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Cite as: AIP Conference Proceedings **2437**, 020100 (2022); https://doi.org/10.1063/5.0092511
Published Online: 17 August 2022

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Effect of Erosion Parameters on the Surface Direction Texture -Study by Experimental Plans

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Abstract. The aim of this work is to study the effect of solid particle impact erosion parameters of sand on the isotropy parameter "Std" which presents the direction of surface texture. The experimental methodology adopted for this experimental work is the Box Behnken plan with three factors, each at three levels (-1, 0 and +1), the parameters considered are: time "t", pressure "P" and angle of impact "θ". 3D roughness measurements were carried out using a laser source profilometer type Cyper-Technologie-CT100, in order to characterize the different surfaces after erosion test. The statistical analysis was carried out using the Mini Tab software, where a mathematical model was established showing the relationship between the input parameters (t, P, θ) and the output parameter "Std". This model predicts the "Std" response in the field of study as well as the parameters of the sandblasting regime. The results show the significant effect of the impact angle on "Std" and the interaction between the different parameters in the study domain, of which the highest value of "Std" is equal to 130 ° for an average time combined with low pressure and impact angle.

Keywords: Erosion, topography, roughness surface, mathematical model, Box plans.

INTRODUCTION

Ordinary steels are commonly used in the manufacture of pipelines for the transportation of petroleum products due to their mechanical properties and low cost. These pipelines can undergo several types of damage, including the erosion phenomenon. The latter can cause pipeline failure, leading to serious financial losses in the oil and gas industries [1-3]. The phenomenon of erosion is often caused by the impact of solid particles on the surface of the pipeline [4, 5], causing particle removal from the surface. The latter plays an important role; hence, a change in its topography and morphology (roughness) caused by wear, in particular the phenomenon of erosion influence of fatigue resistance. Therefore, considerable attention has been given to the characterization and quantification of surface roughness. Surface roughness is an essential parameter for many industrial engineering applications, due to its considerable influence on the functionality and service life of manufactured products [6, 7].

The direction of surface texture is characterized by the predominant direction of the oriented pattern of the surface. This direction influences the behavior of the surface with respect to environmental attacks (wear, friction, etc.), it is evaluated by the surface texture direction parameter "Std" called isotropy parameter or spatial surface parameter. This parameter indicates the pronounced direction of surface texture; in effect it represents the angle measuring the direction of the surface texture with respect to the y axis [7]. The calculation of this parameter is based on several approaches, such as spectral analysis of the Fourier transform and the autocorrelation function. They are particularly useful for distinguishing isotropic surfaces from anisotropic surfaces [8-10]. The objective of this experimental work is to study erosion parameters effect by impact of solid particles of sand on the evolution of the spatial parameter "Std". Erosion tests were carried out according to Box-Benknhen plans on X70 steel samples.

Technologies and Materials for Renewable Energy, Environment and Sustainability
AIP Conf. Proc. 2437, 020100-1–020100-8; https://doi.org/10.1063/5.0092511
Published by AIP Publishing. 978-0-7354-4372-3/$30.00

MATERIALS AND METHODS

Material

The material used in this study is low carbon X70 steel used in the petroleum industry supplied by the SIDER steel factory. The chemical analysis of the material was carried out in the chemistry laboratory of URASM research unit, the chemical composition of which is given in table 1.

TABLE 1. Chemical composition of API 5L-X70 steel in % by mass

C	Si	Mn	S	P	Cr	Nb	Ni	Ti	Fe
0.123	0.27	1.68	0.005	0.012	0.051	0.033	0.04	0.03	Ball

Experimental Methodology

In this work, the experimental erosion tests were carried out according to the Box Behnken plans [11] with three factors, each at three levels (-1, 0 and +1), in order to evaluate the influence of erosion parameters and their interactions on the envisaged response "Std". Three factors were considered: coded "t" time (X1), coded "P" pressure (X2) and coded "Ɵ" impact angle (X3). The experiments were performed according to the experiment matrix shown in Table 2. These designs allow us to formulate a quadratic model with the second-order interactions presented in equation (1).

$$Y = a0 + a1X1 + a2X2 + a3X3 + a12X1X2 + a13X1X3 + a23X2X3 + a11X1^2 + a22X2^2 + a33X3^2 + e \quad (1)$$

TABLE 2. Coded factors for erosion (sandblasting) test

Test N°	X1 (t)	X2 (P)	X3 (θ)
1	-1	-1	0
2	+1	-1	0
3	-1	+1	0
4	+1	+1	0
5	-1	0	-1
6	-1	0	+1
7	+1	0	-1
8	+1	0	+1
9	0	-1	-1
10	0	+1	-1
11	0	-1	+1
12	0	+1	+1
13	0	0	0
14	0	0	0
15	0	0	0
level -	1 min	4.5 bars	30°
level 0	3 min	5 bars	60°
level +1	5min	5.5 bars	90°

Experimental Procedure

Before carrying out the erosion tests, fifteen samples (15) of size (1cmx1cmx1cm) were prepared according to Box Behnken plans. Preparation includes cutting and mechanical surface polishing using abrasive paper (SiC) of different particle sizes. After polishing and cleaning, the samples were submitted projection with solid particles of the sand under pressure using a sandblaster.

3D Roughness Measurement

Three-dimensional surface analysis broadens the possibilities of knowing and representing the surface condition. The roughness parameter "Std" after impact of the sand particles was measured using a 3D laser source profilometer of Cyber Technology CT100 type according to DIN ISO 25178 at the ENSMM laboratory. The average values of "Std" are shown in Table 3.

TABLE 3. Values of Std

N° d'essai	Std
1	79.5
2	90
3	93.1
4	84.7
5	89.95
6	90.8
7	90
8	89.95
9	179.95
10	89.95
11	83.35
12	90
13	73.6
14	70.55
15	88.65

INTERPRETATION AND DISCUSSION OF THE RESULTS

Modeling and Statistical Analysis of Results

The digital data processing was carried out with Minitab, according to Box-Behnken plans, and made it possible to establish a mathematical model for the parameter "Std" according to the three parameters considered (t, P, θ). This mathematical model offers the possibility of predicting the response studied in the field of study. The direction of texture "Std" is expressed by equation (2).

$$Std = 2160 + 32.6\,t - 698\,P - 10.89\,\theta - 1.43\,t^2 + 59.7\,P^2 + 0.0203\,\theta^2 - 4.7\,t \times P - 0.004\,t \times \theta + 1.611\,P \times \theta \quad (2)$$

Statistical analysis indicates that the residuals appear to follow a straight line (Figure.1a) where there is no evidence of non-normality or asymmetry. The residual distribution curve (Figure.1b) shows that these residuals are distributed randomly around zero; hence the established model perfectly explains the results obtained.

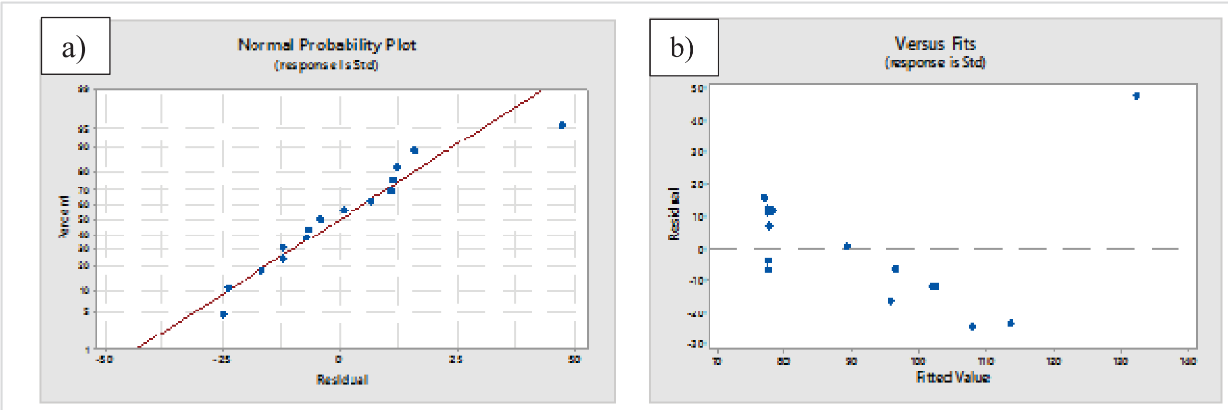

FIGURE 1. a) Normal probability plot, b) Residuals plot

3D Response Surfaces and Contours

The variation of "Std" parameter, the indicator of texture direction according to the test erosion parameters (t, P, θ) is highlighted by the 3D curves (Figure 2).
Figure 2a illustrating the variation of "Std" as a function of the impact angle (θ) and the projection pressure of sand particles (P) which shows that the minimum values of the two parameters tend to increase "Std". This confirms that the anisotropic surface texture, exhibiting different characteristics in various directions, i.e. a surface has oriented patterns. On the other hand, if two parameters (P, θ) are at their maximum levels, the texture direction "Std" decreases to reach a value of 90°. Thus indicating that the surface comprises a dominant layer at 90° and the texture direction is following the direction of the projection flow of the sand particles.

Figure 2b shows the variation of "Std" as a function of hold time (t) and pressure (P). It is observed that when the time is taken at its average level combined with a low pressure, the "Std" converges towards a maximum value equivalent to 130°. Whereas the parameter "Std" tends to decrease to a value of 90° by combining a low time with a medium pressure, which confirms that the pressure is the most relevant parameter which influences the texture direction, compared to the projection time.

Figure 2c illustrates the evolution of "Std" parameter as a function of the impact angle (θ) and the hold time (t). The "Std" texture direction reaches its maximum value of 130° (negative direction) when time is taken at its average level combined with a low impact angle. Indeed, the flow of sand particles under low incidence (θ = 30°), the surface is stressed in all directions, hence the increase in "Std".

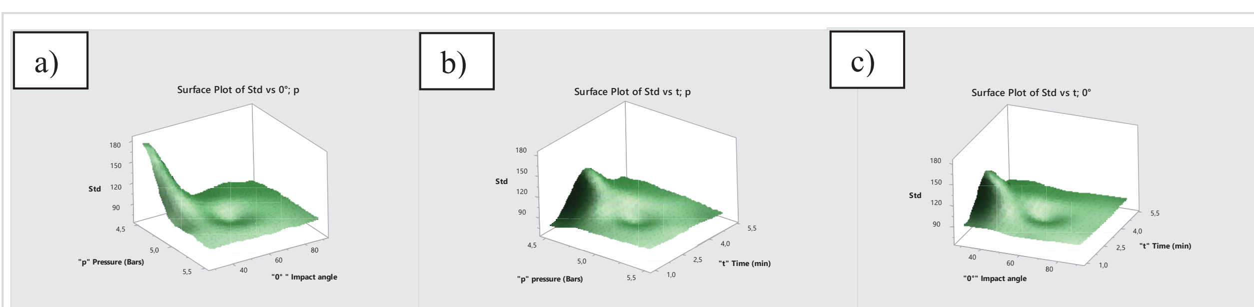

FIGURE 2. Influence of erosion parameters on "Std"

The contour graphs are shown in Figure 3, they describe the response surfaces and allow to establish the response values "Std" as well as the corresponding parameters (t, P and θ).

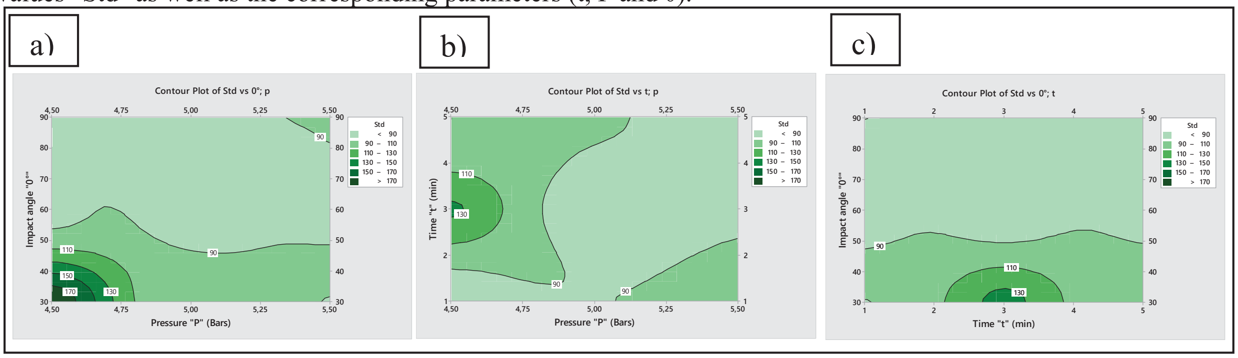

FIGURE 3. "Std" Contours in function of parameters (t, P, θ)

The average effects (figure.4a), showing the impact of each of the parameters (t, P, θ) on the "Std", show a predominance of the impact angle "θ" followed by the pressure. These graphs reveal that there seems to be a big difference in the magnitude of the effects where the angle of impact is the most significant in relation to pressure and time.

Regarding the interaction between the different parameters (t, P, θ) and their effects on the texture direction "Std" illustrated in Figure.4b, which indicates a single apparent interaction (Angle of impact / Pressure).

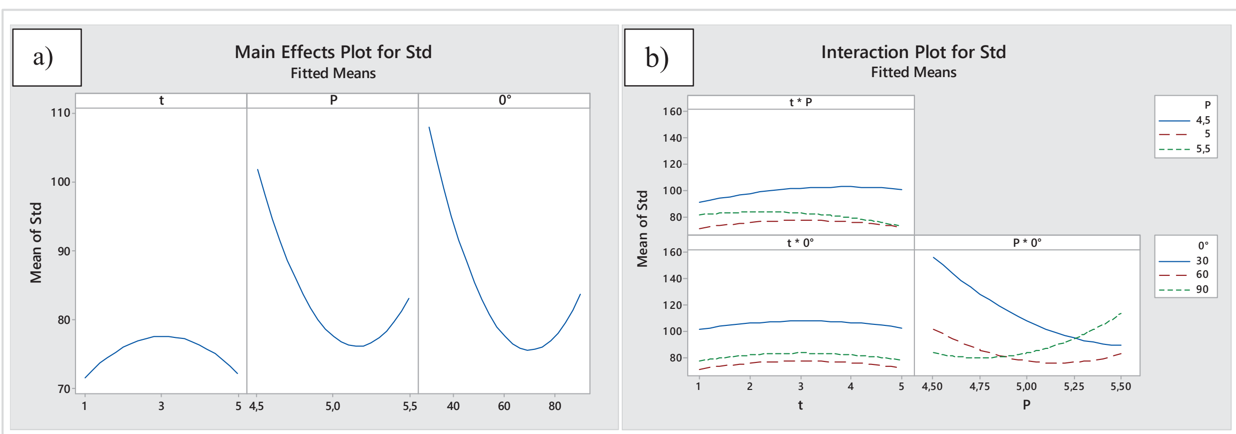

FIGURE 4. a) Main effects plot for "Std", b) Interaction plot for "Std"

Effect of Erosion Parameters on the Texture Direction "Std"

The "Std" is a parameter that provides information on the pronounced direction of the surface texture with respect to the y axis. The texture direction, "Std" would not make sense if the texture aspect ratio Str > 0.5 [9]. The erosion effect process on this parameter is illustrated in Figure 5. The measured values of "Std" are between 70.55° and 179.95°, values recorded for test 14 (t = 3min, P = 5bar, θ = 60°) and for test 9 (t = 3min, P = 4.5bar, θ = 30°) respectively. The 3D surface topography, as well as the polar graphs of these two tests is shown in Figures 6 and 7. From these results, it is confirmed that the impact angle is the most significant factor influencing the texture direction, hence an angle less than 90°, causes a strongly anisotropic texture ie directional structure increasingly stronger, where the isotropy indicator Str is less than 0.3. The low impact angle flow generates oriented patterns of the surface. These surfaces exhibit a curved texture pattern with non-uniform irregularities as shown in Figure 6.

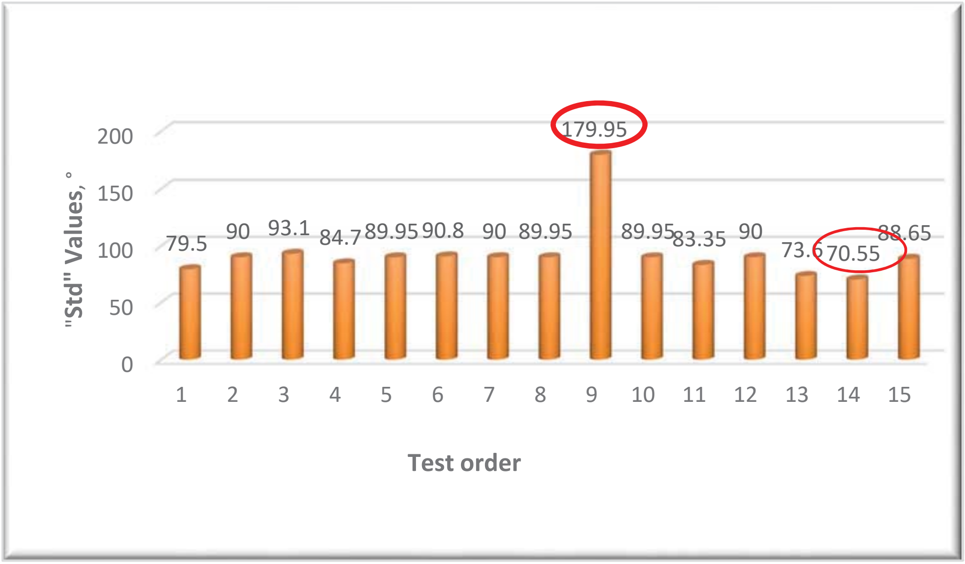

FIGURE 5. Variation of texture direction for the different tests

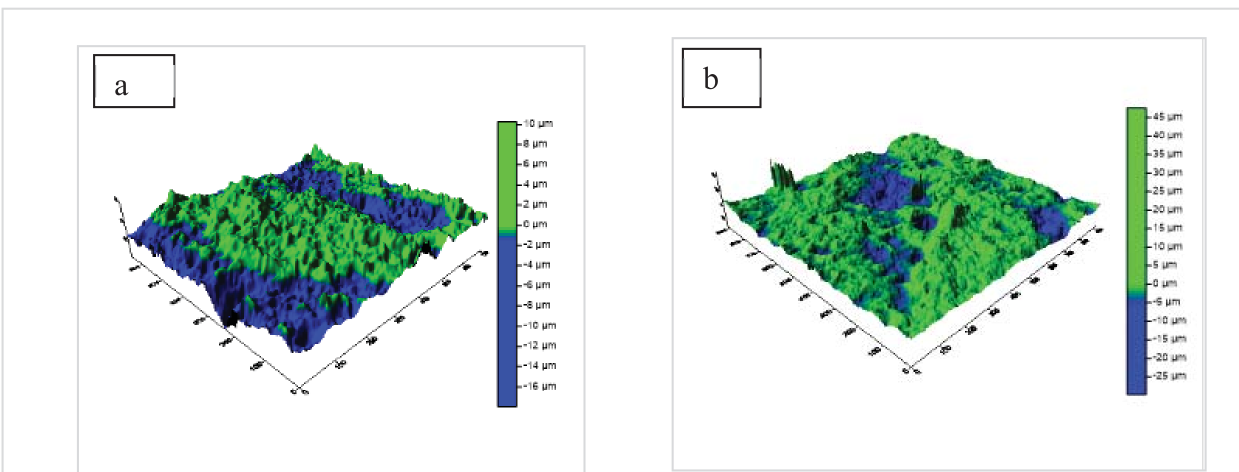

FIGURE 6. 3Dsurface topography a) for test N° 9, b) for test N° 14

The representation of the polar spectrum (Figure 7) clearly shows the preferred directions of the surface structures of the two samples. Therefore, the orientation of the surface patterns for sample 9 has a value of Std = 179.95°, while that of sample 14 has a value of Std = 70.55°. This confirms that the surface has a strong privileged orientation, hence it does not have the same characteristics in all directions. What is readable in figure 8 a and b where the central lobe are very stretched and the max radius is much greater than the min radius [12].

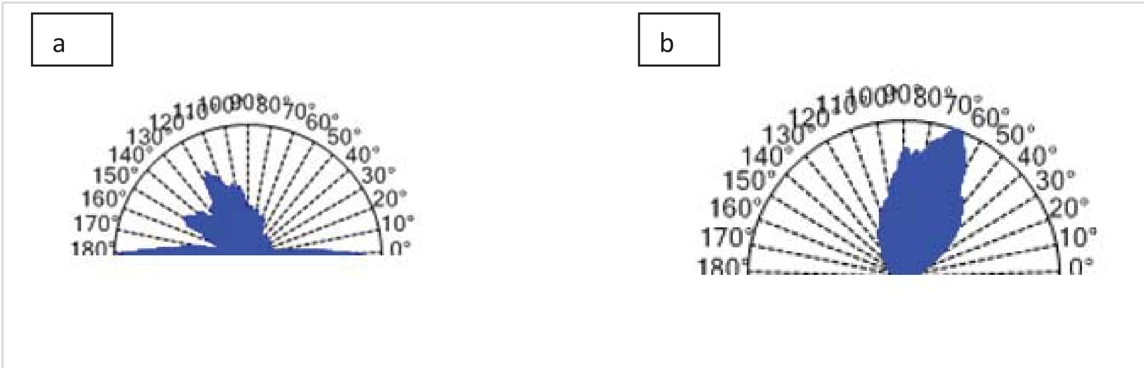

FIGURE 7. Polar graphs a) for test N° 9, b) for test N° 14

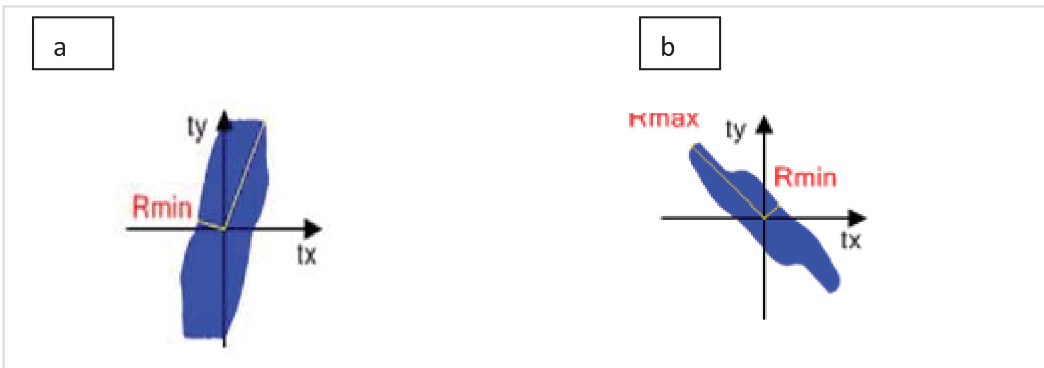

FIGURE 8. Central peak of a) for test N° 9, b) for test N° 14

CONCLUSION

The influence of erosion parameters by projection of sand particles on the topographic surface parameters, in this case the "Std" texture direction, was highlighted. The three factor Box design methodology used in this experimental work allows us to draw the following conclusions:

- The mathematical model allowed establishing a correlation between the input parameters (t, P, θ) and the spatial parameter "Std".
- The erosion parameters, and in particular the impact angle, have an influence on the direction of surface texture.
- The angle of impact (θ) is the most significant factor that influences the isotropy parameter "Std".
- Increasing "Std" induces a non-uniform texture.

ACKNOWLEDGEMENTS

The authors would like to thank engineers of the AMM/Sider workshops. We would also like to thank the engineers of the laboratory of Higher School of Mines and Metallurgy, Annaba.

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