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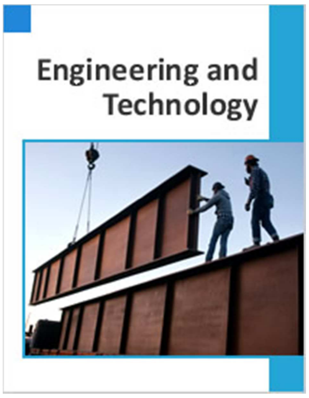

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Field and Image Based Assessment of the Tool's Lifespan Impact on Roughness Parameters in a Context of Advanced Machine Depreciation

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Abstract
This paper aims at assessing experimentally, on the field and by image, the main roughness parameters on work pieces made-up of Aluminum, Bronze and steel through milling, rectification and bedding operations in order to establish the contribution of the tool's lifespan as well as the overriding factors in the final appreciation of the surface profile. The 2D sampling and the non-contact methods of roughness parameters assessment have been deployed, respectively on the surface of pieces and on its corresponding image texture. With 81.5% as follow-up rate of the maximum profile height (R_a) values with those of the standard (ISO norms), we appreciated the roughness behavior in relation with the material and the tool's lifespan on the milling process. The study revealed that depending on the using stage of the tool, there is a net improvement or degradation of the roughness. And so, the surface profile and the final roughness take into account the machining process, the tool and machine-tool added to the measurement device, measuring techniques and the nature of the surface.

1. Introduction

Machined surfaces are not always perfectly smooth; they usually carry tools' print, machine's vibrations and dispersions leading to surface defects on the final piece. The previous are classified at the macroscopic and microscopic levels and range from the first to the fourth order [1] or to the sixth order [2]. It has been proved that the lower the roughness, the more difficult the machining process no matter the machine's performance [3]. Technologies and manufactured parts are becoming lighter due to the preservation of natural resources and the reduction of thickness implies more accuracy in the smoothness' research.

The appreciation of roughness on machined part can be exercised in contact with a roughness tester [4], surface profilometer [5], in non-contact through the acoustic interferometry and speckle correlation [6], Scanning Electron Microscopy, Atomic Force Microscopy [7] and in both ways [8]. The last decade, works concerning the determination of roughness' parameters were focused on roughness as a function of the machine's settings, stating clearly a specific interest on the speed N (RPM), the cutting speed V_c, the feed f [4] [9] and lightly on lubrication [10]. Actually, *Mohammed T. Hayajneh et al, (2007)* [11] studied the Effects of Machining Parameters on the Surface Roughness in the End-Milling Process. They developed a better understanding of the effects of spindle speed, cutting feed rate and depth of cut on the surface roughness in order to build a multiple regression model. They presented at 12% the prediction of the roughness through the model including the effect of spindle speed, cutting feed rate and depth of cut, and any two variable interactions. *H. Bouchelaghem et al, (2007)* [4] in their works outlined the influence of cutting conditions of the surface roughness on the AISI D3 machined with a CBN tool in turning operation. And so, they established the surface degradation or final roughness of the machined surface as a result of the superficial damage of tool's facet and cutting edge and the surface quality as a result of the cutting conditions taken as major. Also, *Bourebia Mounira (2010)* [9] worked instead on the effect of the machining processes on the surface roughness. As a conclusion, he highlighted the increase of the cutting speed and the cutting depth as well, favor the surface quality in opposition to the feed rate.

The objectives of the works carried out, on the universal milling machine (700 CRGS 6121 of 1967), on the grinding machine (ITAMEK RWH - 1000) and the bedding (Abro grinding paste), are to present how significantly, it is possible to intervene on the tool's lifespan. Taking into consideration the advanced depreciation of the machine in terms of poor effectual control and mastery of the machine's maintenance records, the results of the works are colored with the reality of a geographical location which cannot afford, most often, machines at their new state to operate, but is trying as much as possible to follow the international standards. Therefore, this is done in order to achieve a desired surface finish with respect to the machine operation and the norm in force as far as average roughness (Ra) is concerned. The work is thus organized in presenting the materials and resources identifying namely the parts, the tools and machines, followed by the methodology putting in over line the tool's lifespan determination, thereafter the up-lighting of data and results, all the previous termed with a conclusion.

2. Materials and Resources

Constituting the base with which the precision of the exercise was to be carried out, the materials used in the roughness parameters' assessment are presented in terms of work piece samples, machine and measurement tools and acquisition and processing systems.

2.1. Identification of Parts

For the contextual use and the impact in the engineering at large, the choice was made on 3 cylindrical rough pieces of metal namely structural carbon steel C40, Bronze CuSn9P and Aluminum EN AC-AlSi5, with the specifications diameter $\varnothing 38mm$ and length $L = 35mm$.

2.2. Tools

The machine-tools were selected according to the specific work, thus the milling cutter type R220.69-0050-09-5AN with carbide insert type XOEX090308FR-E05 H15 from SECO enterprise recorded in table 1 for the milling operation, the rectification and bedding processes used the grinding stone $1-B\ 200 \times 16 \times 10\ SC1\text{-}60-K-6-VY$ referenced with the norm DIN EN ISO 14001 from ATLANTIC Enterprise and Abro grinding paste from ABRO respectively. The measurement tool used to implement the field evaluation of the roughness' parameters was the digital dial gauge NU-1365/0506 from FACOM.

2.3. Machines

According to the operations to perform, Alcera 700 CRGS 6121 for the milling and ITAMEK RWH – 1000 for the rectification were the machines at our disposal. The bedding process was carried out manually.

2.4. Acquisition and Processing Systems

The acquisition system was put in place in the image processing laboratory through the use of the optical microscope VP eye 6.6 with an inserted protractor. The computer Intel® Core™ i3-4030U CPU @ 1.90GHz; 1.90GHz - 6Go was employed for the pre-processing and the processing of the images.

3. Methodology

3.1. Choice of Machining Conditions

Related to the various tools and machining processes, the selection and the calculation of the key factors were implemented as portrayed in table 1 and the following one has been highlighted [1] [12]:

$$n = \frac{V_f}{f_z \times Z} \text{ (for milling) and } n = \frac{1000 \times 60 \times V_c}{\pi \times \phi_{Gs}} \text{ (for rectification)} \quad (1)$$

V_f the feed per minute, n the rotational speed of the spindle or the grinding stone (Gs) in rpm and Z the number of tool's teeth. The feed per tooth is calculated and the value of the cutting is related to the material and the type of machining operation.

3.2. Tool's lifespan "t_{ls}" Determination

In order to progress while taking into consideration the heuristic method of roughness parameters' assessment, the focus was on the milling operation as the base of the works done in order to portray the roughness value as a result of the tool's lifespan. And so, the maximum profile height (peak-to-valley height) "R_t" obtained from conventional milling operation can be written as shown in equation (2) below [1];

$$\text{Rt} = 0.032 \times \left(\frac{f_z}{r_\varepsilon}\right)^2 \quad (2)$$

f_z the tooth feed and $r_\varepsilon = 0.4$ from the abac or nomogram [12]. Considering the table feed calculation [1] [13] and the tool-in-cut time tc, the profile average height (arithmetic average) with the relation "$R_a = 1/4\ R_t$" will be:

$$\text{Ra} = 2 \times 10^{-2}\left(\frac{L_p}{t_c \times z \times n}\right)^2 \quad (3)$$

Lp is the length of the piece, z is the number of tool's teeth, n is the number of revolution. The previous permitted to have the theoretical appreciation of the tool-in-cut time:

$$t_{c_i} = \frac{0.1 \times L_p}{Z \times n}\sqrt{\frac{2}{R_{a_i}}} \quad (4)$$

Bringing the operator to consider each run in the machining process while using the same tool in the smoothness research. And so,

$$t_c = \sum_{i=1}^{n} t_{c_i} = t_{c_1} + t_{c_2} + \cdots + t_{c_n} \quad (5)$$

with i taken as each operation where the tool is used with the same cutting conditions and with the roughness parameters plotted.

The technical elements in terms of materials and resources are therefore recorded in table 1:

Table 1. *Machining conditions.*

Operation	Description of the machine	Precision	Materials	Tools and cutting parameters					
				V_c	f_z	n	Tools	Sense of rotation	Lubrication
Milling	Alcera 700 CRGS 6121	2/100	C40 EN AC-AlSi5 CuSn9P	126 132 132	0.2	800 840 840	Plain milling cutter indexable carbide insert Ø50 – 5tips	Up-milling	Automatic and continuous lubrication
Rectification	ITAMEK RWH - 1000	1/100	C40 EN AC-AlSi5 CuSn9P	80		1530	Grinding stone type 1 – B – 200x16x10 SC1- 60 – K – 6 – VY	Plane	No lubrication
Bedding	ABRO Grinding paste	/	C40 EN AC-AlSi5 CuSn9P	Manual	None		Bedding grease (fine size)	None	

We can therefore relate its formula with the other cutting parameters through the expression:

$$t_{ls} = t_c + \varepsilon \quad (6)$$

With $\mathcal{E}$ considered as minor factors due to the wear variation on the tool and machine's depreciation.

3.3. Determination of Roughness' Parameters

The preparation of the parts through tap testing and their machining led us to the evaluation of the surface finish and roughness. In order to better understand and discuss the results, we used 2D and 3D sampling methods in the workshop and in the image processing laboratory respectively.

3.3.1. 2D Sampling Method

The parameters *Ra, Rp, Rv* and *Rt* have been estimated on the surface of the work pieces through the gridding approach with the help of the dial gauge. The value obtained at each point from the line on the length and on the width permitted to plot the graphs and to determine the values of those parameters. From the previous, we determined the profile average height using the formula [14]:

$$\text{Ra} = \frac{1}{M \times N}\sum_{i=1}^{M}\sum_{j=1}^{N}\left|r_{ij}\right| \quad (7)$$

3.3.2. Non-contact Method

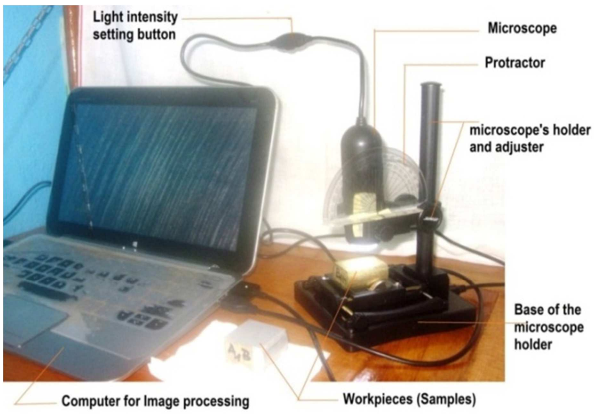

Figure 1. *Image Acquisition system.*

The images acquisition of micro-photographs from the different samples was done following the set-up principle [14]. The digital microscope used for the acquisition of the images is mounted on its support and connected to the computer through a USB cable. The protractor permits to control the variation of the angles during acquisition in such a way to cover 60º through the length of the piece and 30º through its width. And so, we extracted images at the angles: 60º, 75º, 90º, 105º, and 120º in order to balance the information from the acquired images. The acquisition system is shown on figure 1.

The image pre-processing was carried out with the conversion of RGB image to grayscale and the Gaussian filtering [15] of the obtained image was then performed [16]. The Image processing in the work was carried out with the help of Mountains Map from Digital Surf surface intelligence, version 7.2.7334 [17].

4. Data, Results and Discussion

4.1. Data

The presentation of data is done according to the field of works. Data from the workshop are the samples that we obtained from the machining conditions (table 1) for a total of 27 work pieces, 9 for each material and lengths of 32mm, 42mm and 33mm for aluminum, bronze and steel respectively. Upper flats of 8mm and lower flats of 5mm were performed on the work pieces. The figure 2 shows some samples.

Figure 2. *Some samples of the work pieces after machining processes.*

We took at least five images at each angle varying the position and for all the samples giving us a total of about 675 images to analyze. Some samples of the extracted images bitmap, 8bits, 640x480 are shown in the figure 3.

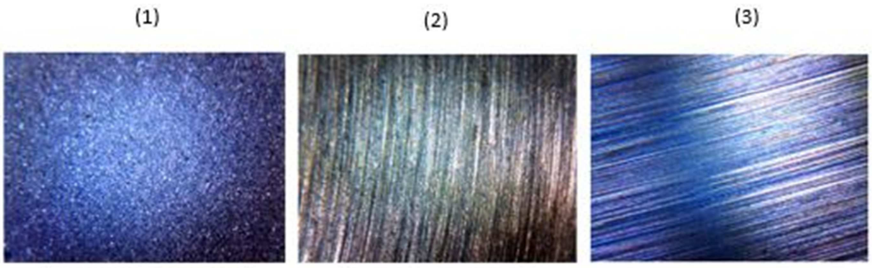

Figure 3. *Image Samples, (1) Aluminum by bedding; (2) Bronze by milling; (3) Steel by rectification.*

4.2. Results

4.2.1. Workshop and Laboratory Results

The table 2 presents the results of the four (4) parameters of the roughness as announced in the methodology. According to the maximum profile height (peak-to-valley height) "R_t" with the machining methods [1], we evaluated the follow-up rate of the number of pieces between our results and the values of the international standard ISO and we established the table 3

Table 2. *Workshop results (values in μm).*

Samples	Along the length			Along the width			Average	Along the diagonal		
	Rp	Rv	R_t max	Rp	Rv	R_t max	Ra	Rp	Rv	R_t max
A1B	3.5	-1.25	2.25	0.4	1.6	2	2.125	4	-1	3
A2B	2.4	2	4.4	2.5	1.25	3.75	4.075	4	2	6
A3B	2.25	2	4.25	2.6	2	4.6	4.425	4	4	8
A1M	8.25	5.5	13.75	8.2	-2	6.2	9.925	66	35	101
A2M	4.25	7.5	11.75	4.6	6	10.6	11.175	35	1	36
A3M	15.25	7.5	22.75	14.6	16	30.6	26.675	37	42	79
A1Rc	0.2	6	6.2	0.6	4	4.6	5.4	9	9	18
A2Rc	5.75	2.5	8.25	5.8	-1.4	4.4	6.325	4	6	10
A3Rc	6	2.8	8.8	7.4	0.6	8	8.4	9	1	10
B1B	-2.5	-4.25	1.75	3	0	3	2.375	4	6	10
B2B	3.75	0	3.75	2.4	3.4	5.8	4.775	5	3	8
B3B	4.5	0.25	4.75	1.2	4.8	6	5.375	5	2	7
B1M	9.75	4.5	14.25	8.4	7.6	16	15.125	26	70	96
B2M	11	17.75	28.75	13.75	4.25	18	23.375	23	42	65
B3M	9	23.75	32.75	17.75	4.25	22	27.375	4	38	42
B1Rc	-0.25	2.75	2.5	2	0.4	2.4	2.45	4	6	10
B2Rc	-0.25	4.25	4	2.4	0	2.4	3.2	4	6	10
B3Rc	3	2.25	5.25	3.8	1	4.8	5.025	6	6	10

Samples	Along the length			Along the width			Average	Along the diagonal		
	Rp	Rv	R_t max	Rp	Rv	R_t max	Ra	Rp	Rv	R_t max
S1B	2	2.5	4.5	1.6	1.8	3.4	3.95	4	2	6
S2B	3.75	3.5	7.25	2.4	1	3.4	5.325	5	5	10
S3B	2.75	2	4.75	4	3.6	7.6	6.175	7	7	14
S1M	11.25	12	23.25	17	0	17	20.125	-5	63	58
S2M	42	-15.5	26.5	29	-6	23	24.75	46	2	48
S3M	23.75	2.2	25.95	13.5	15.75	29.25	27.6	-7	65	58
S1Rc	3.75	0.5	4.25	2.2	-0.4	1.8	3.025	6	0	6
S2Rc	2.25	3.25	5.75	1.8	3.2	5	5.375	1	6	7
S3Rc	4.75	2.25	7	2.4	4.2	6.6	6.8	6	-6	12

Table 3. *Fraction of R_t between the results and international standard.*

	Aluminum	Bronze	Steel	Total
Milling	6/6	6/6	6/6	9/9
Rectification	6/6	6/6	6/6	9/9
Bedding	3/6	3/6	2/6	4/9

The evaluation carried out in the table 3 helps us to conclude that the follow-up rate (FR) of our results to the international standard is: FR = $\frac{ENp}{TNp}$ FR = 0.815 for a percentage of 81.5. Where, *ENp* is the Effective Number of pieces respecting the standard and *TNp* is the Total Number of pieces.

4.2.2. Comparison Between 2D and 3D Results

The table 4 portrays the profile average height R_a obtained from the method in the workshop standing as 2D profile measurement, the arithmetic average S_a from the laboratory works standing as 3D surface measurement [16] and the efficiency of Ra with respect to Sa of each sample and from each machining operation. The error (E) and the efficiency (η) are therefore calculated [14] using the formula:

$$E = \frac{R_{a(measured)} - R_{a(estimated)}}{R_{a(measured)}} \text{ and } \eta = (1 - E) \times 100.$$

Table 4. *Arithmetic Roughness (Ra) for 2D and 3D methods.*

Samples	Ra (μm)	Sa (μm)	Efficiency (η)
A1B	2.125	0.595	23.977
A2B	4.075	0.618	15.189
A3B	4.425	1.043	79.115
A1M	9.925	7.891	79.115
A2M	11.175	9.157	81.946
A3M	26.675	20.334	76.231
A1Rc	5.4	4.197	77.74
A2Rc	6.325	6.735	93.502
A3Rc	8.4	9.285	89.461
B1B	2.375	0.809	33.984
B2B	4.775	0.819	17.155
B3B	5.375	0.809	15.069
B1M	15.125	12.571	83.115
B2M	23.375	22.046	94.316
B3M	27.375	17.763	64.889
B1Rc	2.45	2.066	84.359
B2Rc	3.2	3.179	94.4
B3Rc	5.025	6.391	72.813
S1B	3.95	0.659	16.686
S2B	5.325	0.728	13.675
S3B	6.175	0.932	15.103
S1M	20.125	18.005	89.468
S2M	24.75	20.268	81.890
S3M	27.6	23.158	83.905
S1Rc	3.025	2.922	96.595
S2Rc	5.375	6.205	84.546
S3Rc	6.8	7.743	86.123

Referring to the software announced in the paragraph 3.3.2, we established the efficiency which, from all machining processes, is 84.13%. Due to the measurement tool, we left out the bedding operation while evaluating the cited percentage. And so, the results of the table 4 permit to continue the roughness' determination considering the field measurements closed to those from the laboratory.

4.2.3. Presentation of Roughness as a Result of the Tool's Lifespan

A direct relation between the tool's lifespan and the profile average height was determined only for the milling operation [1]. The table 5 presents the results of the average roughness Ra with record of the variable "t" under its real value (effective tool's lifespan "*t used*") and its estimated value (calculated tool's lifespan "t_{c_i}"). The other variables which contribute or impact on the roughness have been fixed and coming from the technical standard documents and related works [1] [11] [12] in order to better observe a variation of the roughness due to the action on the parameter "t".

Table 5. *Average roughness with the consideration of the time (tool's lifespan).*

samples	Lp	VBb	n	a_p	V(av)	f	t_{c_i}	t used	Ra(mea)	t_{ls}
A1M	63	0.3		1			0.0239	0.5	7.83	29.5
							0.0213	1	9.925	29
A2M	63	0.3	840	1	132		0.0234	1.5	8.15	28.5
							0.0200	2	11.175	28
A3M	63	0.3		1			0.0166	2.5	16.225	27.5
							0.0130	3	26.675	27
B1M	63	0.3		1			0.0188	3.5	12.784	26.5
							0.0172	4	15.125	26
B2M	63	0.3	840	1	132	0.2	0.0148	4.5	20.431	25.5
							0.0139	5	23.375	25
B3M	63	0.3		1			0.0143	5.5	22.142	24.5
							0.0128	6	27.375	24
S1M	63	0.3		1			0.0156	6.5	18.561	23.5
							0.0150	7	20.125	23
S2M	63	0.3	800	1	126		0.0146	7.5	21.07	22.5
							0.0135	8	24.75	22
S3M	63	0.3		1			0.0137	8.5	23.95	21.5
							0.0128	9	27.6	20

From the table 5, we drew the curves (laboratory assessment of Aluminum, Bronze and Steel) in figure 4 in order to portray graphically the roughness behavior in relation with the effective time (t used). The graphs presented in figure 4, each one in its relation with the material and the machining conditions, let appear the correlation (linear approximation curves) existing between the tool's lifespan and the roughness.

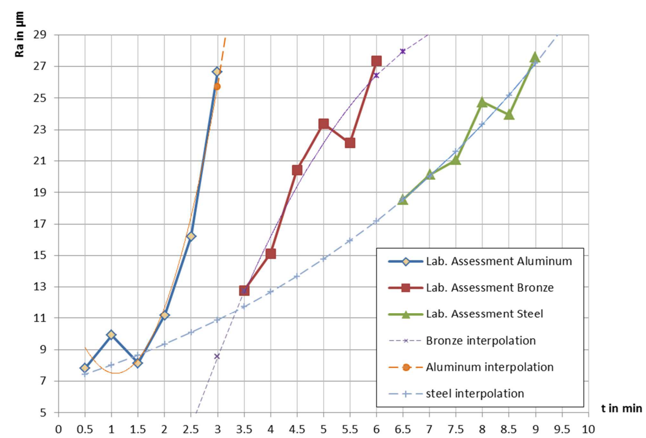

Figure 4: Roughness progress curves – **EN AC-AlSi5, CuSn9P** and **C40**

Figure 4. *Roughness progress curves – EN AC-AlSi5, CuSn9P and C40.*

The curves obtained can be used for the interpolation (Aluminum, Bronze and Steel interpolation) when presented in their correlated forms. However, the following statements can be made. The roughness increases as the machining time is growing. So as to say, the roughness is a function of the time ($Ra = f(t_{ls})$). The curve trend is different on each graph due to the nature of the material. This permits to assert the roughness as a function of the material. With the consideration of the three stages of the tool's lifespan [11], the slope of the curves shows that the works on the aluminum and the bronze were carried out when the tool was still at the first phase and the transitory one respectively.

The compilation of curves on the gridline portrays definitely the considerable number of points entering in the arithmetic roughness interval in milling process. This is justified no matter the material.

4.3. Discussion

The Roughness parameters assessment carried out in the workshop helps to establish time or tool's lifespan as a conditional factor. We understand finally that we can act on the tool's lifespan in order to improve the final value of the roughness no matter the machining operation. The works carried out by H. Bouchelaghem et al. [4] and those of J.F. Debongnie [12] quote certainly this factor but do not emphasize how when considered alone it can affect powerfully the final roughness in relation with the nature of the material. This result completes the assertion about the speeds on the final roughness of a machined part [4] [12]. Thus, as announced in the framework of this paper, we highlighted the importance of the tool's lifespan in the roughness assessment. Moreover, it's relevant to gaze at how to evaluate the individual contribution in a system of roughness assessment in which all of the machining conditions, the material of the work piece and the tool's lifespan are to be taken into consideration in order to better present the specific uptakes.

The measurement of average roughness of machined parts, in link with specific and high precision machining process like bedding, is not the prerogative of measurement device like dial gauge as demonstrated by the results. R. Dietrich et al. [1] declare in the profile and the measurement direction that the approximation rate of the measured profile with consideration to the real profile depends on the precision of the measurement tool, the measurement techniques and the real nature of the surface. However, for the assessment and a better understanding of the surface's profile, we have to take into account the complete history of the surface formation; including here as addition the tool, the machine and the machining conditions. This assertion lightly revokes the previous three conditions and adding three new elements. Therefore, we practically (experimentally) proved the first condition of the approximate point of effective profile in the surface's profile and measurement direction [1]. And we established a new set of elements to be taken into consideration in the machined surface profile's appreciation.

As discussing about the roughness assessment, we are in straight line to question ourselves on how to understand whether the multiplication of measurement techniques and tools cannot reveal the average roughness as an additive quantity or a superimposed value in one hand. In the order hand, while reading at the curves, there could be factors like hysteresis and even inertia to take into consideration in order to work in the same objective and build at low cost a prediction model of the roughness on the same material at different machining conditions.

Many works are approaching the roughness evaluation or appreciating it in a context of perfect availability of machines-tools and measuring equipment. However, the advanced machine depreciation which is ours, in terms of multiples corrective maintenance and also in the series of dimensional dispersions initiated by the approximate maintenance's parameters, reveals complex the control of the roughness during the machining process as compared to the one with machines at a new state or with a mastered maintenance. Therefore, the contextual appreciation of the machines' depreciation doesn't help to vividly estimate the follow-up's rate of the international norms or standards in order to ensure a global competitiveness in physical outputs.

5. Conclusion

Works on roughness research and assessment permit to understand that the exercise doesn't take into consideration only the speeds condition but also the lifespan of the equipment and the measurement tool. The multiplication of machining processes namely milling, rectification and bedding helped to appreciate the obtained roughness values compared with the international standards in order to demonstrate, without any ambiguity, the reliability of the surfaces obtained in the machining context which is ours. Nevertheless, we are to move ahead with the thinking of following the open directions which are linked to the roughness assessment in one hand. In the other hand we have to consider all the parameters entering as hypothesis and those taken into the process to approach the perfect prediction of the surface profile.

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