Effect of the Oxidation on the Tribological Behaviour of Steels

Kaid-Ameur Djilali

Laboratory of Industrial Engineering and Sustainable Development
Department of Mechanic/ Centre Universitaire de Relizane, Bormadia 48000, Algeria
djilalikaidameur@yahoo.fr

Ahmed Hebbar

Université Ibn Badis de Mostaganem, 27000-Algeria
e-mail: a_hebbar@yahoo.fr

The work presented in this study focus on the application of the method of the plans of experiences (MPE) to the study and the optimization of the quantification of the wear of the steels (XC48, A60) under the effect of a factor of environment in the occurrence Hydrogen. Modeling can draw inspiration from the mathematical models established by the (MPE) in order to analyze more deeply the phenomenon of the wear while taking account of the various relevant factors [1].

The MPE, introduced is a consistent set of tools and methods algèbro-statistics to establish and analyze the relationships in the quantities studied (responses) and their sources of variations (factors) [2]. This analysis may be qualitative: study of "screening" (determination of influential factors) or quantitative: methodology of the surfaces of answers (variation of responses according to the influential factors). In all cases, it has for the purpose of determination of mathematical models approached the answers expressed in terms of the factors. These models are deducted from the values obtained of series of experiments. The definition of these plans of experiences determines the measurable quality of models. The multiple facets of the MPE are then used as the basis for the development of strategy to optimize [3].

Keywords: experimental design method, screening analysis, response surface methodology, optimisation, distributed calculations, wear, oxygen.

1. Introduction

The theory of friction always seems to lag behind the practice, although the friction is involved in many scientific disciplines. Industrial interested for many years in the development and characterization of materials to provide mechanical parts wear resistant.

One of the major issues of tribology is to control friction and wear. Indeed, the friction and wear that negatively manifest the proper functioning of assemblies and mechanical assemblies and generate the displacement resistance, friction losses, energy dissipation, temperature rise, noise, causing and adverse effects such as loss of rating, loss of function, the issue of debris, environmental pollution, clogging of interfaces, altered mechanical properties of the components, the fluctuation of friction, degradation surfaces and galling [1–4]. In the current economic context, the competitiveness depends heavily on the productivity and product quality, which leads to businesses through improvements in the quality of products in shorter time. In mechanical manufacturing, since the metal forming to final product assembly for example, this rate increase often leads to accelerated wear parts with consequences for failure due to seizure of rhe bearing or the ball which will be more severe than the rate of production is higher [5,6].

To increase the reliability of the rubbing parts and lifetime of tools, engineers often offer solutions in the optimization of the design, choice of materials and surface treatments and lubrication. The security and economic issue machines often requires prior approval by bench tests before integrating the new solution in the system, particularly in the field of transport and energy production [7, 8]. The choice of the method of tribological tests representative of the real system becomes an essential step in the success of the whole project.In this sense, we have developed our experimental work to determine the evolution of wear based on service parameters such as the contact force between the two surfaces, the rate of relative motion of two surfaces, the nature of the material part (area) under the effect of the brine (salt) having respective impacts oxidation and embrittlement, and the duration of operation or service. Where we try to express this mathematically and evolution which will be governed by the polynomial model to determine the optimal conditions that reduce us as strongly as possible wear and also know what setting should it be correct and thus pinpoint the deadlines maintenance and maintenance fallible and elements related to the parameters considered [9, 10].

2. Experimentation

In general usage, design of experiments(DOE) or experimental design is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. However, in statistics, these terms are usually used for controlled experiments. Formal planned experimentation is often used in evaluating physical objects, chemical formulations, structures, components, and materials [11].

2.1. *Materials Test Samples*

2.1.1. *Pawn Wiper*

The extent of Vickers hardness is done with a tip pyramid of normalized in diamond square base and angle to the summit between sides equal to $136°$. The fingerprint was therefore the form of a square; we measure the two diagonals d_1 and d_2 of this square to the aid of an optical device. This is the value by performing the average of d_1 and d_2. The d parameter that will be used for the calculation of the hardness; the strength and the duration of support are also standardized.

Superior Steel Fast, type **HS2-9-2**:
C% $= 0.95 - 1.05$; Si%$=0.70$; Mn%$=0.4$; P%$= 0.03$; S%$=0.03$; Cr%$= 3.50 - 4.50$; Mo%$= 8.20 - 9.20$; V%$= 1.70 - 2.20$; W%$= 1.50 - 2.10$. Hardness after quenching 68HRC $= 1150$–1200 daN/mm^2

The steels used are ($\mathbf{X}_1$): **A60** (new standard $E = 335$, $R_e = 335$ MPa, $R_m = 600$ MPa, hardness Vickers $H_v = 118$) and **XC48** (new standard C45, $R_e = 375 - 580$ MPa, $R_m = 710$ MPa. A% $= 15$, $H_v = 224$) [NF EN 10027-1].

The steels used are: **A**60 **($\mathbf{X}_1$)**, $H_v = 118$ and **X**C48, $H_v = 224$.
The sliding speed (X_2) is selected on the machine 02 levels 0.08 and 0.04 m/s. The immersion time in seawater (accelerated oxidation) (X_3) is 02 levels (01 and 02 months). Samples tested in two threads (1 and 2 months) plastic made and hung suspended from the "rock block"isolated. Load (X_4) is 03 levels 5, 12.5 and 20 Newtons.

2.1.2. *Time to Test*

It is chosen equal to a time after a test "pilot" taking into account of the condition or the wear is theoretically the most low and after that the reading experimental of the loss of mass is significant.

The condition of the test is established at:

- X_1 (hardness) $= -1\ldots$ equivalent to 118 Hv.

- X_2 (speed) $= +1 \ldots$ equivalent to 0.4 m/s.

- X_3 (load) $= +1 \ldots$ equivalent to 20 Newton

- X_4 (load time) $= -1\ldots$ equivalent to 2 hours.

The speed of sliding X_2 is selected on the machine with 02 levels (0.08 and 04) m/s. The load X_3 is in Newton is 02 levels 5 and 20 Newton. The time of loading in hydrogen X_4 is to 03 levels (2, 4 and 6 hours) which is done by electrolysis of a solution of H_2SO_4 to 10% of concentration.

2.2. *Determination of the Mathematical Model Describing the Wear Samples "Immersed" in Seawater*

2.2.1. *Determination of the Mathematical Model (Based on Algorithm Box and Wilson [12]*

Economic order quantity (EOQ) is the order quantity that minimizes the total inventory holding costs and ordering costs. It is one of the oldest classical production scheduling models. The framework used to determine this order quantity is also known as Wilson EOQ Model or Wilson Formula. The model was developed by Ford W. Harris in 1913, but R. H. Wilson, a consultant who applied it extensively, is given credit for his in-depth analysis [13].

$$\bar{Y} = \sum \bar{Y}i$$

Sum of the arithmetic mean mass loss by line read.

Variance of survey is:

$$S_i^2 = \frac{1}{2} \sum (Y_i - \bar{Y})^2$$

and equal to sum of the variances of survey.

Residual variance

$$\hat{Y}_i = \sum (B_i X_{ui} + B_{ij} X_{u,ij} + B_{ii} X_{ui}^*).$$

Arithmetic mean value of repeated observations $= (21, 7/3) = 7.23$.

Calculation of the regression coefficients:

$$\beta_{tt} = \frac{\sum_1^N X_i^* \bar{Y}}{\sum_1^N X_i^{*2}}$$

So, $b_{44} = (-6.35426662/5.33) = -1.191$

$$X_4^* = X_4^2 - \frac{2}{3}$$

$$\beta_0 = \bar{Y} - \frac{2}{3} \sum \beta_{ii} = 21.7 - 0.666 * (-1, 19) = 22.49$$

$$B_i = \frac{1}{N} \sum_{u=1}^N X_{iu} \bar{Y}_u$$

$$b_1 = (-13.89303333/24) = -0.5795; \quad b_2 = (-0.175833/24) = -0.0073;$$

$$b_3 = (0.651966/24) = 0.02712; \quad b_4 = (1.876666/16) = 0.1042;$$

$$b_{12} = (-3.276166/24) = -0.1362; \quad b_{13} = (-2.577966/24) = -0.1064;$$

$$b_{14} = (-0.823666/16) = -0.0457; \quad b_{23} = (0.876433/24) = 0.0364;$$

$$b_{24} = (0.284733/16) = 0.0158; \quad b_{34} = (0.56633/16) = 0.0314;$$

$$b_{123} = (0.609966/24) = -0.0253; \quad b_{124} = (-0.94653/16) = -0.0525;$$

$$b_{134} = (-0.043333/16) = -0.0240; \quad b_{234} = (0.482266/16) = 0.0267;$$

$$b_{1234} = (-0.643266/16) = -0.03573; \quad b_{44} = (-1.708/5.33) = -1.191.$$

The overall mathematical model describing wear Y based on the influential parameters and their interactions:

$$\begin{aligned}
Y(X_i) = {} & 23.28 - 0.579X_1 - 0.0073X_2 + 0.027X_3 + 0.104X_4 - 0.136X_1X_2 \\
& - 0.106X_1X_3 - 0.045X_1X_4 + 0.036X_2X_3 + 0,0158X_2X_4 \\
& + 0.031X_3X_4 + 0.025X_1X_2X_3 - 0.052X_1X_2X_4 - 0.024X_1X_3X_4 \qquad (1) \\
& + 0.026X_2X_3X_4 - 0.035X_1X_2X_3X_4 - 1.19X_4^2
\end{aligned}$$

Reproducibility variance is:

$$S_{rep}^2 = \frac{1}{N} \sum_{i=1}^{N} S_i^2$$

$$S_{rep}^2 = \frac{532.93 \, 10^{-3}}{24} = 22.2 \, 10^{-3}$$

Finally, values of the distributions of the regression coefficients are:

$$S^2(b_i) = \frac{S_{rep}^2}{N \cdot m}, \quad S^2(b_i) = [(0.0222)/24 * 3] = 30.84 \cdot 10^{-5}$$

2.2.2. *Student Test*

A *t*-test is any statistical hypothesis test in which the test statistic follows a Student's *t*-distribution if the null hypothesis is supported. It can be used to determine if two sets of data are significantly different from each other, and is most commonly applied when the test statistic would follow a normal distribution if the value of a scaling term in the test statistic were known. When the scaling term is unknown and is replaced by an estimate based on the data, the test statistic (under certain conditions) follows a Student's *t*-distribution [14].

$$-t(\alpha, fy) = [\alpha = 0.05, N(m-1)] = t(\alpha, fy) = [\alpha = 0.05, 48] = 2.0086 .$$

Acceptable coefficient must be greater than or equal to $\mid b_i \mid$:

$$t_\alpha, f_y S^2(b_i) = \mid b_i \mid = 2.0086 * 30.84 \cdot 10^{-5} = 61.94 \cdot 10^{-5} = 0.62 \cdot 10^{-3}$$

Considering only the significant regression coefficients. the model has the form:

$$\begin{aligned}
Y(X_i) = 23.28 &- 0.579X_1 - 0.0073X_2 + 0.027X_3 + 0.104X_4 \\
&- 0.136X_1X_2 - 0.106X_1X_3 - 0.045X_1X_4 \\
&+ 0.036X_2X_3 + 0.0158X_2X_4 + 0.031X_3X_4 \\
&+ 0.025X_1X_2X_3 - 0.052X1X_2X_4 - 0.024X_1X_3X_4 \\
&+ 0.026X_2X_3X_4 - 0.035X_1X_2X_3X_4 - 1.19X_4^2
\end{aligned} \tag{2}$$

2.2.3. *Cochran's Test*

In statistics, Cochran's C test [15], named after William G. Cochran, is a one-sided upper limit variance outlier test. The C test is used to decide if a single estimate of a variance (or a standard deviation) is significantly larger than a group of variances (or standard deviations) with which the single estimate is supposed to be comparable. The C test is discussed in many text books [16] and has been recommended by IUPAC [17] and ISO. Cochran's C test should not be confused with Cochran's Q test, which applies to the analysis of two-way randomized block designs [18].

The C test assumes a balanced design, i.e., the considered full data set should consist of individual data series that all have equal size. The C test further assumes

that each individual data series is normally distributed. Although primarily an outlier test, the C test is also in use as a simple alternative for regular homoscedasticity tests such as Bartlett's test, Levene's test and the Brown–Forsythe test to check a statistical dataset for homogeneity of variances. An even simpler way to check homoscedasticity is provided by Hartley's F_{max} test, [19], but it has the disadvantage that it only accounts for the minimum and the maximum of the variance range, while the C test accounts for all variances within the range.

$$G_{max} = \frac{S^2(\max)}{\sum_{i=1}^{N} S_i^2}$$

$G_{max} = (0.008050601/0.053293) = 0.0874$. Note that there are homogeneous dispersions as $G_{max.exp}$ is less than $G_{th} = 0.1907$ according to the test of Cochrane (15,24) interpolated between G_{th} coordinates [(10,24) or $G_{th} = 0.1113$ and (16,24) or $G_{th} = 0.0942$].

2.2.4. *Fischer Test*

$$F_{exp} = \frac{S_{res}^2}{S_{rep}^2}$$

$$S_{res}^2 = \frac{\sum_{i=1}^{N}(\hat{Y}_{iu} - \bar{Y}_i)^2}{N - L}$$

$$S_{res}^2 = [(84,6099/(24 - 15)] = [84,61/9] = 9.401$$

and above it follows that the factor "Fischer" experimental (F_{exp}) from the relation:

$$F_{exp} = (9.401/22.2) = 0.423$$

F_{th} (Fischer theoretical factor is "pulled" from the Fischer table). F_{th} is the point whose coordinates are $f_1 = N - L$ and $f_2 = N(m - 1)$. $f_1 = 8$ and $f_2 = 48$ and by Fischer table $f_2 = 48$ is between the interest values of f_2 (40–60) which gives with $f_1 = 8$ the 02 values $F_{th} = (2.10; 2.18)$. This gives us the right to say that $F_{exp} < F_{th}$ where the mathematical model describes the phenomenona widely adequately.

3. Graphs and Discussions

3.1. *Event 1*

Maintaining X_1 and X_2 attached at their actual values averages ($X_1 = 0, X_2 = 0$) model can be reduced as follows:

$$Y(X_3, X_4) = 23.28 + 0.027X_3 + 0.104X_4 + 0.031X_3X_4 - 1.19X_4^2, \qquad (3)$$

and it will graph the Fig. 1 where it is noted that when the immersion time increases from 1 month to 1.2 months of wear increases linearly and rapidly to any change in the load of 5 Newtons to 20 Newtons and continuous wear this linear but slowly when the immersion time from 1.2 months to 1.475 months growth.
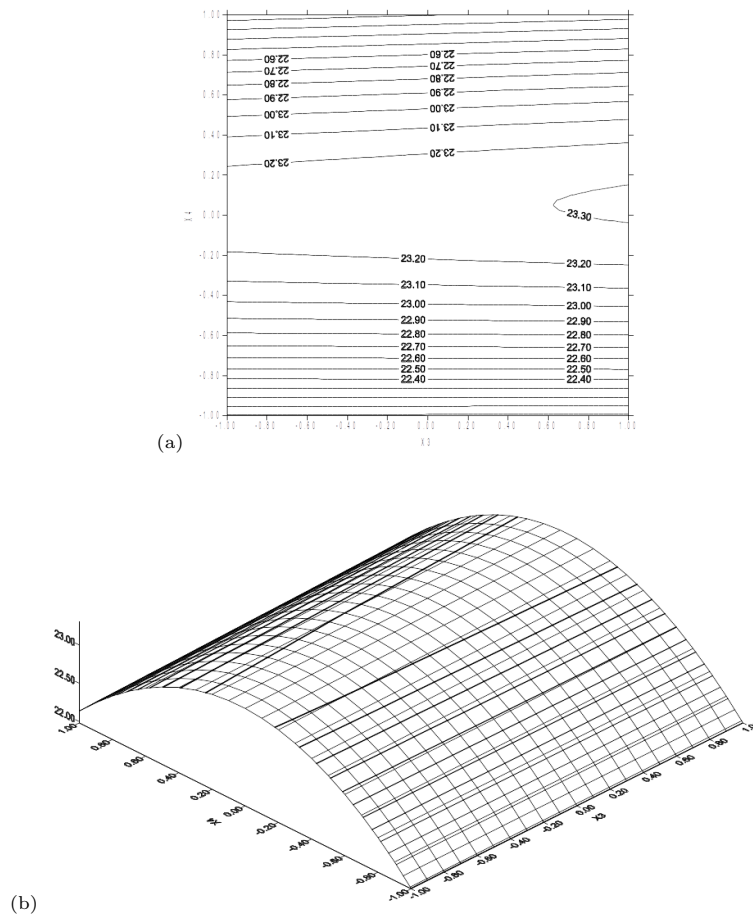
(a)

(b)

Figure 1 Effect of load (a) and immersion time (b) on the wear

Wear decreases linearly and rapidly moving the immersion time value of 1.575 months to 1.9 months. Whereas above 1.9 months to 2 months, always wear decreases in the same way as before, but slowly with the load variation of 18.125 Newton to 20 Newton and an increase in the duration of 1.475 to 575 months, wear tends to rise to extreme values. In this case the model does not have an optimum.

3.2. *Event 2*

Maintaining X_1 and X_3 set to their mean actual values ($X_1 = 0$, $X_3 = 0$) the model becomes:

$$Y(X_2, X_4) = 23.28 - 0.0073X_2 + 0.104X_4 + 0158X_2X_4 - 1.19X_4^2 \qquad (4)$$

and unfolding graphically in the following Fig. 2 which shows that the wear increases linearly and rapidly when the immersion time is increased from 1 month to 1.325 months for speeds ranging from 0.08 up to 0.4 m/s and when the time increases

to 1.375 months to 1.65 months wear continues to grow linearly and then regresses rapidly varying the immersion time of 1.65 to 1 month.
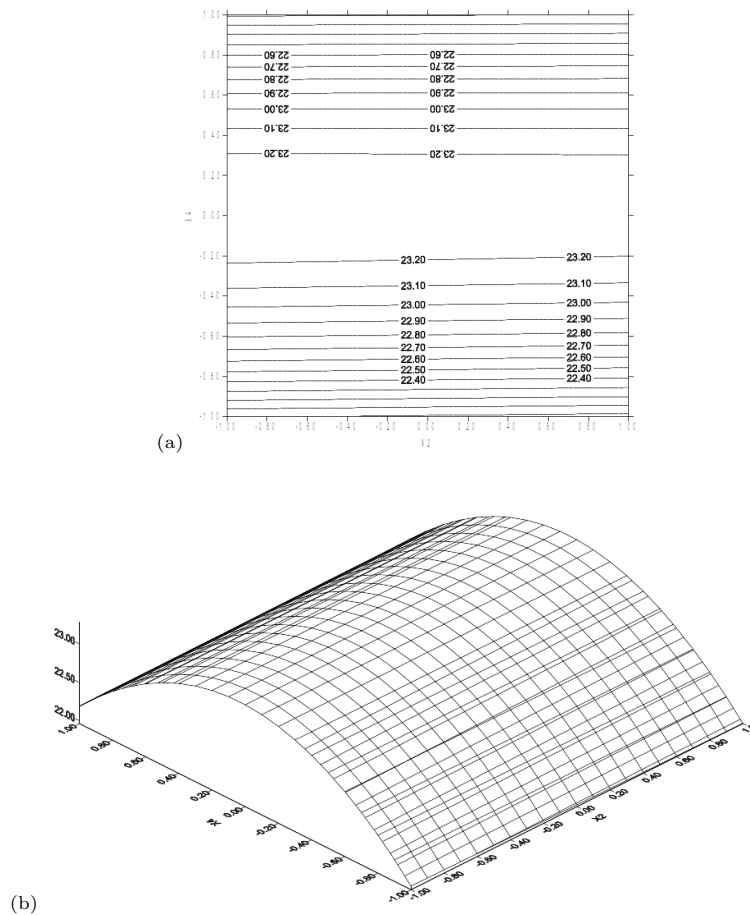

(a)

(b)

Figure 2 Effect of speed (a) and immersion time (b) on the wear

We also note that the wear maintains its high values longer for low values of speed as she maintains shorter time when the speed increases to 0.4 m/s.

3.3. *Event 3*

For values (X_1, X_4) at their mean $(X_1 = 0, X_4 = 0)$ the model becomes:

$$Y(X_2, X_3) = 23.28 - 0.0073X_2 + 0.027X_3 + 0.036X_2X_3 \tag{5}$$

and graphically describes the phenomenon of wear to the Fig. 3.

When the speed decreases to 0.104 to 0.08 m/s, wear decreases nonlinearly and rapidly for load values ranging from 10.25 to 5 Newtons. The same pattern is repeated wear when the load drops from its maximum value 14.75 Newtons to 20 Newtons with the variation of the speed of 0.4 to 0.144 m/s.
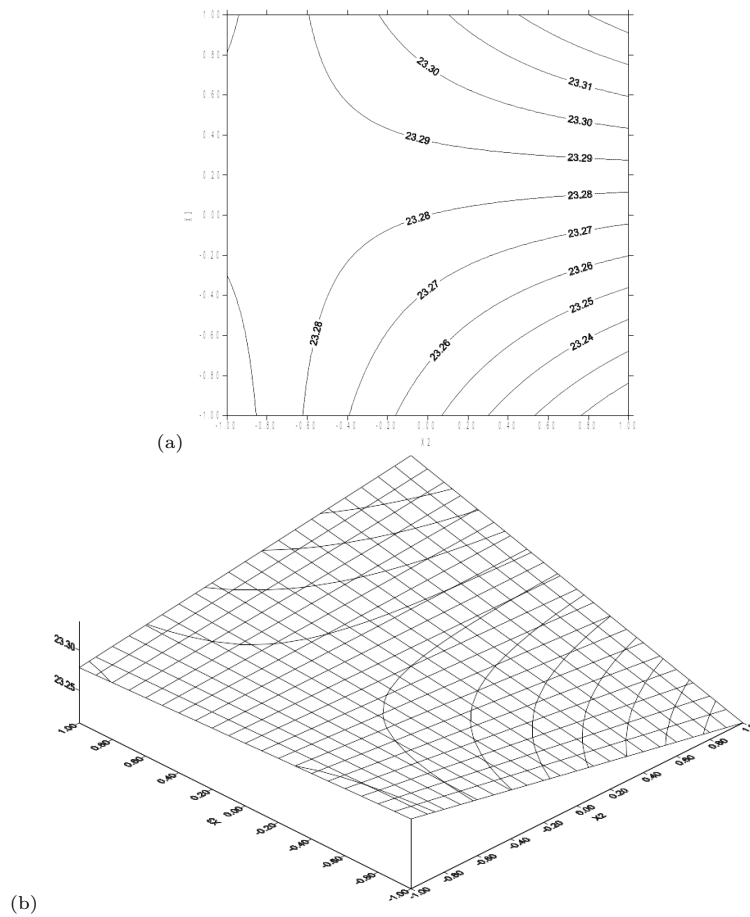
(a)

(b)

Figure 3 Effect of speed (a) and load (b) on the wear

However, wear believe nonlinearly and rapidly when the load increases from 5 to 14.75 Newtons and as the speed varies from 0.1392 to 0.4 m/s the curve has an optimum which is a minimax at coordinates (0.2027, -0.75) corresponding to actual coordinates (0.12 m/s, 14.02025 N) where wear equals to $Y = 23.7182$ g. The coordinates of the optimum are calculated by the method of Cramer.

3.4.   *Event 4*

Now in this time values X_2 and X_3 at the average value ($X_2 = 0, X_3 = 0$), the model becomes:

$$Y(X_1, X_4) = 23.28 - 0.579X_1 + 0.104X_4 - 0.045X_1X_4 - 1.19X_4^2 \qquad (6)$$

and in the graph as Fig. 4, where the wear increases linearly and slowly when the immersion time increases from 1 month to 1 2 months for a hardness ranging from 224 to 131.5 Hv, then she believes nonlinearly and slowly when the immersion of 1.25 to 1.425 months duration increases, but it decreases nonlinearly and slowly

decrease the immersion from 2 months to 1.65 months duration. The model has no optimum in this case.
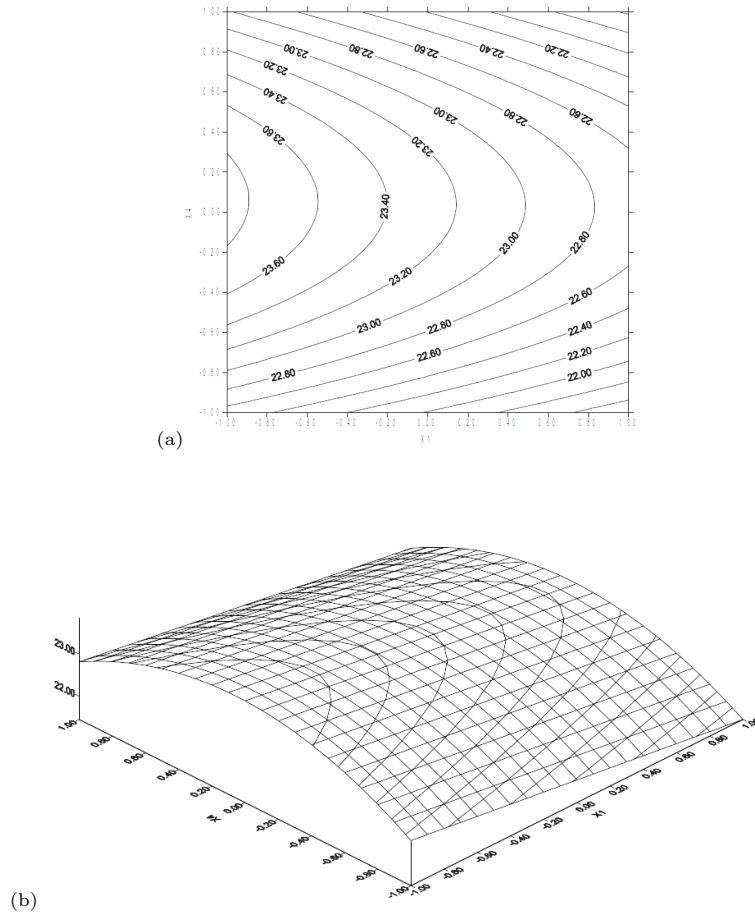

(a)

(b)

Figure 4 Effect of hardness (a) and immersion time (b) on the wear

3.5. *Event 5*

In this case X_2 and X_4 is maintained at the average value ($X_2 = 0, X_4 = 0$) the model becomes:

$$Y(X_1, X_3) = 23.28 - 0.579X_1 + 0.027X_3 - 0.106X_1X_3 \tag{7}$$

The graph in Fig. 5 shows that after increasing the load of 5 to 20 Newtons Newtons, wear increases linearly and rapidly varying hardness of 118 Hv to 224 Hv, while the wear decreases linearly and rapidly with decreasing load. Based on this graph model does not have an optimum.
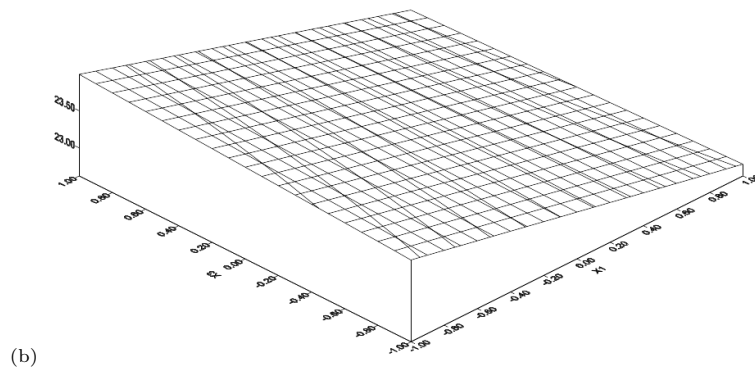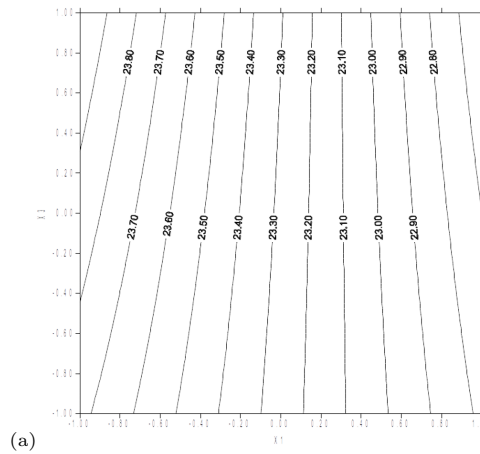
(a)

(b)

Figure 5 Effect of hardness (a) and load (b) on the wear

3.6.   *Event 6*

In this event it maintains X_3 and X_4 at the average value $(X_3 = 0, X_4 = 0)$ the model becomes:

$$Y(X_1, X_2) = 23.28 - 0.579X_1 - 0.0073X_2 - 0.136X_1X_2 \qquad (8)$$

The graph in Fig. 6 by increasing the rate of 0.08 to 0.4 m/s, the wear increases linearly and rapidly to a hardness ranging from 118 to 224 Hv, while the wear and linearly decreases rapidly with decreasing speed. The graph of this model has no optimum.
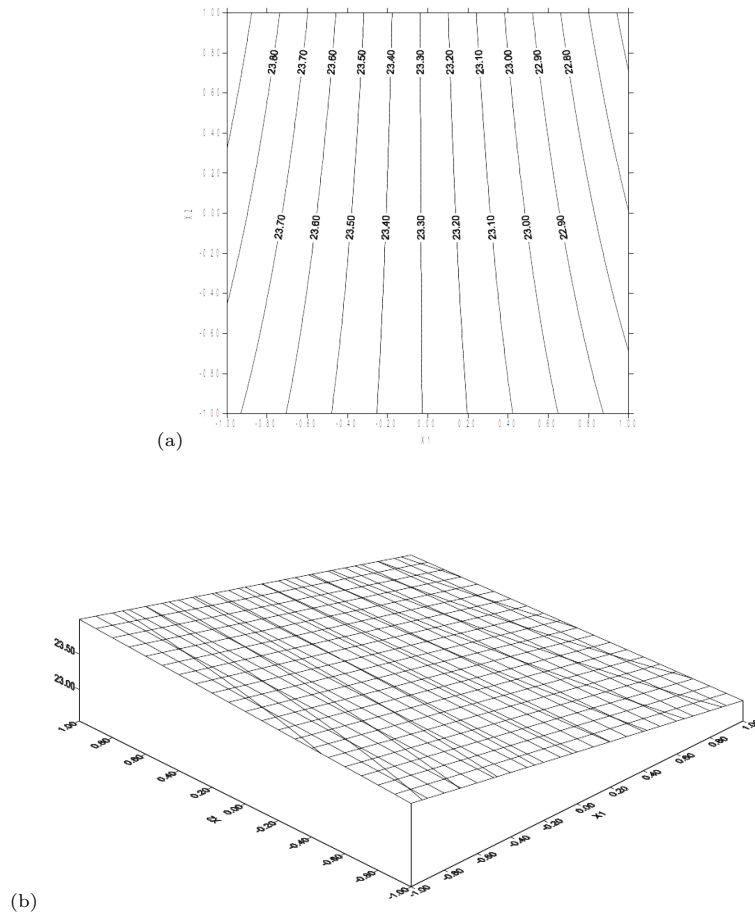
(a)

(b)

Figure 6 Effect of hardness (a) and speed (b) on the wear

4.   Conclusions

By focusing on the effect that can cause the (marine) environment setting on the wear of steels in question and at the end of the bibliographic search various related work wear construction materials mechanical and following various tests ($72 = 24 \times 3$ readings) made, it was observed that the wear is and will remain the phenomenon difficult to quantify and control but very possible to mitigate by making some regulations the optimal parameters influencing this phenomenon (hardness of the parts in contact, speed of service on between the parts in contact, loads applied to the contact surfaces and, the time of immersion in sea water, contact surfaces).The experimental study allowed us to establish the relationship of these parameters with the wear is expressed by a mathematical model resulting from the statistical approach to planning experiments.

This model is represented graphically by setting each case two of the four parameters considered in their average value to enable us to visualize the effect that can be applied the other two parameters not set, this operation has given us six

graphs of the six cases likely called "response surface" allowing us to observe the following:

- The speed and impact load alternately wear when the immersion time is kept to its average value as mentioned in the third graph model (Fig. 3) and it has an optimal weight loss.

- The effect of speed and load on the wear is the same when acting simultaneously with each immersion time where wear varies parabolically with negative concavity on the plans (X_4, Y) and (X_4, Y) of the respective graphs (Figs. 1 and 2) which means that wear is influenced more by the immersion time as the load and speed.

- The immersion time is "fatally" on softer steels as steels with the hardness and high resistance to weight loss even when the immersion time is significant as seen in the fourth event (Fig. 4).

- When the immersion time is held at its average load speed and act negatively on the wear resistance of softer while the so-called "hard" steel steels exhibit good wear resistance (Figs. 5 and 6).

- It is worth noting that the evolution of the steel immersed in the marine environment is governed not only by chemical interactions of sea water, but also by biological factors associated with the presence of a bio-film causing consequences the metabolic activity of microorganisms that inhabit because they attract more oxygen at particularly sensitive to corrosive wear surfaces.

If we intersect the two experiments, we notice that the behaviour of steel to wear is closely related to the metallurgical structure of the steel (proportion of carbon in) before it is influenced by the experimental parameters and conditions of their use.

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