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Experimental Study of the Correlation the Surface Roughness 2D and 3D in the Honing Process of the Steel Cylinder

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Abstract

Objectives: This research proposes the feasibility of working on surfaces obtained by honing with 2D roughness parameters, as the 3D roughness measurement commonly used in the industry requires many hours of measurement time. **Methods/Statistical Analysis**: In this article, we study the values of surface roughness in two dimensions and three dimensions measured inside cylinders, machined by honing in industrial honing machines. Hardness has been measured with a contact probe roughness meter, as this type of instrument is widely used in academic and especially industrial applications and is standardized in international standards such as ISO 3274 or ASME B46.1. **Findings:** It is concluded that due to the excellent association obtained, it is sufficient to work with adjustments in two dimensions to characterize the surface, since the roughness in three dimensions takes a long time to be measured with a contact roughness meter like the one used in this investigation, so 2D parameters can be used because due to their normal behavior, they offer competitive advantages due to their ease of determination and require shorter measurement times. **Application/Improvements:** Manufacturers of hydraulic cylinders, surface finish of the inner wall of internal combustion engines and all those applications where it is machined with honing.

Keywords: Honing Process, Surface Roughness, Steel Cylinder, 2D/3D Roughness

1. Introduction

One of the generations of surface textures is one of the leading characteristics of abrasive processes with a crucial random component that has been widely studied[1,2]. Some factors that influence the variability of the measured roughness values have been considered experimentally, such as the angle of surface scratching in processes such as honing[3], since the orientation of this scratch depends on the best functionality of the cylinder in terms of sealing and proper lubrication between it and the piston or segments that slide inside it[4,5]

Bearing, in mind that in the scratched process its orientation can be visualized and measured from the roughness parameters in both 3D[6] and 2D[7–9]. This study presents a comparative analysis between the parameters of the process in 2D and 3D between the measurements made in the mentioned points of the same cylinder, in its differ-

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ent replicas and also in different types of honing, according to experimental configurations that have been taken into account for this process[10].

The measurement of the 3D roughness to see the orientation of the scratch on honing surfaces has been of particular interest, which can also be determined by the relationship between the linear speed of the head and the rotation speed[11] so that the scratch angle can be known and controlled with these process parameters.

On an industrial level, it is more common to use 2D parameters and contact roughness gauges with a probe. However, the primary objective of this work is to determine if it is possible to work on surfaces obtained with honing with 2D roughness parameters, since measuring roughness in 3D with a contact type roughness tester commonly used in the industry requires many hours of measurement time for each measuring point or area. To carry out the experimental study, three levels of honing with Rough, honing with semi-finished and honing with rough were applied to the inner wall of the hydraulic cylinders.

2. Methodology

2.1 Initial Study Conditions

To analyze the variability of the roughness values measured on the surface measured by honing in hydraulic cylinders, six tubes were machined with the characteristics shown in Table 1.

All the tubes were machined on a machine of the manufacturer HONINGTEC of reference N842, but different machining operations were carried out as shown in Table 2. The rough stones used are made of CBN, with a grain density in the binder of 50 according to the FEPA standard[12], with different coarse grain sizes.

As for the geometric characteristics of the pieces, the length of the tubes was 607 mm, the external diameter is 70 mm, and the internal diameter after honing is Ø60H8, as shown in Figure 1, where the dimensions of these tubes are detailed.

In the rough operation, 7 hundredths of a diameter were removed from the tube with approximately 10 passes, while in the semi-finished process, 5 hundredths of a width were removed from the container with about 10 passes, and in the finished operation, 2 hundredths of a diameter were removed from the tube with approximately 20 passes of the machining tool.

2.2 Description of the Roughness Measuring Instrument

The measuring instrument used was the TAYLOR HOBSON "Talysurf Series 2" profile roughness tester, shown in Figure 2, which was equipped with an inductive probe with 16 nm resolution, with a diamond tip radius of 2 µm, and a measuring speed of 0.5 mm/s. The filter used was of the Gaussian type, setting the high-pass filter at Lc = 0.8 mm and the low-pass filter at Ls = 0.0025 mm, with a measuring length of 5.6 mm in the direction of the tube generator and an evaluation length of 4 mm, according to ISO 3274[13]. For the three-dimensional measurement, a 4 × 4 mm evaluation area was used, with uncertainty given by the manufacturer's calibration certificate of ± 0.004 µm + 2%. The tests were carried out with a roughness meter located in the Metrology and Surface Quality Laboratory of the Mechanical Engineering Department of the Escuela Técnica Superior de Ingeniería Industrial de Barcelona-ETSEIB-UniversitatPolitécnica de Catalunya, at an average temperature of 20±1°C.

2.3 Selection of Roughness Parameters

The three-dimensional roughness parameters used in the study are shown in Table 3, which provide a fuller range of research of surface texture and are associated with the functional behavior of the surface and allow the study of phenomenology such as contact, tribology and wear, etc., especially the influence of scratching on the surface[14]. Similarly, Table 3 shows a comparison between the 2D and 3D roughness parameters, which allows a comparative analysis between the scopes of both processes.

2.4 Sampling and Data Collection Technique

To take the samples, the tube was cut into three pieces (piece A, piece B and piece C) because the probe of the

Table 1. Characteristics of machined tubes

# CYLINDER	NUMBER	MATERIAL	MACHINING
2	189 – 190	ST-52	ROUGH
2	191 – 192		ROUGH + SEMI-FINISH
2	193 – 194		ROUGH + SEMI FINISH + FINISH

Table 2. Machining parameters

Process Variables	Rough	Semi-Finish	Finish
Abrasive Stone (FEPA)	B252	B126	B30
RotationalSpeed (rpm)	230	260	340
Axial Speed (m/min)	40	40	40
Pressure N/cm2	700	700	700
Coolant	Sunnen MB30		

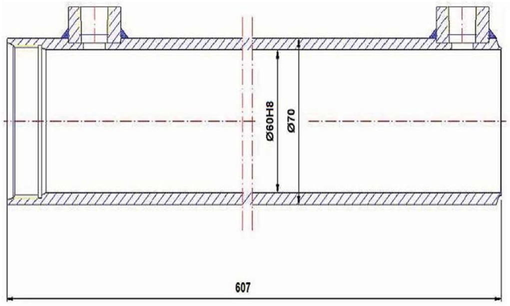


Figure 1. Test tube used in the study.

Figure 2. Roughness tester Taylor-Hobson.

roughness meter did not reach more than 150 mm from the edge of the tube and it was desired to measure the roughness in different areas along the tube. Each piece was measured at three points, in the longitudinal direction of the generator, and in the same diametral plane equidistant at 120º, for a total of 9 measurements on each piece of the tube and 27 on the entire machine, as shown in Figure 3.

The 2D roughness profiles measured for each type of honing machining process studied are shown in Figure 4, for both the machined tube with rough honing, the machined tube with rough and semi-finished sharpening and the machined tube with semi-finished and finished honing.

The representative 3D roughness of each of the processes is shown in Figure 5, for all process types.

3. Result and Discussion

The results of the 2D and 3D roughness parameters measured are shown in Tables 4-5, where the averages and deviations for each type of process are highlighted, both in the A, B and C pieces and in zones 1, 2 and three respectively as shown in Figure 3. For each zone at the three-measuring points P-1, P-2 and P-3 equidistant 120º in the corresponding diametral measuring plane the test was applied obtaining the results shown below.

In order to study whether it is necessary to evaluate the parameters in three dimensions or whether 2D measurement is sufficient to characterize the process, a correlation analysis has been performed for some of the most common settings such as Ra-Sa, Rq-Sq, between the different equivalent parameters from the measured values of surface roughness, as can be seen in Figures 6-7.

The results shown in the figures show that the two-dimensional and three-dimensional roughness parameters maintain the same trend in the representation of surface roughness for their respective sampling lengths in the different tubes machined by the various processes described in the initial conditions, which are rough, rough with semi-finished, rough with semi-finished and finished.

Similarly, when adjusting the values to calculate the level of correlation of the measured values, high levels of correlation were presented for the Ra vs. Sa parameters, in this case, 98% of the values measured for the different machining conditions.

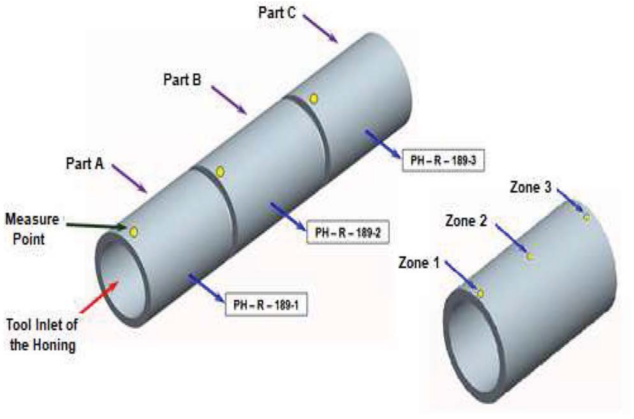


Figure 3. Measuring zones.

Table 3. Equivalence between 2D and 3D roughness parameters

	Parameters 3D	**Parameters 2D**
Amplitude Parameters	*Root mean square deviation* Sq	*Root mean square roughness*Rq
	*Skewness*Ssk	*Skewness*Rsk
	*Kurtosis*Sku	*Kurtosis*Rku
	*Maximumpeakheight*Sp	*Maximumpeakheight*Rp
	*Maximumvalleyheight*Sv	*Maximumvalleyheight*Rv
	Maximum height of texture surface Sz	*Maximum height of the profile* Rt *or* Rmax
Spacing Parameters	*Densityofsummits*Sds	*High spot count*HSC
	Fastest decay auto-correlation Length Sal	
	Textureaspect ratio Str	*Mean radius of asperities* rp
Hybrid Parameters	*Arithmetic mean peak curvature* Ssc	*Mean slope of the profile* Δa
	Root mean square slope of the Assessed texture surface Sdq	*RMS slope of the profile* Δq
	Developed interfacial area Ratio Sdr	
Fractal Parameters	*Fractal dimension*Sfd	*Fractal dimension D*
Other Parameters	*Texture direction of the texture Surface* Std	
	Ten point height of surface S5z	*Ten pointheight*Rz
Lineal Areal Material Curve Parameters	*Core roughness depth* Sk, Spk	*Core roughnessdepth*Rk
	*Material portion*Svk	
	Reduced peak height/valley depth SMr1, SMr2	*Reduce peak valley/peak height* Rvk, Rpk
VoidVolume	*Core void volume of the texture surface* Vvc	
	Valley void volume of the Texture surface Vvv	
Material Volume	*Material volume of the texture surface* Vmp	
	Core material volume of the texture surface Vmc	

Table 4. The result of the 2D measurements of parameter Ra for rough, rough + semi-finished and rough + semi-finished + finished

	Ra(µm)	**PHR-189**							**PHR-190**						
		P - 1	*P - 2*	*P - 3*	*Ave rage*	*Dev.*	**Aver age**	**Devi ation**	*P - 1*	*P - 2*	*P - 3*	*Ave rage*	*Dev.*	**Ave rage**	**Devi ation**
Rough	**A--1**	2,145	3,098	2,835	2,693	0,492			3,204	3,585	2,896	3,228	0,345		
	A--2	3,007	2,779	3,047	2,944	0,145			3,967	3,405	2,645	3,339	0,663		
	A--3	3,116	2,792	3,065	2,991	0,174	2,876	0,304	3,511	2,920	3,257	3,229	0,296	3,266	0,406
	Average	2,756	2,890	2,982					3,561	3,303	2,933				
	Deviation	0,532	0,181	0,128					0,384	0,344	0,308				
	B--1	2,972	3,098	2,964	3,011	0,075			3,002	3,123	2,640	2,922	0,251		
	B--2	3,034	2,882	3,224	3,047	0,171			2,732	2,559	3,925	3,072	0,744		
	B--3	3,251	3,295	3,548	3,365	0,160	3,141	0,209	2,976	2,999	2,780	2,918	0,120	2,971	0,404
	Average	3,086	3,092	3,245					2,903	2,894	3,115				
	Deviation	0,147	0,207	0,293					0,149	0,296	0,705				
	C--1	3,445	3,636	4,620	3,900	0,631			3,459	3,028	2,986	3,158	0,262		
	C--2	3,172	3,209	2,844	3,075	0,201			3,019	3,400	3,483	3,301	0,247		
	C--3	2,836	3,237	2,930	3,001	0,210	3,325	0,554	2,603	2,865	2,967	2,812	0,188	3,090	0,298
	Average	3,151	3,361	3,465					3,027	3,098	3,145				
	Deviation	0,305	0,239	1,001					0,428	0,274	0,293				
	Average	2,998	3,114	3,231	**3,114**				3,164	3,098	3,064	**3,109**			
	Deviation	0,365	0,274	0,566	**0,415**				0,424	0,319	0,423	**0,379**			

	Ra (µm)	**PHR-191**							**PHR-192**						
		P - 1	*P - 2*	*P - 3*	*Ave rage*	*Dev.*	**Ave rage**	**Devi ation**	*P - 1*	*P - 2*	*P - 3*	*Ave rage*	*Dev.*	**Ave rage**	**Deviation**
Rough+Semi-Finished	**A--1**	2,008	1,731	1,866	1,868	0,139			1,687	2,315	2,019	2,007	0,314		
	A--2	2,112	1,841	1,689	1,881	0,214			1,941	2,146	1,718	1,935	0,214		
	A--3	1,861	2,364	1,816	2,014	0,304	1,921	0,210	1,796	1,697	1,631	1,708	0,083	1,883	0,237
	Average	1,994	1,979	1,790					1,808	2,053	1,789				
	Deviation	0,126	0,338	0,091					0,127	0,319	0,204				
	B--1	2,303	2,044	2,292	2,213	0,146			2,102	2,309	2,403	2,271	0,154		
	B--2	2,288	1,989	2,652	2,310	0,332			2,049	1,714	1,741	1,835	0,186		
	B--3	1,887	1,963	1,720	1,857	0,124	2,126	0,282	2,330	2,056	2,155	2,180	0,139	2,095	0,243
	Average	2,159	1,999	2,221					2,160	2,026	2,100				
	Deviation	0,236	0,041	0,470					0,149	0,299	0,334				
	C--1	1,992	1,976	2,419	2,129	0,251			2,139	2,232	2,634	2,335	0,263		
	C--2	2,029	2,023	2,048	2,033	0,013			2,123	2,280	2,093	2,165	0,100		
	C--3	1,894	2,047	2,206	2,049	0,156	2,070	0,155	2,627	2,092	2,046	2,255	0,323	2,252	0,227
	Average	1,972	2,015	2,224					2,296	2,201	2,258				
	Deviation	0,070	0,036	0,186					0,286	0,098	0,327				
	Average	2,042	1,998	2,079	**2,039**				2,088	2,093	2,049	**2,077**			
	Deviation	0,164	0,172	0,336	**0,231**				0,279	0,238	0,328	**0,274**			

	Ra (µm)	PHR-193							PHR-194						
		P - 1	*P - 2*	*P - 3*	*Average*	*Dev.*	**Average**	**Deviation**	*P - 1*	*P - 2*	*P - 3*	*Average*	*Dev.*	**Average**	**Deviation**
Rough+Semi-Finished+Finished	**A--1**	0,176	0,209	0,164	0,183	0,023			0,219	0,198	0,179	0,199	0,020		
	A--2	0,207	0,197	0,213	0,206	0,008			0,179	0,189	0,198	0,189	0,010		
	A--3	0,242	0,191	0,223	0,219	0,026	0,202	0,024	0,187	0,179	0,201	0,189	0,011	0,192	0,013
	Average	0,208	0,199	0,200					0,195	0,189	0,193				
	Deviation	0,033	0,009	0,032					0,021	0,010	0,012				
	B--1	0,227	0,241	0,185	0,218	0,029			0,210	0,203	0,197	0,203	0,007		
	B--2	0,216	0,218	0,183	0,206	0,020			0,208	0,197	0,201	0,202	0,006		
	B--3	0,219	0,248	0,217	0,228	0,017	0,217	0,022	0,216	0,201	0,270	0,229	0,036	0,211	0,023
	Average	0,221	0,236	0,195					0,211	0,200	0,223				
	Deviation	0,006	0,016	0,019					0,004	0,003	0,041				
	C--1	0,237	0,206	0,216	0,220	0,016			0,221	0,189	0,233	0,214	0,023		
	C--2	0,225	0,204	0,195	0,208	0,015			0,218	0,204	0,206	0,209	0,008		
	C--3	0,183	0,190	0,209	0,194	0,013	0,207	0,017	0,205	0,207	0,230	0,214	0,014	0,213	0,014
	Average	0,215	0,200	0,207					0,215	0,200	0,223				
	Deviation	0,028	0,009	0,011					0,009	0,010	0,015				
	Average	0,215	0,212	0,201	**0,209**				0,207	0,196	0,213	**0,205**			
	Deviation	0,023	0,021	0,020	**0,021**				0,015	0,009	0,027	**0,019**			

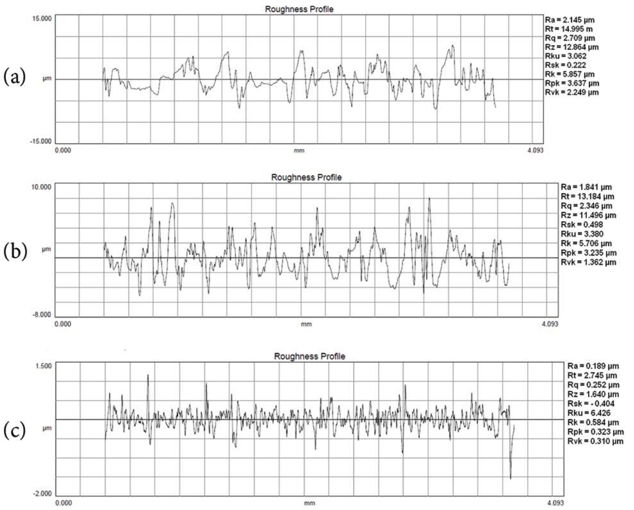


Figure 4. 2D roughness measurement data. (a) Machined tube with rough honing. (b) Machined tube with rough and semi-finished sharpening. (c) Machined tube with rough honing + semi-finished + finished.

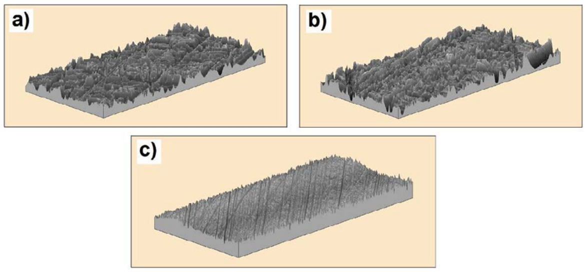


Figure 5. Type of 3D surface. **(a)** Machined tube with rough honing. **(b)** Machined tube with rough honing and semi-finished. **(c)** Machined tube with rough honing + semi-finished + finished.

4. Conclusions

Taking into account the excellent correlation between 2D and 3D roughness parameters, it is concluded that 2D parameters can be used since due to their normal behavior, they offer competitive advantages due to their ease of determination and require shorter measurement times. On the other hand, because the orientation is determined by the relationship between the linear and rotational velocity of the honing process tool, 3D roughness is not affected by the direction of the honing surface scratch.

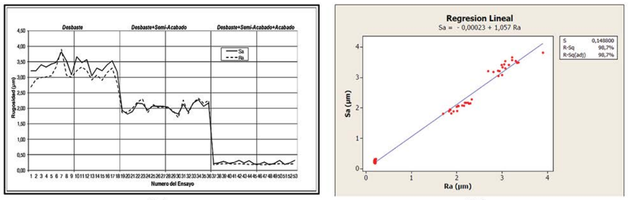
A study of the correlation of the roughness parameters in 2D and 3D was carried out, which concluded that due to the excellent association obtained, it is sufficient to work with settings in two dimensions to characterize

Table 5. The effect of the 3D measurements of parameter Sa for rough, rough + semi-finished and rough + semi-finished + finished

	Sa (µm)	*PHR-189*							*PHR-190*						
		P - 1	*P - 2*	*P - 3*	*Average*	*Dev.*	**Average**	**Deviation**	*P - 1*	*P - 2*	*P - 3*	*Average*	*Dev.*	**Average**	**Deviation**
Rough	**A--1**	3,150	3,480	3,000	3,210	0,246			3,570	3,820	3,610	3,667	0,134		
	A--2	3,350	3,130	3,170	3,217	0,117			3,660	3,620	3,180	3,487	0,266		
	A--3	3,120	3,320	3,790	3,410	0,344	3,279	0,240	4,070	3,100	3,560	3,577	0,485	3,577	0,295
	Average	3,207	3,310	3,320					3,767	3,513	3,450				
	Deviation	0,125	0,175	0,416					0,267	0,372	0,235				
	B--1	3,250	3,490	3,260	3,333	0,136			2,770	3,270	3,120	3,053	0,257		
	B--2	3,110	3,320	3,870	3,433	0,392			3,330	2,930	3,650	3,303	0,361		
	B--3	3,470	3,360	3,660	3,497	0,152	3,421	0,232	3,190	3,430	3,060	3,227	0,188	3,194	0,265
	Average	3,277	3,390	3,597					3,097	3,210	3,277				
	Deviation	0,181	0,089	0,310					0,291	0,255	0,325				
	C--1	3,630	3,380	4,440	3,817	0,554			3,520	3,610	3,100	3,410	0,272		
	C--2	3,280	4,010	3,320	3,537	0,410			3,530	3,620	3,480	3,543	0,071		
	C--3	3,010	3,090	3,160	3,087	0,075	3,480	0,471	3,100	3,130	3,320	3,183	0,119	3,379	0,220
	Average	3,307	3,493	3,640					3,383	3,453	3,300				
	Deviation	0,311	0,470	0,697					0,245	0,280	0,191				
	Average	3,263	3,398	3,519	**3,393**				3,416	3,392	3,342	**3,383**			
	Deviation	0,196	0,267	0,460	**0,332**				0,373	0,300	0,236	**0,298**			

	Sa (µm)	*PHR-191*							*PHR-192*						
		P - 1	*P - 2*	*P - 3*	*Average*	*Dev.*	**Average**	**Deviation**	*P - 1*	*P - 2*	*P - 3*	*Average*	*Dev.*	**Average**	**Deviation**
Rough+Semi-Finished	**A--1**	2,040	2,060	1,720	1,940	0,191			2,020	2,100	2,010	2,043	0,049		
	A--2	1,900	1,810	1,770	1,827	0,067			2,110	2,060	1,510	1,893	0,333		
	A--3	1,840	2,210	1,650	1,900	0,285	1,889	0,182	1,830	1,800	1,800	1,810	0,017	1,916	0,197
	Average	1,927	2,027	1,713					1,987	1,987	1,773				
	Deviation	0,103	0,202	0,060					0,143	0,163	0,251				
	B--1	2,400	1,970	2,140	2,170	0,217			2,120	2,120	2,180	2,140	0,035		
	B--2	2,260	1,950	2,260	2,157	0,179			2,030	1,900	1,750	1,893	0,140		
	B--3	2,020	1,990	1,830	1,947	0,102	2,091	0,185	2,160	2,130	2,230	2,173	0,051	2,069	0,153
	Average	2,227	1,970	2,077					2,103	2,050	2,053				
	Deviation	0,192	0,020	0,222					0,067	0,130	0,264				
	C--1	1,930	1,990	2,330	2,083	0,216			2,000	2,290	2,560	2,283	0,280		
	C--2	2,040	2,170	2,020	2,077	0,081			2,080	2,070	2,080	2,077	0,006		
	C--3	1,900	2,070	2,220	2,063	0,160	2,074	0,141	2,380	2,070	2,080	2,177	0,176	2,179	0,188
	Average	1,957	2,077	2,190					2,153	2,143	2,240				
	Deviation	0,074	0,090	0,157					0,200	0,127	0,277				
	Average	2,037	2,024	1,993	**2,018**				2,081	2,060	2,022	**2,054**			
	Deviation	0,184	0,120	0,257	**0,188**				0,147	0,140	0,306	**0,205**			

	Sa (µm)	*PHR-193*							*PHR-194*						
		P - 1	*P - 2*	*P - 3*	*Average*	*Dev.*	**Average**	**Deviation**	*P - 1*	*P - 2*	*P - 3*	*Average*	*Dev.*	**Average**	**Deviation**
Rough+Semi-Finished+Finished	**A--1**	0,198	0,237	0,225	0,220	0,020			0,213	0,196	0,185	0,198	0,014		
	A--2	0,227	0,234	0,286	0,249	0,032			0,212	0,208	0,194	0,205	0,009		
	A--3	0,275	0,244	0,323	0,281	0,040	0,250	0,038	0,246	0,307	0,238	0,264	0,038	0,222	0,038
	Average	0,233	0,238	0,278					0,224	0,237	0,206				
	Deviation	0,039	0,005	0,049					0,019	0,061	0,028				
	M--1	0,251	0,222	0,196	0,223	0,028			0,185	0,187	0,169	0,180	0,010		
	M--2	0,247	0,246	0,254	0,249	0,004			0,241	0,221	0,205	0,222	0,018		
	M--3	0,314	0,350	0,307	0,324	0,023	0,265	0,049	0,255	0,334	0,362	0,317	0,055	0,240	0,067
	Average	0,271	0,273	0,252					0,227	0,247	0,245				
	Deviation	0,038	0,068	0,056					0,037	0,077	0,103				
	B--1	0,220	0,202	0,275	0,232	0,038			0,182	0,186	0,210	0,193	0,015		
	B--2	0,223	0,273	0,209	0,235	0,034			0,219	0,234	0,259	0,237	0,020		
	B--3	0,315	0,299	0,318	0,311	0,010	0,259	0,046	0,316	0,323	0,318	0,319	0,004	0,250	0,057
	Average	0,253	0,258	0,267					0,239	0,248	0,262				
	Deviation	0,054	0,050	0,055					0,069	0,070	0,054				
	Average	0,252	0,256	0,266	**0,258**				0,230	0,244	0,238	**0,237**			
	Deviation	0,041	0,045	0,048	**0,043**				0,041	0,060	0,065	**0,054**			



(a) (b)

Figure 6. Experimental results in 2D and 3D roughness. **(a)** Ra vs. Sa trend graph. **(b)** Correlation between 2D and 3D roughness for Ra vs Sa.

the surface, since roughness in three dimensions takes a long time to be measured with a contact roughness meter like the one used in this investigation. The other important aspect of the three-dimensional study is the surface scratching, which can be controlled and analyzed with both the line speed and the rotation speed of the machining process.

Finally, the type of abrasive stone presented a significant effect on the surface finish, since in the graphic results the roughness tendency decreases to the extent that a more beautiful stone is used, so that the abrasive stone is a decisive factor to take into account later in the study of the parameters that influence the process.

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