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RESEARCH

Experimental Investigation on Roughness Parameters of 42CrMo4 Steel Surface During Nitrocarburizing Treatment

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A B S T R A C T

To evaluate the performance characteristics of various surfaces, a detailed and precise description of the surface's micro-geometry properties is required. In this context, roughness is a reliable indicator of the possible behavior of mechanical piece performance, since distortions on the surface can form a direct cause for cracks or corrosion. As a result, characterization of surface roughness is very important for zero-defect fabrication. This paper investigates the 2D roughness parameters of a 42CrMo4 steel surface before and after nitrocarburizing treatment. The latter was accomplished at 580 °C for 10 hours in a salt bath containing sodium cyanates and potassium carbonates. A surface profilometer was used to analyze the influence of nitrocarburizing treatment on the material's surface roughness parameters behavior. The parameters that comprehensively describes the surface structure, namely the amplitude, spacing, hybrid parameters, and material ratio parameters were highlighted. The results of the experiments indicated that the nitrocarburizing treatment was effective in increasing almost all the 2D roughness parameters of the 42CrMo4 steel surface.

1. INTRODUCTION

Surface roughness is among the fundamental properties of the surface of industrial components when they are used. Surface roughness in the manufacturing industry must be compatible with both job requirements and quality standards [1]. Surface roughness evaluation is required for describing functional behavior and monitoring product quality [2]. Furthermore, it is a crucial characteristic in many fundamental industrial concerns, such as friction [3], adhesion [4], electrochemical potential [5-6], aesthetic appearance [7], as well as positional accuracy [8]. As an outcome, many experimental and theoretical studies have been conducted on surface roughness.

Recently, the growing demands for practical surfaces obtained by machining (corrosion resistance, wear resistance, greater hardness, and, fatigue limit) leads to a dependence significantly on the use of thermochemical treatments on exposed parts, particularly nitriding treatment [9]. Surface roughness-specific properties, such as surface hardness, modified surface chemistry, and increased surface roughness, are essential considerations in evaluating surface changes in nitriding components. Hence, inspecting the surface roughness of the workpiece surface is critical for determining the quality of a part.

Badisch et al [10]. Investigated the behavior of surface roughness and layer development in nitrocarburized 31CrMoV9 steel. It was reported that the formation of ε-Fe2–3N on the surface increases surface roughness. The white layer is formed at the exterior surface of industrial parts and components made of ferrous alloys, such as steels or cast irons, during nitriding processes, which causes an increase in surface roughness [11]. Dobrocký et al [12]. examined the behavior of surface texture functional parameters of 34CrNiMo6 and 14NiCr14 steels during plasma nitriding treatment. Very slight changes in surface roughness were reported for 34CrNiMo6 steel. As for 14NiCr14 steel, plasma nitriding led to considerable changes in all parameters evaluated. The impact of nitriding on the dimensional accuracy of 42CrMo4 steel components has been studied. It was revealed that during the nitriding treatment, the parameters of the functional surfaces could be altered based on their use in operation. The surface roughness of the nitrided samples was reduced when compared to the ground surfaces, according to surface texture analysis using specified 2D and 3D parameters [13]. Dobrocký et al [14] in other study. investigated the effects of plasma nitriding on the surface texture parameters of the CoCrMo alloy. It was subsequently found that formation of the nitrided layers on the surface affects the surface morphology parameters Ra and Rt. The salt bath nitriding process improved the surface characteristics of AISI 4140 steel. It was found that enhancing the nitriding time significantly raises the Ra, Rq, and Rz [15]. During plasma nitriding, various parameters of the surface roughness of 30CrMoV9 steel was evaluated. It was reported that, during plasma nitriding, practically all parameters of surface roughness had been changed [16].

According to the previous studies, It has been observed that very few research papers on the relationship between nitrocarburizing treatment and surface roughness of steels have been reported. Or rather, the research papers on the effect of nitrocarburizing treatment processes on the surface topography of functional parts, as an independent, detailed and comprehensive topic for the most important parameters of surface roughness. Therefore, the main objective of this work was to compare the behavior of the roughness parameters of a 42CrMo4 steel surface before and after the nitrocarburizing process.

2. EXPERIMENTAL PROCEDURE

2.1 Material

The steel 42CrMo4 has been chosen for investigation. It is frequently utilized in the machinery industry. Among its major uses are aerospace and automotive construction, as well as the manufacture of higher strength components and gear wheels such as crankshafts, axle shafts, housing, etc. [17].

The chemical composition of the workpiece material element weight percentages: C 0.47%; Si 0.25%; Cr 0.93%; Ni 0.13%; P 0.015%; S 0.037%; Mn 0.79%; Mo 0.2%; Fe balance. A SOLARIS CCD Plus spectrometer has been used to determine the chemical composition of 42CrMo4 steel. Specimens had been prepared in the form of a cylinder with a diameter of 16 mm.

2.2 Nitriding processes

42CrMo4 steel samples were subjected to a multi-stage heat treatment that included heating to 850 °C for 30 minutes, rapid cooling with oil, tempering for 120 minutes, and lastly gradual cooling with air.

To prepare the samples for nitrocarburizing treatment, the specimens were preheated in the oven until 350 °C. After that, the nitrocarburizing operations were performed in a salt bath containing sodium cyanates and potassium carbonates. The specimens had been submerged in a salt bath at 580 °C for 10 hours. Finally, the specimens were placed in a cooling bath to cool.

2.3 Measurement of surface roughness parameters

According to the ISO 4287:1997 and ISO 135653-2:1996 standards [18,19], surface roughness was described by evaluating the two-dimensional parameters of the surface roughness, which are amplitude parameters, spacing parameters, hybrid parameters, and material ratio parameters. The evaluation length for surface roughness of the samples of 42CrMo4 steel was set to 20 mm during the measurements, after which the average of five values was selected for each sample. Fig. 1 shows the STIL surface profilometer associated with MountainsMap® software used to measure the parameters of the surface texture of untreated samples and samples treated with nitrocarburizing.

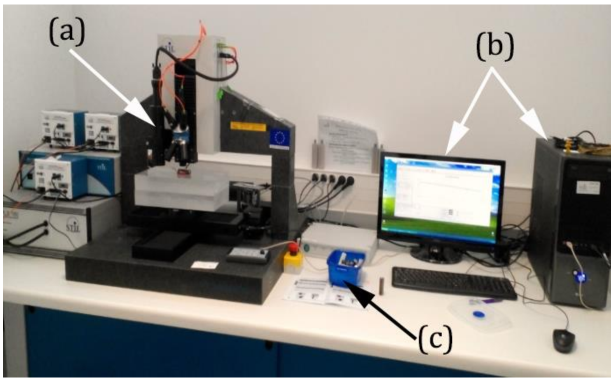

Fig. 1. (a) Surface profilometer, (b) Computer, (c) 42CrMo4 steel specimen.

3. RESULTS AND DISCUSSION

Table 1 show the values of surface roughness parameters of the samples of 42CrMo4 steel before and after nitrocarburizing treatment. The surface roughness parameters in this study were classified as follows:

Amplitude average parameters

- Ra arithmetic average roughness
- Rq root mean square average
- Rp maximum profile peak height
- Rv maximum profile valley depth
- Rz maximum height
- Rt total height
- Rsk Skewness of the roughness profile
- Rku Kurtosis of the roughness profile

Spacing parameters

- RSm mean width

Hybrid parameters

- Rdq root mean square of the mean slope of the profile

Material ratio parameters

- Rpk reduced peak height
- Rvk reduced dale height
- Mr1 upper material portion
- Mr2 lower material portion

It can be seen that most of the surface texture parameters values have increased after the nitrocarburizing process.

Table 1. Values of the parameters of surface roughness of untreated and nitrided samples.

Parameters	Unit	Untreated sample	Nitrided sample
Ra	µm	0.3378	1.023
Rq		0.4770	1.350
Rt		3.878	7.492
Rz		2.271	5.877
Rp		0.9659	2.718
Rv		1.305	3.159
Rsk	-	-0.5743	-0.2039
Rku	-	3.597	2.888
RSm	µm	13.91	24.14
Rdq	°	14.17	17.19
Rpk	µm	1.308	1.811
Rvk		2.047	2.495
Mr1	%	10.89	12.86
Mr2		86.98	85.44

Fig. 2 shows two-dimensional images of the surface topography of the steel specimens under investigation. The surface topography of the studied steel before nitrocarburizing treatment has been seen in Fig. 2a, whereas the surface topography of the studied steel with nitriding process at 580 °C for 10 hours can be seen in Fig. 2b. Fig. 2a depicted relative stability throughout the surface, with changes in surface topography ranging between 5 and 10 µm. The figure also included some protrusions that did not have a significant impact on the general condition of the surface. Fig 2b shows that the surface topography has many micro-level protrusions (peak to valley), which means that 42CrMo4 steel surface treated by using nitrocarburizing process has a different number of surface layers up to 50 µm.

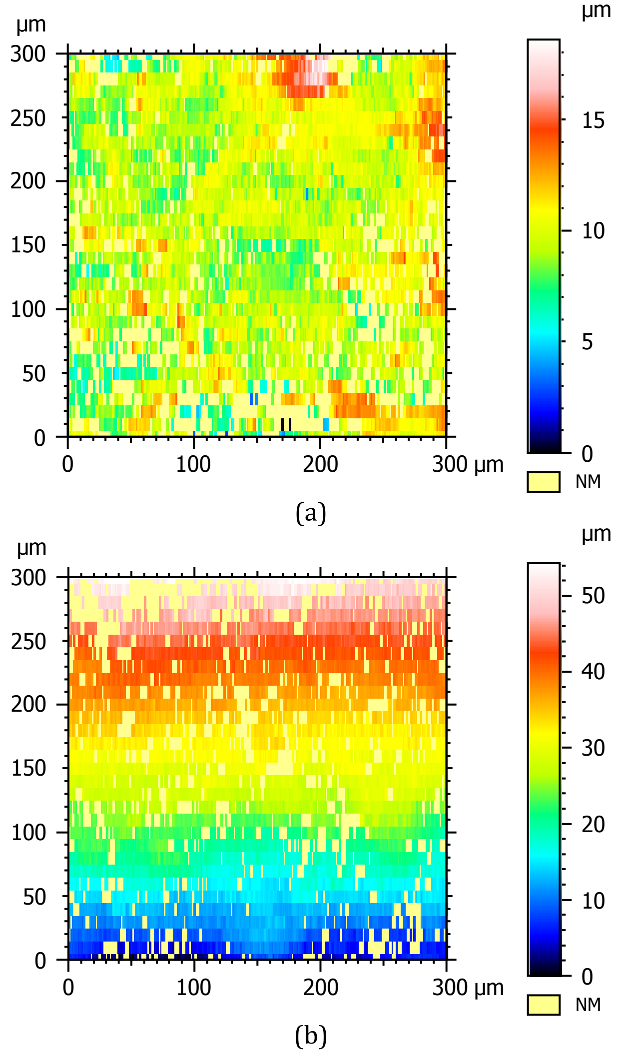

Fig.2. (a) 2D surface topography of untreated sample, (b) 2D surface topography of treated sample.

This result can be confirmed in Fig 3, which represents the 2D surface profiles along the direction of the 42CrMo4 steel surface in both treated and untreated samples. It's important to note that all the 2D profiles were clean rough values, with the waviness aspects subtracted, knowing that the height of the reference surface for the roughness measurements is 0 µm. It can be seen that the range of change in surface profiles for the untreated sample was between 5 and -15 µm, whereas the range of change in surface profiles for the treated sample was between 10 and -18 µm.

3.1 Amplitude parameters

Table 1 illustrates the amplitude average parameters (Mean values of coordinates) of the untreated and treated specimens during nitrocarburizing at 580 °C for 10 hours. After the nitriding process, both the arithmetic average roughness Ra and the root mean square average Rq increased significantly, with the values of Ra and Rq of the untreated sample being 0.3378 µm and 0.4770 µm, respectively, and the values of Ra and Rq of the treated sample being 1.023 µm and 1.350 µm, respectively. The rate of increase of the amplitude parameters has been shown in Fig. 4, showing Ra and Rq was increasing at 203% and 183%, respectively.

In the industry, Ra is the most commonly used factor, whereas Rq is less commonly applied in general engineering but more essential in statistical processing. It should be mentioned that, according to the two studies [13,20], an increase in the Ra and Rq values indicates a deterioration in the surface roughness.

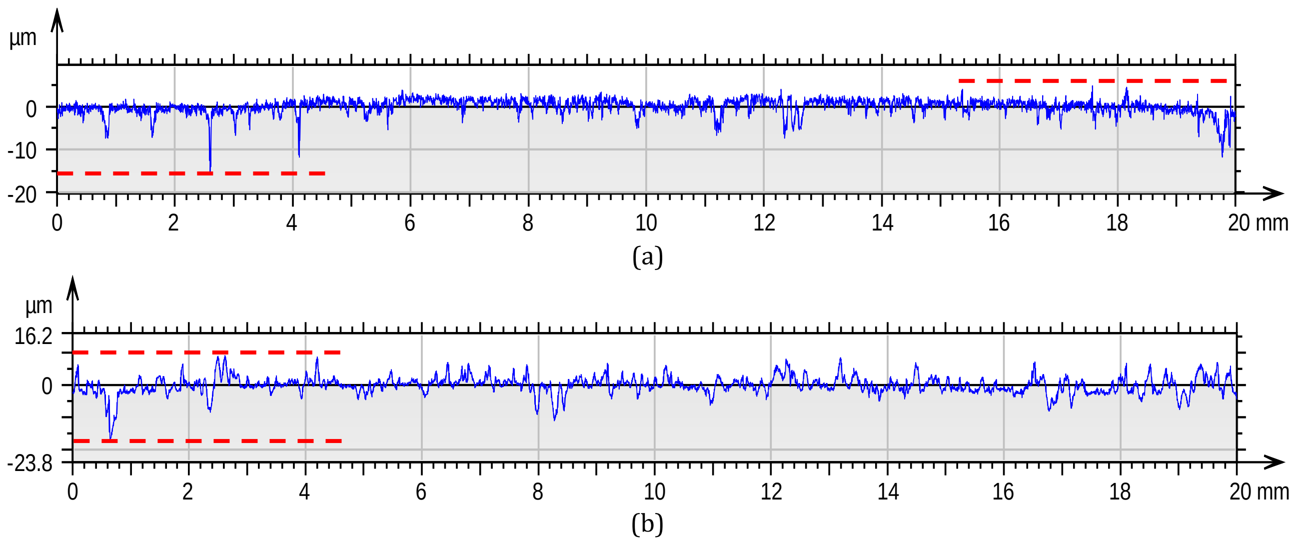

Fig. 3. 2D surface profiles of 42CrMo4 steel samples, (a) untreated sample, (b) treated sample at 580 °C for 10 h.

Through the Table 1 and Fig. 4 also, it can be observed that the value of Skewness of the roughness profile Rsk increased from -0.5743 to -0.2039 with an increase of 64%, moreover, the value of Kurtosis of the roughness profile Rku decreased from 3.597 to 2.888 with a decrease of 25%. The degree of the geometry of the surface heights about the mean plane is represented by skewness (Rsk). A negative Rsk value indicates that the surface is mostly made up of valleys, whereas a positive skewness indicates that the surface is mostly made up of peaks and asperities [21]. As a result, as mentioned in the study [22], a negatively skewed surface is advantageous for lubrication. A decrease in Rku, according to a study [23], indicates a rougher surface texture.

Furthermore, the Rku value of an untreated sample surface (Rku = 3.597) is often used to represent sharp peaks and surface texture. The decreased Rku value during the nitrocarburizing process, on the other hand, indicates that the sharp peaks and surface texture have divided. Based on the results obtained, it can be supposed that the newly formed nitrided layer by the nitrocarburizing process has spread out over each surface of the 42CrMo4 steel untreated, resulting in the creation of sharper tapered peaks. It should be noted that sporadic peaks and valleys have a significant impact on both of these parameters.

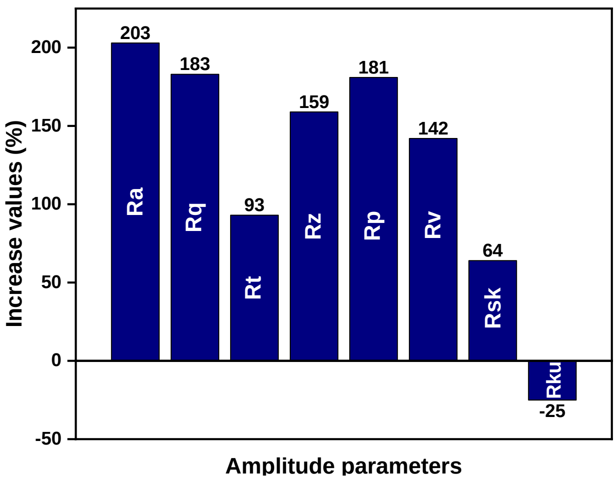

Fig. 4. The percentage increase in the values of the amplitude parameters.

Consequently, it can be said that after the nitriding process, the values of the height parameters that provide an assessment of valleys and peaks increased, resulting in a worsening of the 42CrMo4 steel's surface roughness. The results obtained above can be explained by the Fig. 5, which represents the cross-sectional microstructure of the nitride layer formed during the nitrocarburizing treatment at 580°C for 10 hours were determined by SEMSEM type of JEOL JSM 6060 LA.

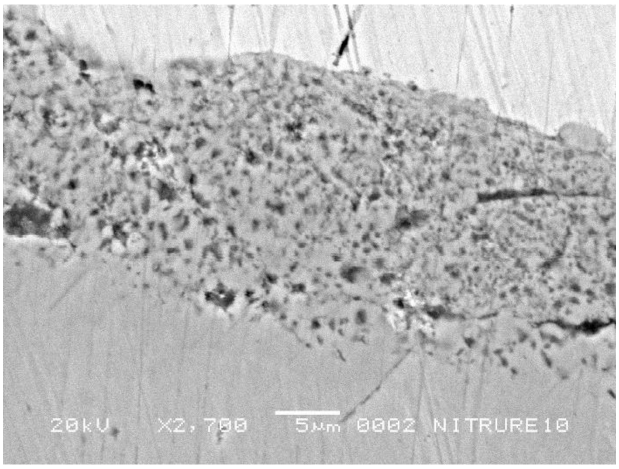

Fig. 5. The nitride layer after nitrocarburizing treatment at 580°C for 10 hours.

As also illustrated in Table 1 and Fig. 4, the maximum profile peak height Rp value was increased by 181% after nitrocarburizing, from 0.9659 µm to 2.718 µm. In the same way as Rp, the maximum profile valley depth Rv value was increased by 142%. There is a relationship between high peaks and the two phenomena of friction and wear, according to studies [24,25]. Additionally, deeper grooves and valleys in the surface texture might cause crack propagation [26,27] and corrosion [28,29]. It can be seen from the table 1 and the Fig.4 also that the maximum height Rz value has been increased from 2.271 µm to 5.877 µm with an increase of 159%, while the total height Rt value has been increased from 3.878 µm to 7.492 µm with an increase by 93%.

From the above findings, the nitrocarburizing treatment contributes more rapidly to the peak formation mechanism in the 42CrMo4 steel surface, whereas it contributes less rapidly to the valleys filling mechanism.

3.2 Spacing parameters

In this study, from the spacing parameters, the mean width RSm was evaluated. The mean width has been described as the arithmetic mean value of the width of roughness profile elements within the sampling length, in which a profile element is a peak and valley in the surface profile [30]. Table 1 shows the RSm values of the sample's surface before and after the nitrocarburizing process, where it can be seen that the RSm value increased from 13.91 to 24.14 µm with an increase of 74%. There are many factors that contribute to determining the width of the elements on the grinded surface of our untreated sample, including grain spacing, the shape of grain, grinding tool, and the grinded material [31]. As for the treated sample, a significant increase was observed in the RSm value. This can be explained by the appearance of a nitride layer on the profile elements, increasing their width.

3.3 Hybrid parameters

The hybrid characteristic combines height and length parameters. Any variations in height or length parameters may have an impact on the hybrid parameters. Therefore, it was considered a statistical parameter for the sensitivity of relatively small measurement errors [32,33]. Table 1 indicates the values of the root mean square of the mean slope of the profile of untreated and treated samples. It can be seen that the Rdq value increased from 14.17° to 17.19° with an increase of 21%. Increasing the Rdq value is considered a significant aspect of tribology analysis and contact mechanics since it is related to the standard deviation of roughness heights [33,34].

3.4 Material ratio parameters

Table 1 also summarizes the material ratio parameters (Rk parameters) of the 42CrMo4 steel surface before and after nitrocarburizing treatment. The Abbott–Firestone curves for untreated and treated samples have been shown in Fig. 6.

Surface roughness has been described using Abbott–Firestone curves (Also known as material ratio curves [35] or bearing area curves [36]). The methodology for determining numerical values of the kernal roughness depth Rk, the reduced peak height Rpk, the reduced dale height Rvk, and two material ratios (Mr1 and Mr2) has been described by standard ISO 135653-2:1996. The functional characteristics of the workpiece surface have been well described by this method of describing the Abbott–Firestone curves [37].

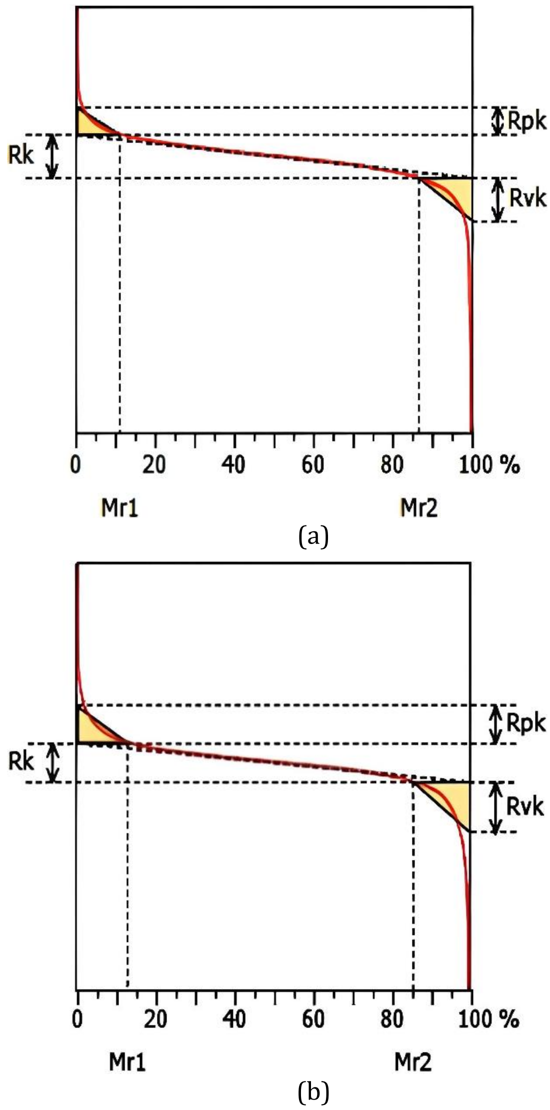

Fig. 6. Graphical construction of material ratio parameters of 42CrMo4 steel samples, (a) untreated sample, (b) treated sample at 580 °C for 10 h.

Through Table 1, Fig. 6, it can be seen that after the nitrocarburizing process, both Rpk and Rvk parameters have their values increased from 1.308 and 2.047 µm to 1.811 and 2.495 µm, respectively. The Rpk and Rvk parameters show a significant difference in the Abbott–Firestone curve. This significant difference has been considered one of the most fundamental aspects of the surface topography, allowing valleys and peaks to be distinguished [38]. The value of the upper material portion (Mr1) of the treated sample was increased from 10.89 to 12.86%, unlike the lower material portion (Mr2) value which decreased slightly from 86.98 to 85.44%. Mr1 is the portion of surface heights categorized as peaks by Rpk in the Abbott–Firestone curve, whereas Mr2 is the percentage of surface heights categorized as valleys by Rvk [39].

The percentage increase in the values of the Rk parameters has been shown in Fig. 7. It can be seen that the percentage raise in the values of both Rpk and Rvk parameters of the treated sample was around 38 and 21%, respectively. Furthermore, the value of Mr1 increased by 18%, meanwhile, the value of Mr2 declined by 2%.

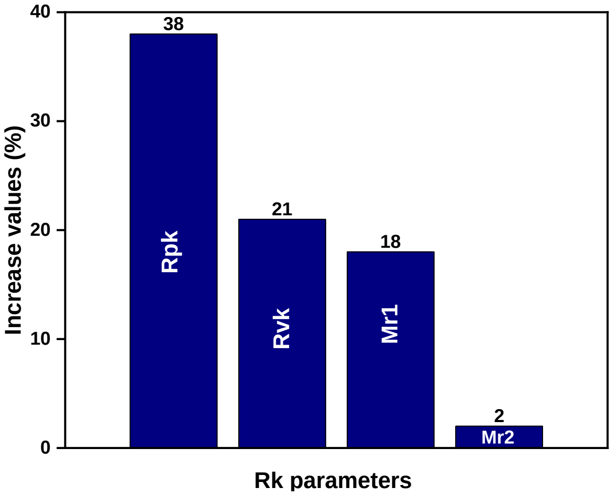

Fig. 7. The percentage increase in the values of the material ratio parameters.

Based on the above findings, it can be stated that the nitrocarburizing treatment affects the material ratio parameters that characterize the surface roughness of the our studied material. Therefore, changes in the tribological behavior of materials can be explained by providing a comprehensive description of surface wear and friction using parameters calculated by Abbott-Firestone curves [40], which also connects directly to the length and ratio of peaks and valleys for a given surface [41]. As a consequence, it appears that such a characterization Technique has been very effective suited for estimating the proportion of valleys on a surface, as is often the case for 42CrMo4 steel surfaces that have been treated by the nitrocarburizing process.

4. CONCLUSION

The paper presents a study of the influence of nitrocarburizing process on the roughness parameters of the 42CrMo4 steel surface.
The experimental findings can be summed up in the following points: the nitrocarburizing process had a significant influence on the surface topography of the examined material. This is due to the high chemical sputtering rate of N and C into the interior of the material, which in turn forms nitride layers (a compound layer and a diffusion layer). The values of the height parameters that allow an assessment of valleys and peaks increased after the nitriding process, resulting in a degradation of the surface roughness. The nitrocarburizing treatment has a faster contribution to the peak formation mechanism, but a slower contribution to the valley filling mechanism. The nitrocarburizing procedure expanded the width of the surface profile's peaks and valleys. Changes in the surface roughness profile obtained by analyzing the amplitude, spacing, and hybrid parameters had been confirmed by evaluating the material ratio parameters using Abbott–Firestone curves. In the end, it can be said that we succeeded to a large extent in achieving the main objective of this work as we tried to compare the behavior of the most important surface roughness parameters of 42CrMo4 Steel Surface before and after nitrocarburizing treatment.

Through experimental analysis, the future goal of this experimental research work is to investigate the relationship between surface roughness, coefficient of friction, wear, crack growth, and corrosion of 42CrMo4 steel subjected to the nitriding process.

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