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Tribological interests of borocarbonitruration in robotics

Aicha Rezala[#1]

[#] *Materials Science and Chemical Processes Laboratory (LSMPC), Chemistry Faculty, University of Science and Technology Houari Boumediene (USTHB)*

B.P. 32, El-Alia, 16111, Bab-Ezzouar, Algiers, Algeria

[1]aicha.rezala@usthb.edu.dz

***Abstract*— The work aims is to improve the structure reliability of an industrial robot by improving the tribological mechanical characteristics systems that make it up of a thermochemical borocarbonitruration treatment that leads to the hard variable thickness layer formation which increases the wear and friction resistance properties of the robot elements. This surface layer gives the borocarbonitruration its tribological function and ensures the robot has a smooth operation at a reduced cost. The results show the advantages of additive elements in the basic alloys proposed for the robot modules' wear resistance. A comparison of the results obtained with those found in the literature indicates good agreement.**

***Keywords*— reliability, industrial robot, contact surfaces, error, friction, wear, borocarbonitruration, alloys, thickness, and cost.**

I. Introduction

The failure of industrial materials is almost always an undesirable event for several reasons: it can endanger human lives, cause economic losses and hinder the production of goods and services. Even when the causes of a failure and the behavior of the materials are known, it remains difficult to ensure the prevention of failures. In general, damage caused by wear or corrosion can be mitigated [1], [2], or even avoided, by substituting more resistant materials. However, such materials often have a very high cost. Given these requirements, we are led to consider surface treatment and coating techniques, which offer another way to combat wear and corrosion. For several decades, various processes and filler materials have been used to modify surfaces in order to increase their resistance to external aggression. Surface treatments make it possible to condition a mechanical part as economically as possible for service demands [3]. They are numerous: some are carried out without the new addition elements, the case of all thermochemical treatments [4].

In the industrial competitiveness of robotics, it is a considerable advantage to be able to produce products that do not wear out, are resistant to corrosion, and retain their mechanical properties over time. Surface treatments have become essential. Thermochemical treatments for surface coatings of materials are very effective in remedying static and dynamic errors due to the operation of industrial robots and have a fundamental role in the preventive and curative maintenance of mechanical parts [5], [6]. The borocarbonitriding surface treatment allows surface enrichment in carbon and nitrogen for surface hardening by producing a hard layer of variable thickness that increases the wear and friction resistance properties of the robot elements [7]. The results obtained show the advantages of additive elements in the base alloys proposed for the wear resistance of the modules.

The robot is a mechanism that includes a certain number of parts (kinematic couples, links, etc.). These elements are made with ferrous alloys that must resist wear. Therefore, for good robustness and to remedy a set of problems [5], we have provided for the wearing parts materials having high mechanical characteristics and heat treatments such as: carburizing, quenching and income…etc. For effective surface treatment, our choice fell on the borocarbonitriding technique. [8], [9] which is widely used in the industrial field due to its major advantages: reduced cost, requiring neither sophisticated equipment nor qualified labor. The working methodology includes three chemical treatments: boriding [8], carburizing [9] and nitriding [8]. This technique has the power to produce a hard layer of variable thickness to increase the properties of resistance to wear and friction as well as mechanical fatigue.

II. INDUSTRIAL ROBOTS

Robots are currently very widespread in industry, particularly in automobile manufacturing and among most computer manufacturers. Capable of quickly carrying out repetitive work, they are particularly used in manufacturing and assembly lines. They are also used in environments that are barely bearable for humans (extreme conditions of temperature or pressure, high radioactivity, etc.). The nuclear industry has thus largely contributed to the development of robotics (particularly in the design of remote manipulator arms). It is therefore necessary to adapt the analysis and synthesis tools in order to optimize performance and guarantee the robustness of the solution with regard to reliability and operational safety. The first point that the designer of an industrial robot must be concerned with is the structure of the different segments or joints and especially the nature of the materials constituting it.

III. TRIBOLOGY OF MECHANICAL CONTACTS IN ROBOTICS

For better management and diagnosis of industrial robots, the use of preventive maintenance and reliability is essential. We must contribute to resolving problems of mechanical strength, rigidity and stability of parts and structures that could cause them to fail. Given the diversity of existing robots, comparative studies based on scientific data are necessary for an adequate choice that would take into account the specific conditions of their operation. And subsequently, compare them to the optimal conditions required by the manufacturers without damage to this equipment, the operation of which is a complex problem requiring adequate theoretical studies for the development of mathematical models which clearly describe the interdependence between the tribological forms of the surfaces and materials used for better optimization. A better understanding of the tribological forms involved in the contact of two surfaces in relative motion would make it possible to properly guide the choice of these forms ensuring the desired progress, on the one hand. On the other hand, the tribological behavior of a pair of materials is very influenced by the mechanical, physico-chemical properties of the materials in contact and by the possible existence of a third abrasive body (external element or produced by the wear during friction).

A large part of technical failures begins at the contact surface of mechanical parts in relative motion, therefore, the tribological behavior of materials and the performance of lubricants or coatings in sliding contact ultimately determine the quality of the design initial as well as the operational reliability of industrial robots. Lubricated contacts play an essential role in robotics, as they allow low friction guides to be obtained and also a long lifespan due to the low levels of wear obtained. Therefore, a precise knowledge of surfaces and the laws of contact of solids is an essential prerequisite for the study of friction and wear mechanisms. All these motivations dominate the economic interest of this study which is considerable. The characterization of selected materials to deepen their tribological capabilities according to operating requirements must be well studied in order to minimize maintenance costs and increase the lifespan of mechanical components with reliable and good quality service.

IV. PRESENTATION OF MATERIALS AND PROCESSING PROCEDURE

The choice of a pair of friction materials is an optimization problem between often contradictory properties and qualities. In the field of tribology, there is no general law or coherent method for choosing pairs of friction materials on mechanical equipment, other than the layer rule, without forgetting of course to take into account the operating recommendations given by the various researchers and raw material manufacturers in order to minimize the effect of friction and wear. Friction is a three-dimensional phenomenon that involves a certain thickness of material below the surface. The mechanical contact of two real parts is therefore established via complex layers whose nature, geometry and properties are often poorly known. Experiments carried out in different tribology laboratories tell us that the best friction couples are generally composed of a hard material in the presence of a softer antagonist.

Industry demands for technical coatings are increasingly demanding. The environmental impact of coating shaping processes is also a primary consideration. To satisfy constraints of economic competitiveness linked to a low environmental impact, design engineers are inclined to turn their attention towards processes that use the minimum of resources.

A. Presentation of materials

For the evolution of heat and thermochemical treatment techniques, researchers were increasingly interested in the use and implementation of tool steels [10]. Therefore, we carried out experiments based on the borocarbonitriding treatment (solid powder medium) working at tempering temperatures for three cases of different tool steels [9]: XC38 (ordinary steel for heat treatment), 23MCD5 (steel low alloy) and X210Cr12 (high alloy steel). The chemical composition of these three grades of treated tool steels used in our study is given in the following tables:

TABLE I
ALLOYING ELEMENTS OF THE STEELS USED (WT. %)

Alloys	**Contents of different alloying elements in mass percentage**									
	C	**Cr**	**Mn**	**Si**	**S**	**P**	**Ni**	**Mo**	**Cu**	**Al**
XC38	0,35	0,21	0,66	0,27	0,02	0,015	0,02	0,02	0,22	0,06
23MCD5	0,28-0,38	0,5-0,7	1,05-1,45					0,20-0,40		
X210Cr12	1,90-2,20	11-12	0,15-0,45	0,10-0,40						

B. Treatment process

Surface treatments respond to real needs for improving the performance of materials. Their function is to improve the resistance of the material to external stresses, while preserving its volume properties. Preventing intermetallic contacts amounts to improving lubrication, or strengthening the natural protective coat of oxides, or creating an artificial protective coat [11]. The latter can be secreted by the metal itself, like the graphite in cast iron, or brought from outside, like the iron sulfide generated by Sulfinuz. The two essential goals of surface treatments and coatings are the fight against friction and the limitation of wear. A protective anti-wear layer is only useful if its thickness is at least equal to the admissible loss of material during the life of the mechanism [12]. The objective of this work is to seek to optimize the conditions used for the production of hard wear-resistant deposits. For this, we opted for the thermochemical treatment of borocarbonitriding.

A preliminary treatment was carried out on the different samples and it is summarized as follows:

- Austenitization inside the furnace with a heating salt bath of composition NaCl + KCL + BaCl2, at a temperature of 550°C.
- Under a controlled atmosphere, an income was carried out in a furnace.

C. Borocarbonitriding technique

This borocarbonitriding thermochemical treatment uses a powder with a chemical composition based on carbide and nitride boron. The samples were covered by a paste layer and placed in a hermetic enclosure as illustrated in Fig. 1 to prevent gases from escaping during the process. A relatively thick layer of sand is added to the cover to limit air infiltration to ensure a good seal. Then, the group is set up in an electric oven (Fig. 2) at a temperature of 550°C for 12 hours, followed by slow cooling, and then the parts are cleaned. The borocarbonitriding parameters were constant as a previous work [13], [14].

Fig. 1 Borocarbonitriding set up

Fig. 2 Electric muffle furnace

V. Results and discussion

After the borocarbonitriding thermochemical treatment at a temperature of 550°C for 12 hours, a layer of a certain well-defined thickness was formed on our samples and whose characteristics are as follows as illustrated in table 2: for XC38 steel, the thickness thereof varies from 170 to 190µm, for 23MCD5 steel, from 150 to 170µm and while for X210Cr12 steel it is from 110 to 140µm.

These results show that the quantity of alloying elements in the steel slows down diffusion and influences the diffusion layer. The analysis of the diffusion layer microstructure reflects the difference that exists between the diffusion layer structures for each steel. We have already mentioned that the thickness of this layer varies from one class of steel to another, the following figures confirm our results.

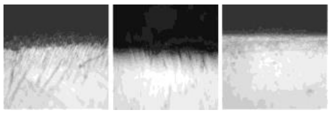
TABLE III
Thickness obtained after the Borocarbonitriding treatment

Nature of materials	XC38	25MCD5	X210Cr12
Thicknesses obtained (µm)	170 to 190	150 to 170	110 to 140

A. *Metallographic observation*

Fig. 3 illustrates an optical microscope observation; which indicates that after borocarbonitriding, the microstructure shows multilayer form. The borocarbonitriding treatment at 550°C and 12h produced different borocarbonitrided layers in terms of morphology, thickness and phase structure. The structure of the nitrided zone therefore corresponds to:

- A thin white outer zone, not attacked by nital, is called a combination layer.
- The intermediate zone is blackened by the nital attack which corresponds to the diffusion layer.
- Area of the core that corresponds to the base metal.



XC38 23MCD5 X210Cr12

Fig. 3 Optical micrograph of borocarbonitrided steels used at 550°C during 12 h

B. *The appearance of microhardness*

Fig. 4 shows the microhardness profile of the treated samples at 550°C for 12h. The microhardness profile obtained from cross-sections of the treated specimens shows a clear increase in the hardness of the layer and sub-layer compared to that of the matrix. The microhardness profile presents an appearance in which three zones can be distinguished:

- Zone I, a surface zone that corresponds to maximum hardness, is between 480 and 760 HV for XC38 steel, between 420 and 760 HV for 23MCD5 steel and between 750 and 1040 HV for X210Cr12 steel.
- Zone II which corresponds to a level where the hardness decreases suddenly, this hardness varies from 320 to 480 HV for XC38 steel, from 290 to 420 HV for 23MCD5 steel and from 420 and 750 HV for X210Cr12 steel.
- Zone III is the heart of the material which is not affected by nitriding, its hardness is constant, it is approximately 270 HV for XC38, 23MCD5 steels and 390HV for X210Cr12 steel.

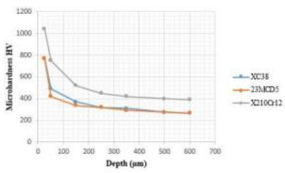
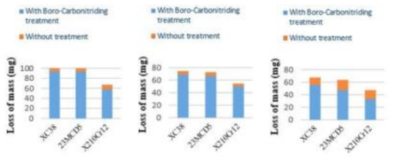


Fig. 4 Microhardness profile of the treated samples at 550°C for 12h

According to the treatment of borocarbonitriding under the conditions (T=550°C and t=12 h), we notice that as we move away from the surface, the microhardness of the diffusion layers decreases which ensures good cohesion between the diffusion layer and the base metal. These results make it possible to avoid slipping during large dynamic forces.

C. Wear resistance

From the histograms shown in Fig. 5, it can be seen that X210Cr12 steel is remarkably resistant to wear compared to other steels XC38 and 23MCD5. For the 23MCD5 steel, the effect of wear resistance decreases with the deterioration of the layer, that is to say, the closer you get to the matrix, that is to say as we get closer to the matrix.



After one minute After two minutes After three minutes

Fig. 5 Wear resistance of the steels used

VI. CONCLUSIONS

The Borocarbonitriding treatment, following the analysis of the results obtained, shows that it is one of the best treatments that can develop a hard layer of variable thickness allowing to increase the properties of resistance to wear and friction, as well as resistance to mechanical fatigue. The existence of this layer obtained by this type of thermochemical treatment on the materials when the temperature rises can be recognized as preventing adhesion or at least as pushing back its appearance towards higher deformation rates and temperatures and a lowering of the coefficient of friction.

This treatment will allow us to obtain robot elements with better surface characteristics (wear resistance and hardness). According to our study, it is preferable to use highly alloyed steels. In addition, the diffusion layer obtained by boro-carbonituring gives the maximum possible thickness to ensure a long lifespan of these parts, thus ensuring certain reliability of the robots. The surface film, created in advance, has the characteristics that would allow it on the one hand to ensure its protective function and on the other hand to last over time to ensure reliable operation of the mechanisms.

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