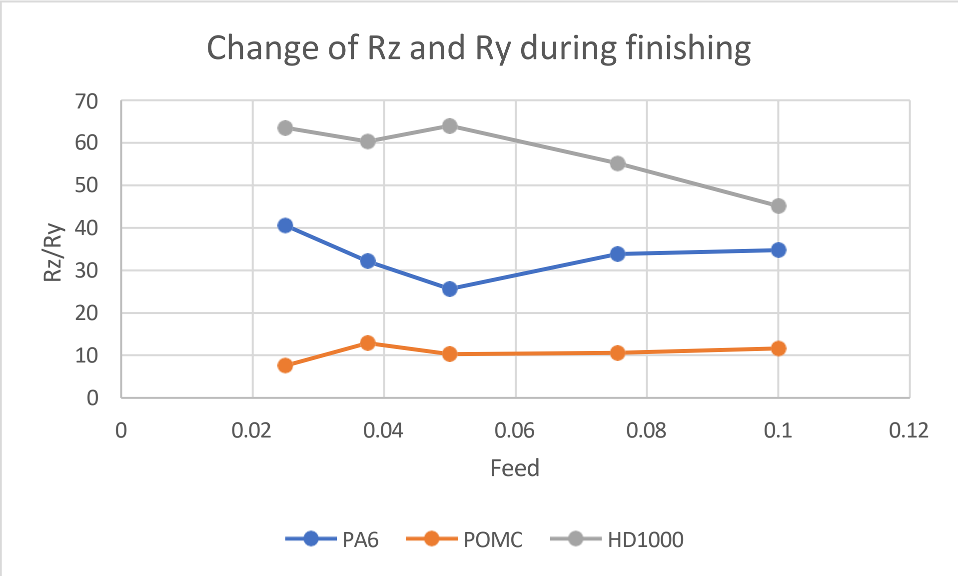


Figure 28: Change of Rz and Ry during finishing

The change of Rz and Ry is not constant for all 3 materials. We can see that for UHMW-PE it is decreasing then increasing then decreasing again. The same happens for POMC. Its Rz and Ry value are decreasing the increasing at the feed rate of 0.05. For Polyamide 6, the values are increasing then decreasing then it stays at the same value after the feed rate of 0.05.

We could conclude that the feed rate of 0.05 is a critical point during the finishing of the those. It acts differently for each material, so for UHMW-PE, Rz and Ry started decreasing after this value. And for POMC, it started increasing. As for PA6, Rz and Ry both stay at the same value after 0.05.

3.3.6- Change of Rq during the machining of materials:

Now, let’s talk about the change of Rq during the machining. The conditions of the machining did not change.As in the previous paragraphs, we will start with the roughing then we will move to the finishing.

The figure below will show us the change of Rq during roughing (Figure 25):

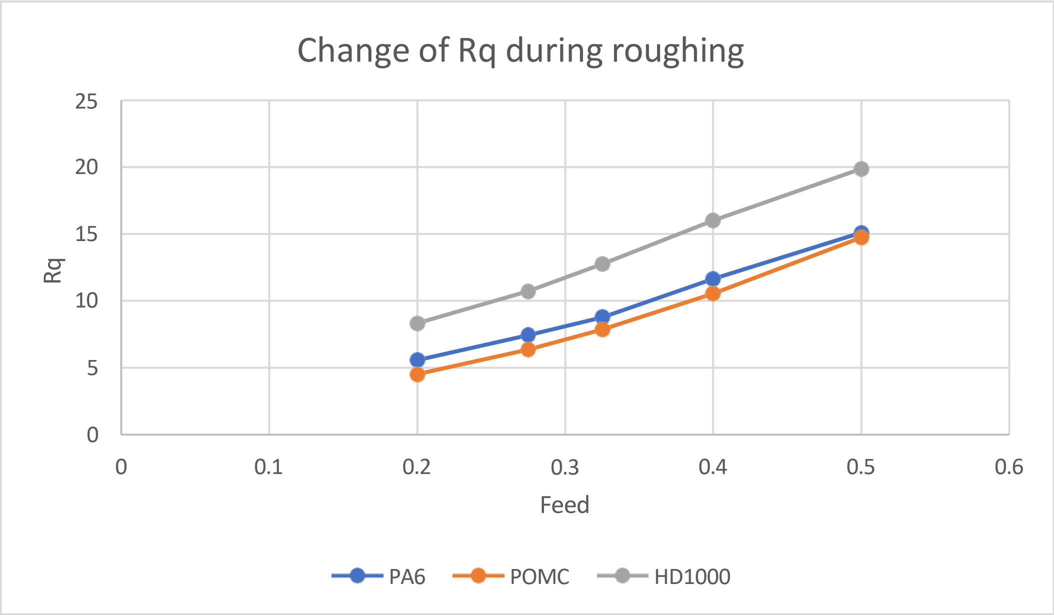


Figure 29: Change of Rq during roughing

We can see from the figure that, as we saw for Ra and Rz and Ry, the values of Rq for PA6 and POMC are approximately the same. This means that they have the same characteristics and morphology. Therefore, the value of Rq for UHMW-PE is higher than the other materials. The root mean square roughness does not differ from the other roughness. During roughing, we can see two things from the diagram:

-The values of PA6 and POMC are approximately equal.

-The value of UHMW-PE is higher than the other 2 materials.

Now, we will see the change of Rq during finishing. The figure below will show us this change (Figure 26):

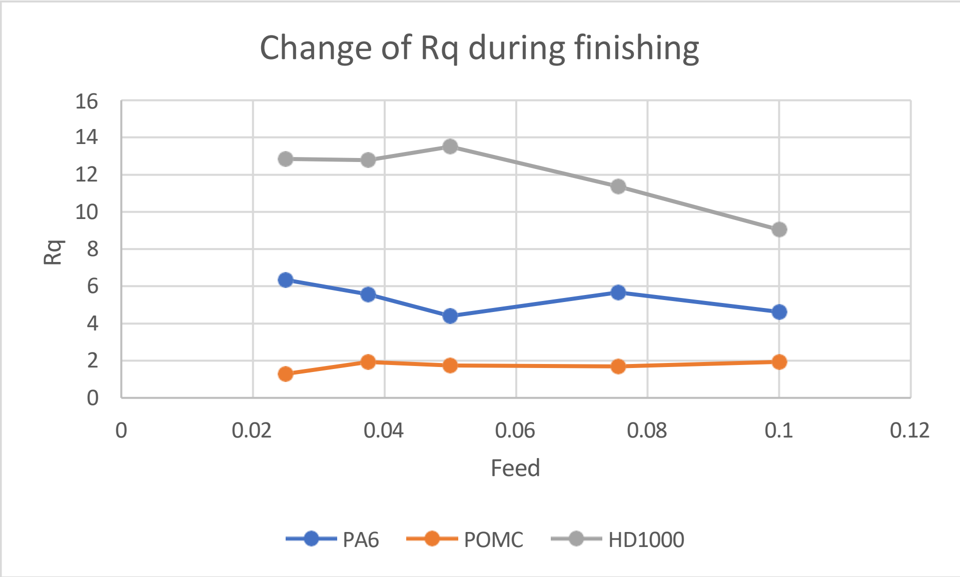


Figure 30: Change of Rq during finishing

The change of Rq during finishing is not constant. For PA6, we can see that it decreases at the beginning, then starts increasing, and at the feed of 0.0755 it starts decreasing again. The same happens for UHMW-PE, it is increasing at the beginning, but starts decreasing starting from 0.05.

We can also see that for POMC the values are lower than the other 2 materials and Rq is constant for all feed rates. Compared for PA6 and UHMW-PE, POMC has a more constant root mean square roughness.

CONCLUSION:

As we could see during this whole research work, surface roughness has an important impact in polymer's manufacturing. The analysis of roughness showed us that the roughness can be influenced by various factors, such as the material's properties, and the conditions of machining. We can also conclude that surface roughness can be optimized using perfect machining conditions.

This research work has helped us to know that polymers can be used without any problems for mass production. It is important to state that each polymer has its own characteristics and morphology. Manufacturers should take into consideration this fact, so each polymer can be used under the right circumcentatces.

We could also state that some polymers have the same characteristics during some parts of the machining. For example, in our case, PA6 and POMC have approximately the same surface roughness when it comes to roughing. Roughing which is known for a higher spindle speed and a higher feed's rate. Therefore, when it comes to finishing, the same materials have different surface roughness. We can say that PA6 and POMC have some similarities when it comes to high strength and toughness.

We can also say that PA6 and POMC respond the same way, in most cases, to the machining processes. The difference in their parameters when we change from roughing to finishing is approximately the same. On the other hand, UHMW-PE's response to the machining process is quite different than the 2 other materials. PA6 and POMC have a stronger difference on their parameters when the machining process goes from roughing to finishing.

This means that the surface roughness is more affected from the change. The parameters of surface roughness change a lot and the smothness of the surface as well.

Although PA6 and POMC have some similarities, they are used in different applications. This applies to UHMW-PE as well.

Each polymer has its own characteristics and morphology, so each polymer can be used in a different application taking into consideration a lot of factors both economically and mechanically.

DECLARATION

on authenticity and public assess of final thesis

Student's name:	Marouane Nadir
Student's Neptun ID:	X02THO
Title of the document:	Surface roughness analyses of engineering polymers
Year of publication:	2023
Department:	Mechanical Engineering Technology

I declare that the submitted final thesis is my own, original individual creation. Any parts taken from an another author's work are clearly marked, and listed in the table of contents.

If the statements above are not true, I acknowledge that the Final examination board excludes me from participation in the final exam, and I am only allowed to take final exam if I submit another final essay/thesis/master's thesis/portfolio.

Viewing and printing my submitted work in a PDF format is permitted. However, the modification of my submitted work shall not be permitted.

I acknowledge that the rules on Intellectual Property Management of Hungarian University of Agriculture and Life Sciences shall apply to my work as an intellectual property.

I acknowledge that the electric version of my work is uploaded to the repository sytem of the Hungarian University of Agriculture and Life Sciences.

Place and date: 2023 year 03 month 02 day

Student's signature

STATEMENT ON CONSULTATION PRACTICES

As a supervisor of Marouane Nadir (X02THO), I here declare that the final essay/thesis/master's thesis/portfolio[1] has been reviewed by me, the student was informed about the requirements of literary sources management and its legal and ethical rules.

I **recommend**/don't recommend[2] the final essay/thesis/master's thesis/portfolio to be defended in a final exam.

The document contains state secrets or professional secrets: no*[3]

Place and date: 02. May 2023

Internal supervisor

[1] Please select applicable and delete non-applicable.
[2] Please underline applicable.
[3] Please underline applicable.

LIST OF REFERENCES:

-The UHMWPE Handbook By Steven M.Kurtz (2004)
https://www.google.hu/books/edition/The_UHMWPE_Handbook/bkuFjppEdMcC?hl=en&gbpv=0
(Downloaded: 21/01/2023)

-Polymer Chemistry: Introduction to an Indispensable Science By David M. Teegarden (2004)

https://books.google.hu/books/about/Polymer_Chemistry.html?id=0qFQ5OuKoy8C&redir_esc=y

(Downloaded: 22/01/2023)

-Polyoxymethylene from Methanol and Acetic Anhydride - Cost Analysis - POM E21A By Intratec (2016)

https://books.google.hu/books/about/Polyoxymethylene_from_Methanol_and_Aceti.html?id=zN0zDwAAQBAJ&redir_esc=y

(Downloaded: 22/01/2023)

-Condensed encyclopedia of polymer engineering terms By Nicholas P. Cheremisinoff (2001)

https://www.google.hu/books/edition/Condensed_Encyclopedia_of_Polymer_Engine/kFZP9aH-wlYC?hl=en&gbpv=0

(Downloaded: 01/02/2023)

-Machining of Polymer Composites By Jamal Ahmad (2009)

https://www.google.hu/books/edition/Machining_of_Polymer_Composites/jYWHVCzjp4g?hl=en&gbpv=0

(Downloaded: 05/03/2023)

-Plastics engineering 4th edition By Russell J. Crawford (2020)

https://www.google.hu/books/edition/Plastics_Engineering/aci2DwAAQBAJ?hl=en&gbpv=0

(Downloaded: 05/03/2023)

-Role of Surface Roughness in Tribology By Chunyan Yang (2008)

https://www.google.hu/books/edition/Role_of_Surface_Roughness_in_Tribology/YrJ95U995CoC?hl=en&gbpv=0

(Downloaded: 07/03/2023)

-Wear resistance and friction of polyamide 66 and polyoxymethylene By Peter Zadorecki

(Downloaded: 08/03/2023)

-Surface measurement of engineering surfaces By J.A. Greenwood (2013)

https://www.google.hu/books/edition/Metrology_and_Properties_of_Engineering/g7LaBwAAQBAJ?hl=en&gbpv=0

(Downloaded: 08/03/2023)

-ISO 4287:1997, Surface structure: Profile method (1997)

https://www.iso.org/standard/10132.html

(Downloaded: 08/03/2023)

-Machinability of engineering polymers By R. Keresztes, G. Kalácska, L. Zsidai, Z. Dobrocsi (2011)

https://www.researchgate.net/publication/303157020_Machinability_of_engineering_polymers

(Downloaded: 08/03/2023)

-Lathe Machine By Er. Amrit Kumar (2019)

https://themechanicalengineering.com/lathe-machine/

(Downloaded: 05/04/2023)

-Nylon 6 production from caprolactam - Cost Analysis - Nylon 66 E12A by Intratec (2019)

https://www.google.hu/books/edition/Nylon_6_6_Production_Cost_Analysis_Nylon/bRmwDwAAQBAJ?hl=en&gbpv=0

(Downloaded: 14/03/2023)