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A Review on Surface Roughness (Ra) Ranges for Some Finishing Processes

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Abstract— The surface finish has a huge impact on machined parts characteristics like wear resistance, fatigue strength, corrosion resistance and power loss due to friction and loss of energy. Unfortunately, conventional machining methods like turning or milling can't meet this requirement. Therefore, surface finish quality is one of the important factors industries searching for in order to ensure reliability and sustainability. Surface roughness average value (Ra) is one of the significant measurements that indicates the finishing quality surface of the machined parts. Usually, typical cutting operations like turning and milling producing high surface roughness values, which force the industries to seek some other finishing operations such as (grinding, honing, lapping, and superfinishing) in order to gain lower surface roughness values and higher quality. In this paper the authors made an investigation and reviewed the surface roughness (Ra) range of some finishing processes to buildup a simple guidance clear for the audience to pick the right process for the required surface roughness (Ra) values.

Keywords— Average surface roughness (Ra); Machining; Superfinishing processes; Review

1. Introduction:

Nowadays turning is one of the important machining processes used in industries to form some cylindrical shapes out of the raw materials due to its simplicity, higher productivity, and low cost. This process is depending on turning the workpiece and removing the undesired material layer out of it when a single point cutting tool fed linearly toward the workpiece in a direction parallel to the rotational axis. Usually, a lathe machine is used for this kind of work and it provides the required power to turn the workpiece and feed the cutting tool at a given rotational speed known as revulsion per minute (RPM). During this process, the undesired layer will be removed when the cutting tool in contact with the workpiece surface on a single point. The metal removal rate is related to the rotational speed of the workpiece, depth of cut, and feed rate of the cutting tool. These are the main principles of the turning process to form a required cylindrical shape out of the raw material [1]. On the other hand, the final shape quality of the produced product from the turning process is very important for both industries and customers. Therefore, one of the most important aspect that industries seeking is the final surface roughness of the produced part which reflect the quality of the product and influences the manufacturing cost. Thus, surface roughness of the produced part is a measurable technique of quality which has a direct description of the geometry of the machined surface combined with the overall surface texture for micro-irregularities of the final surface [2]. Surface roughness in turning depends on some important machining variables such as, cutting speed, feed rate, depth of cut, cutting tool nose radius, rake angle, edge angle, workpiece and tool materials, lubrication type, and machine vibration [3]. One of the most important values used for surface roughness is (Ra) which refers to surface roughness average and a measure of the average height of the roughness peaks as can be seen in figure (1) [4]. The value of Ra usually can be given in micrometer (**μm**) or micro inches (**μin**) and higher value of Ra referring to a surface with higher irregularities and rough surface, while lower value refers to a smoother surface with more flatness texture and higher quality. The aim of this work is to present a review of the roughness average Ra resulted from conventional turning process and to build up a guidance for the finishing processes that may follow the turning process to reach the required surface roughness and quality.

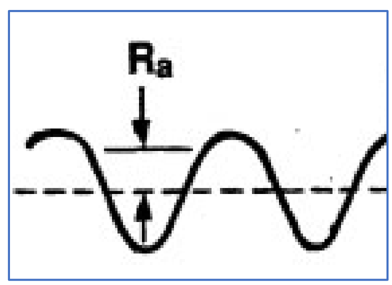

Figure (1): The surface roughness average measurement (Ra) [4].

2. Classification of machining & surface finishing processes:

2.1. Surface Roughness (Ra) Range Resulted from Turning Process:

In the conventional turning operation usually the resulted surface roughness measurements of Ra value for the produced surface showing high surface roughness and may fits between (5 **μm**) to (12 **μm**) as Verma et al. [5] showed in their work when they used the Taguchi method to improve roughness in turning process for ASTM A242 type-1 alloys steel. Moreover, Grzesik et al. [6], presented in their work

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titled by “surface integrity of machined surfaces” that the surface roughness average of turning process can be produced with Ra value fit between (0.4 **µm**) to (6.3 **µm**). Another study made by Courbon et al. [7], which was about comparing a dry turning process with three different superfinishing processes and showed that the dry turning process produces a surface roughness average Ra in a range of (2 **µm**) to (3 **µm**) and has been improved when using superfinishing process by almost (30%) to (95%). One more study made by Kumar et al. [8] which was about investigating the influences of both feed rate and spindle speed on the resulted surface roughness average Ra when five different carbon alloy steels were machined in CNC turning process. Kumar and his team proved that better surface roughness can be achieved by high spindle speed and at low feed rate. The results of surface roughness average Ra for all five investigated machined carbon steels from Kumar and his team work showed a range of (0.8 **µm**) to (6 **µm**). Therefore, the four previous cited studies confirmed that turning process can produce a surface roughness average Ra in a range of (0.4 **µm**) to (12 **µm**) [5-8]. Which means for a requirement of better surface roughness and producing higher surface quality additional finishing processes needed after any turning process [9 & 10].

2.2. Some Conventional Finishing Processes:

Industries seeking and hopping for better and reliable performance to ensure quality by producing products with high geometrical accuracy combined with high surface finish. Therefore, conventional turning process cannot meet the industries hope and additional finishing process will be needed after the turning process to achieve high surface finish quality. There are some conventional finishing and superfinishing processes as can be seen in next figure (2) and may be used after any turning processes to reach the required surface finish quality [10 & 11].

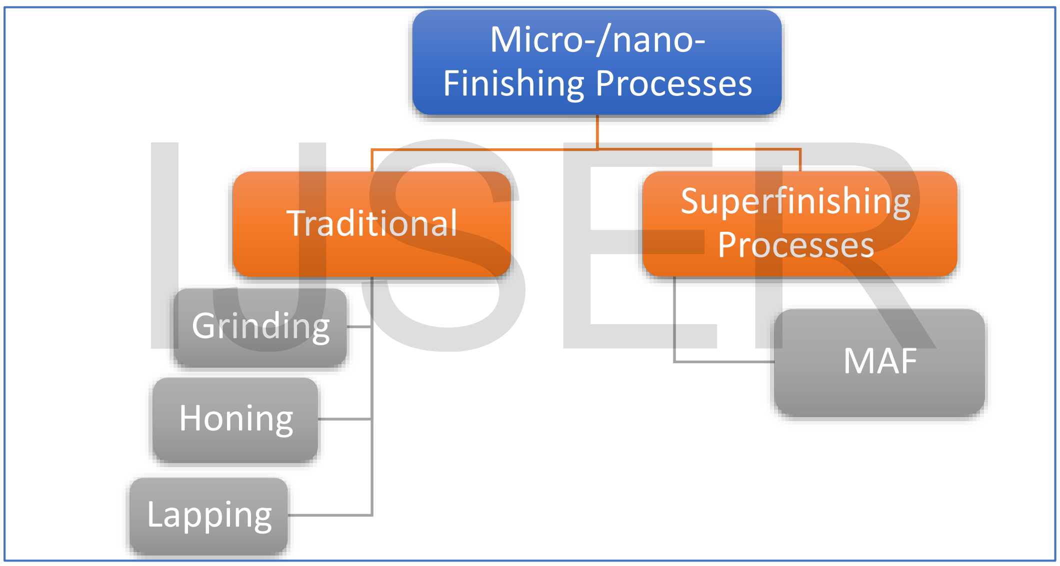

Figure (2): The conventional finishing processes & superfinishing machining processes [11].

2.2.1. Surface Roughness (Ra) Range Resulted from Grinding Process:

Grinding is a process that used after any machining process to combine both good surface finish and dimensional accuracy. In this process abrasives are used to be bounded and fixed on paper, plate, or wheel for precession stock removal [10 & 12]. Therefore, grinding process can be used for flat or round surfaces and for both internal and external surfaces as can be seen in figures (3, 4, & 5) to form better surface roughness and quality when micro-irregularities removed from the surface.

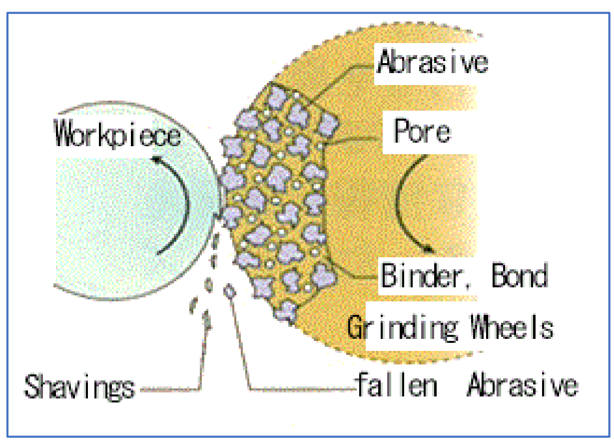

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Figure (3): Grinding process for external round surface using a grinding wheel [13].

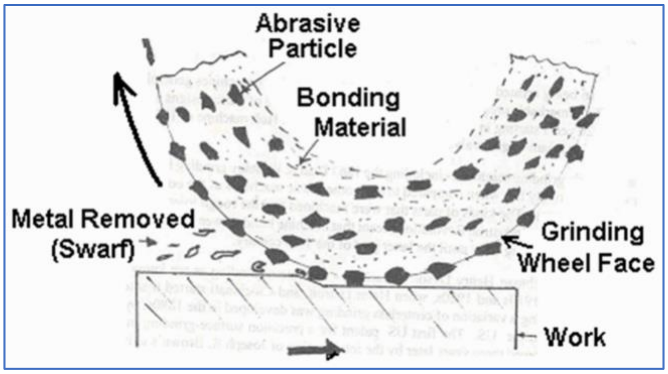

Figure (4): Grinding process for flat surface using a grinding wheel [14].

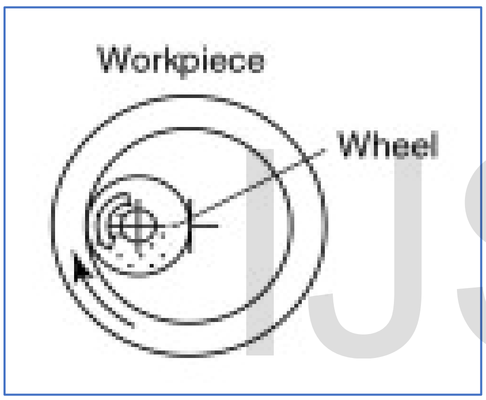

Figure (5): Grinding process for internal cylindrical surface using a grinding wheel [15].

Kwak et al. [16], studied the grinding power spent during the process and the surface roughness of the ground workpiece in the external cylindrical grinding of hardened SCM440 steel using the response surface method and showed that the final surface roughness average Ra range after the grinding process fits between (0.55 **µm**) to of (0.95 **µm**). Another study made by Hassui and Diniz [17], which was about the relation between the grinding process vibration signals and the workpiece quality (Ra) as the grinding wheel gets worn in cylindrical grinding operation of a quenched and tempered AISI 52100 steel. They presented the surface roughness average of a range of (0.2 **µm**) to (1.2 **µm**). One more study made by Lijohn et al. [18] and it was about investigating the surface roughness average of three different alloy steel grades namely EN24, EN31, and EN353 under cylindrical grinding process. The influence of three main grinding process parameters on the final surface roughness average were studied material hardness, work piece speed and depth of cut. The results of the final surface roughness average Ra was in the range of (0.5 **µm**) to (0.8 **µm**). Therefore, the final surface roughness average range of grinding process can fit between (0.5 **µm**) to (1.2 **µm**) [16-18].

2.2.2. Surface Roughness (Ra) Range Resulted from Honing Process:

Honing process is one of the finishing processes that depends on a tool made of abrasive stone and known as hone which carrying out a combination of rotating and reciprocating motions in the same time to form characteristic crosshatch lay pattern whereas the workpiece fixed with no motion. The honing process is usually used for internal cylindrical surfaces finishing as can be seen in figure (6) [19] and figure (7) showing the honing tool motions [20].

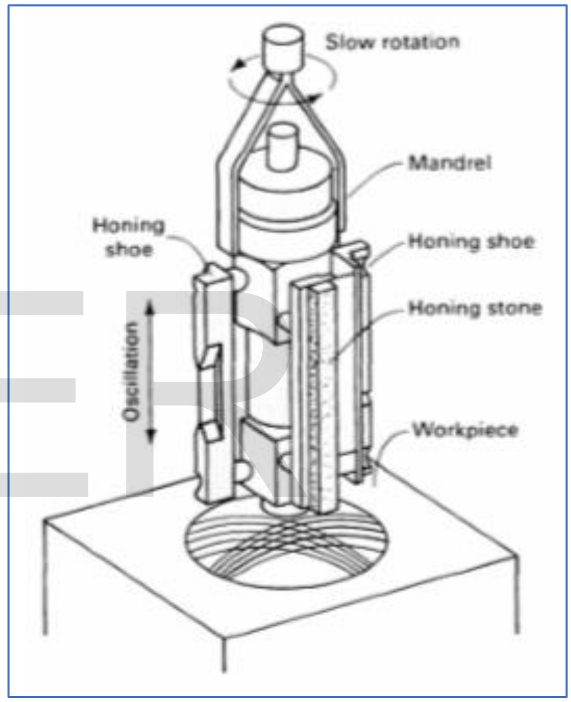

Figure (6): The honing process and its tool [19].

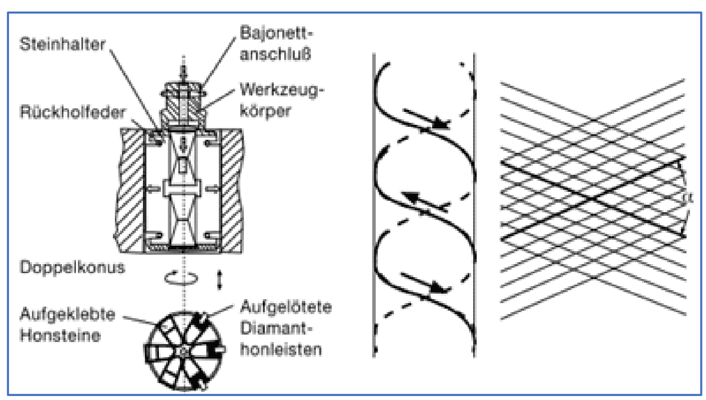

Figure (7): The honing tool on the left, and its motions during the process on the right [20].

There are some literatures made on honing process to optimize the process parameters, one is made by Buj-Corral and Vivancos-Calvet which titled by "Roughness variability in the honing process of steel cylinders with CBN metal bonded tools" [21]. They used four different strategies to calculate surface roughness. These strategies about taking only one measurement per workpiece, taking three measurements per workpiece, taking nine measurements per workpiece, and finally taking nine measurements per workpiece and subsequently eliminating any extreme value. The team made 12 deferent experiments by studying the grain size of the honing stone, expansion pressure of the honing head, and the tangential speed. Therefore, 324 surface roughness measurements were taken, and the recorded range of Ra fit in between (0.3 **µm**) to (2.1 **µm**). another work done by Grzesik et. al. [6] which titled by "surface integrity of machined surfaces" they presented the surface roughness average of honing process can be produced with Ra value fit in between (0.1 **µm**) to (0.8 **µm**). Therefore, the range of Ra found in the previous literatures found to be from (0.1 **µm**) to (2.1 **µm**) [6 & 21].

2.2.3. Surface Roughness (Ra) Range Resulted from Lapping Process:

Lapping process is another finishing process used usually to enhance surface roughness of a flat surfaces and it depends on loose or fixed abrasive particles embedded in between the lap plate made of cast iron mostly and the workpiece surface as can be seen in figure (8). Thus, when the relative motion between the lap and the work surface changed continually the abrasive particles role and slide on the machined surface causing smooth surface with low Ra value [22].

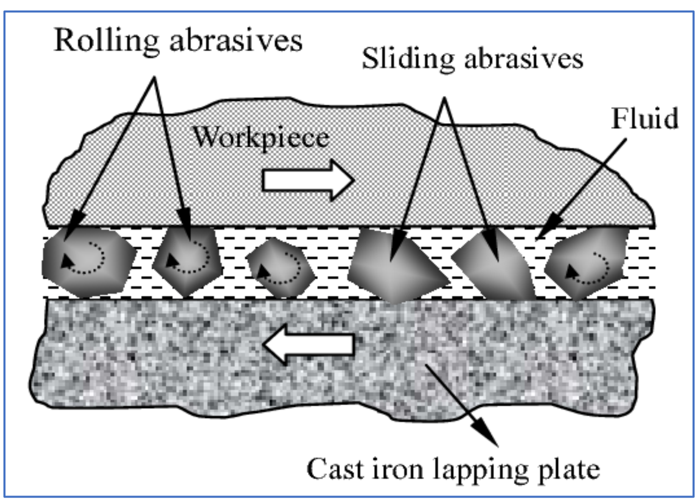

Figure (8): Lapping process and its main components [22].

A study made by Yuan et al. [23] on applying high precision polishing process after a lapping process to obtain a super smooth surface finish of quartz crystal when using three different abrasive powder sizes of AL2O3. Yuan and his team showed a surface roughness (Ra) range obtained after the lapping process is about (0.5 **µm**) to (2.5 **µm**). Grzesik et. al. [6] made a study which titled by "surface integrity of machined surfaces" they presented the surface roughness average of lapping process can be produced with Ra value fit in between (0.05 **µm**) to (0.4 **µm**). Therefore, lapping process can produce a surface roughness average Ra value in the range of (0.05 **µm**) to (2.5 **µm**) [6 & 23].

2.3. Some of Advanced Surface Finishing Processes (Superfinishing Processes):

From the previous section of the finishing processes, we have proved that the conventional finishing processes such as (grinding, honing, and lapping) can finish a surface with a surface roughness average (Ra) from (0.05 **µm**) up to (2.5 **µm**), which is way better than conventional turning process as proved from the literature earlier. Unfortunately, some industries seeking higher surface quality and lower surface roughness average. This has pushed these industries to use different and special finishing processes than conventional ones. These processes known as superfinishing processes and there many of them around the world and we will discuss some of them and their optimum results of surface roughness average Ra. Magnetic aided finishing (MAF) is one of the superfinishing or advanced processes in which a surface is finished by removing the material in the form of microchips by abrasive particles in the presence of magnetic field during the process [24]. MAF processes can be used for flat and round surfaces as can be seen in figures (9 & 10) [10].

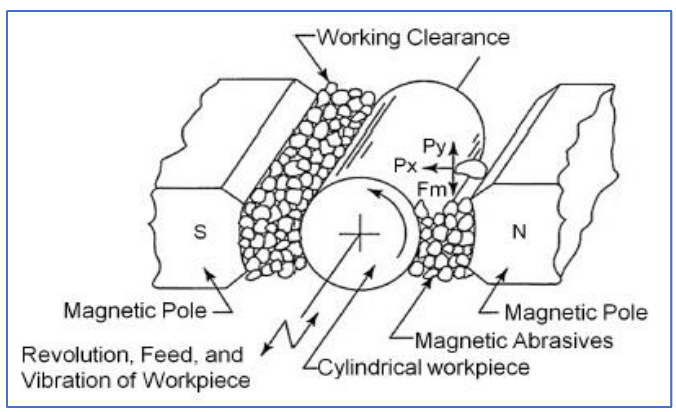

Figure (9): Cylindrical magnetic abrasive finishing process one of MAF processes [10].

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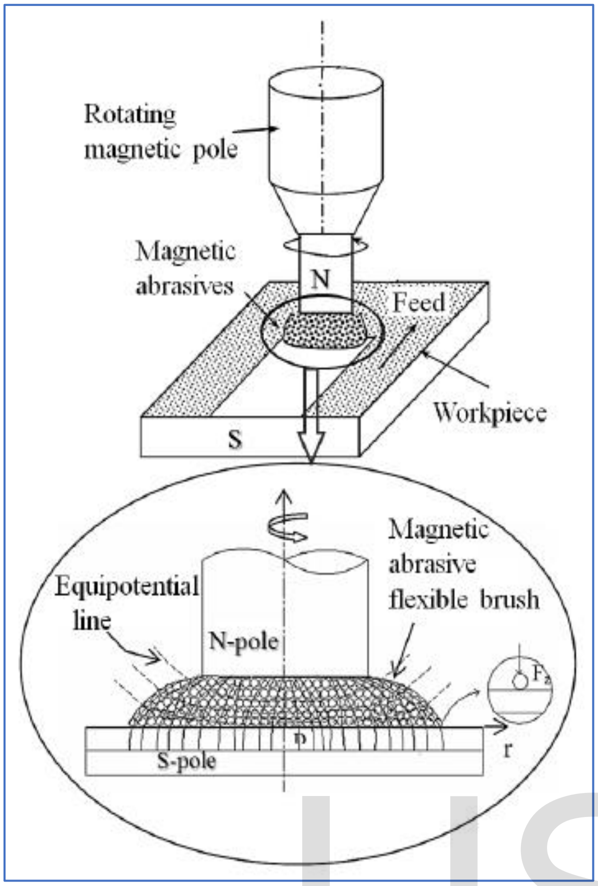

Figure (10): Flat magnetic abrasive finishing process, another MAF process [10].

2.3.1. Surface Roughness (Ra) Range Resulted from Some Superfinishing Processes:

There was a study made by Wu et al. [25] improved the removal rate and surface roughness of SUS304 stainless steel plate using precision MAF process with low frequency with alter-nating magnetic field. The important process parameters such as rotational speed and grinding fluid of magnetic pole were applied to the process for improving the finishing quality. Their results show improvement in surface roughness (Ra) of the SUS304 stainless steel plate from (0.24 **µm**) to (0.004 **µm**). Another work done by Kala et al. [26] developed a new technique using four-pole electro-magnet for finishing copper alloy workpiece. In their experiments, effect of rotational speed, voltage to the electromagnet, mesh size, and pulse on time of ultrasonic vibration on surface roughness were studied. They have found that by using ultrasonic vibrations with the above arrangement a surface finish in nanometer level on a flat copper alloy (C70600) surface could improving it from (0.095 **µm**) to (0.056 **µm**). One more work done by Mulik and Pandey [24] they used an electromagnet with four poles which was found to give better performance in terms of achieving better surface quality in shorter processing time. The voltage, mesh number, rotational speed of electromagnet, and weight of abrasives have been identified as important process parameters affecting surface roughness as they stated. Thus, they have produced a surface finish roughness average of about (0.076 **µm**) to (0.168 **µm**). Moreover, a study made by Kim and Kwak [27] they use improving strategy of the magnetic force by installing permanent magnet (NdBFe) which was applied for the magnetic abrasive polishing to process AZ31 magnesium alloy. Thus, by evaluating the effect of process parameters on the results they have found the finishing roughness average (Ra) fits in between (0.002 **µm**) and (0.09 **µm**). Therefore, from all the MAF literatures mentioned previously we can conclude that the range of surface finishing roughness average (Ra) should fit in between (0.002 **µm**) and (0.24 **µm**) [24, & 25-27].

All the literatures mentioned in this paper previously a comparable table (1) and figure (11) can show the results of all the ranges of surface roughness average (Ra) which can be a good guidance to use the right finishing process for the required application and surface roughness.

Table (1): Showing the (Ra) values range of each process

No	Process Name	Surface Roughness Average (Ra) Interval Range
1	Turning Process	(0.4-12 **µm**)
2	Grinding Process	(0.5-1.2 **µm**)
3	Honing Process	(0.1-2.1 **µm**)
4	Lapping Process	(0.05-2.5 **µm**)
5	Superfinishing Processes	(0.002-0.24 **µm**)

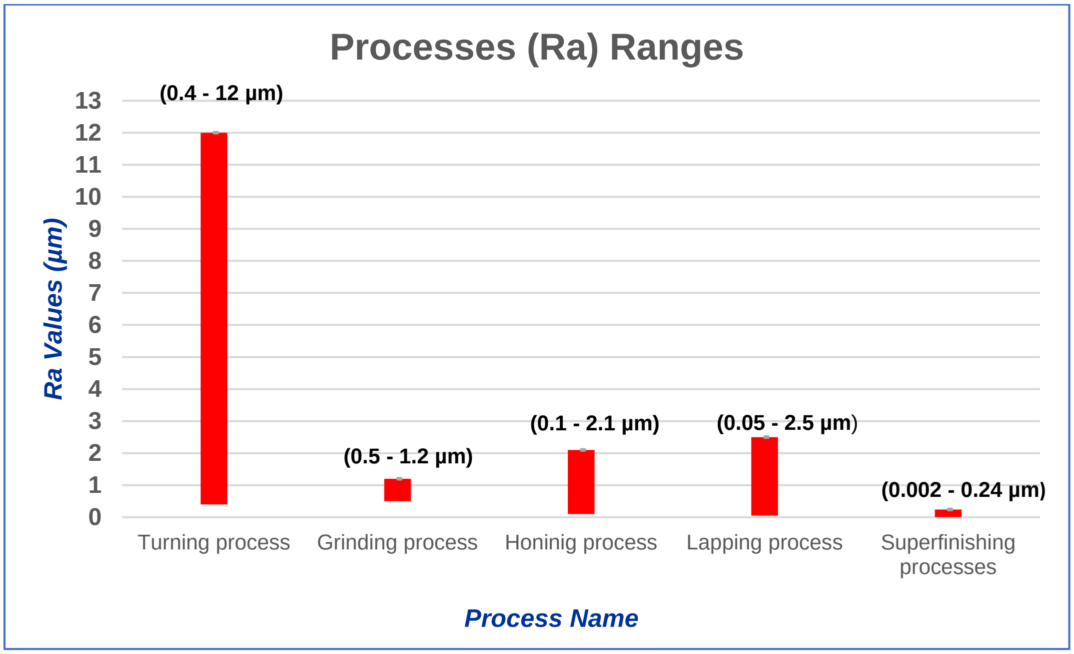

Figure (11): Chart of surface roughness (Ra) ranges for each process

From table (1) and figure (11) it is clear that the shortest range for best quality surface finishing can be obtained by superfinishing or advanced finishing processes which fits between only (2 – 240 nm). While the longest range of finished surface roughness and worst surface quality among all the processes mentioned in this work expected to be obtained by traditional turning process about (0.4 – 12 µm). Even though, traditional grinding process has a short range of (0.5 – 1.2 µm) it still can not produce a surface finish roughness lower than (0.5 µm). On the other hand, conventional honing and lapping processes have intermediate range about (0.1 – 2.1 µm) and (0.05 – 2.5 µm) respectively, and they can reach a good surface roughness quality about (0.1 µm) for the honing process and about (0.05 µm) for lapping process.

3. Concluding Remarks:

This paper reviewed the finishing surface roughness average (Ra) for some of the traditional and advanced finishing processes that can follow any conventional turning processes to build up a guidance for the right finishing process that can be used to achieve the required surface roughness needed. From the resulted guidance made out from this work the following conclusions can be stated:

- In some conventional finishing operations like grinding, honing, and lapping the surface roughness value (Ra) of the finished part can produce an improvement of surface roughness value from (1%) to (95%) when comparing them by conventional turning operations.
- Superfinishing or advanced finishing operations can improve surface roughness values from (1%) to (96%) when they are compared by the conventional finishing operations like grinding, honing, and lapping.
- Superfinishing operations showed better surface roughness values and shorter ranges from lowest quality results to best ones when compared to the conventional finishing operations mentioned in this paper.
- This study focused on some of the traditional finishing processes and some of the superfinishing processes, but there are some other superfinishing processes are not included in this work may have even better roughness results like ultrasonic or burnishing surface finishing processes.
- Additional study may bring significant information about choosing the accurate finishing processes would be a future work by investigating the possible operations defects and residual stresses resulted on the machined parts after each finishing process.

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