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# Effect of Heat Treatment on Wear Behavior of Chromoly Steel

**Soumaya Meddah**
Research Center in Industrial Technologies (CRTI)

**Mounira Bourebia**
Research Center in Industrial Technologies (CRTI)

**Latifa Kahloul**
National Higher School of Technology and Engineering

**Sihem Achouri**
Research Center in Industrial Technologies (CRTI)

**Amel Oulabbas**
Research Center in Industrial Technologies (CRTI)

**Samia Lemboub**
National Higher School of Technology and Engineering

**Ahlem Taleb**
Research Center in Industrial Technologies (CRTI)

**Wafa Boumacheta**
National Higher School of Technology and Engineering

**Abstract**: Chromoly steel is a steel widely used in mechanical manufacturing, it finds many applications for oil and gas, aerospace, and automotive industries. In addition, its ductility, its resistance and its relatively low weight, and its malleability constitute one of the characteristics of choice for the manufacturers. In order to improve the use properties of this steel such as resistance to rupture, corrosion, wear and minimize the risks of fragility, heat treatments are considered in this study. Hence, the objective of this experimental work is to study the effect of heat treatment by quenching followed by tempering at different temperatures on the hardness, structural state, and wear resistance of chromoly steel. In addition, an investigation on the evolution of the rate of bearing surface after friction test was carried out. The results show on the structural level that the sample having undergone quenching followed by tempering at 700°C for 15min, presents a microstructure of globular pearlite with the coalescence of the complex carbides of Mo-Cr-Nb, and a hardness of 226HB. However, regarding the tribological behavior, the sample treated at 600°C recorded an improved wear rate of 49% compared to the sample treated at 550°C. For the wear mechanisms, the abrasive wear mechanism is observed for untreated sample, while the adhesive wear mechanism is dominant for the heat-treated samples. In addition, the rate of the lower bearing surface "Sr2" of this same sample was improved by 2.7% compared to that treated at 550°C.

**Keywords:** Chromoly steel production, Quenching and tempering treatment, Mechanical property, Structure, Wear resistance.

## Introduction

In the mechanical engineering sector, to improve the mechanical properties of materials, quenching and tempering (Q&T) heat treatment is the standard treatment route used for commercial steels with medium carbon low alloy. The demand for these steels is gradually increasing in several sectors, due to their superior mechanical properties, their excellent fracture toughness and their high resistance to fatigue and wear (Hafeez, 2020; Sanij, 2012).These treatments offer the possibility of modifying the structural state and adjusting the mechanical properties of steels, such as hardness, resistance to wear, corrosion and fatigue (Bourebia, 2019; Mosayebi, 2021). By correctly selecting the tempering conditions, a wide range of mechanical properties, among others hardness and wear resistance can be obtained. These mechanical properties are an important aspect for medium carbon steels. However, several researchers have carried out investigations on the influence of quenching and tempering (Q&T) heat treatment, in order to elucidate the effect of this process on the microstructural evolution and the mechanical properties. These treatments provide an opportunity for the development of cost effective parts with improved properties. These research strategies are based on the development of microstructures consisting of ultrafine microconstituents formed in non-equilibrium conditions, such as martensite or bainite, in combination with Retained Austenite (RA) (de Diego-Calderón, 2015).

In this context, de Diego-Calderón et al.(2015) have studied the effect of Q&P with varying parameters (quenching temperature, partitioning temperature and time) on microstructure evolution and mechanical behaviour of Q&P steels with nominal composition of 0.25C–1.5Si– 3Mn–0.023Al (mass %). The results show that, a Multi-phase microstructure was obtained (different fractions of Tempered Martensite (TM), Untempered Martensite (UM) and Retained Austenite (RA)). The PT has a important effect on mechanical properties of the Q&P steel.

Qiangguo Li et al. (2020) studied the effects of bainite content on the mechanical properties of the triplex microstructure (bainite, martensite and retained austenite) in a quenched and partitioned medium-carbon bainitic steel, by controlling the temperature and holding time of the isothermal transformation. The results show that with the increase of the isothermal holding temperature from 320 to 400°C, the bainite changes from lower bainite to higher bainite and the ultimate yield strength and toughness decrease.

In the same context, in the work of Hafeez et al. (2020), the effect of cyclic heat treatment (SQT, DQT and TQT) on the mechanical and corrosion properties of medium carbon low alloy steel is studied. The results show the formation of fine ε-carbide ($Fe_{2.4}C$) after intermediate tempering at low temperature in DQT and TQT heat treatments. In addition, DQT and TQT heat treatments, improved the mechanical and corrosion properties of steel, in comparison to SQT heat treatment.

Hence, medium carbon low alloy steel (chromoly steel) was produced and cast at the URMM/CRTI laboratory in an induction furnace. This steel has been subjected to heat treatments including conventional quenching and tempering processes at different temperatures. Therefore, the objective of the present work is to validate the microstructure/mechanical properties, and Q&T parameters relationship. Dry friction tests were also performed to evaluate the wear resistance. In addition, an investigation on the evolution of the bearing surface rate after friction test was carried out.

## Method

Samples of chromoly steel produced in an induction furnace under atmosphere controller(0.33C–0.55Mn–0.39Si–0.912Cr–0.188Mo–0.013Ni–0.045Cu-0.024Nb-0.079V-0.017P –0.007S, wt%) have undergone a heat treatment of quenching (austenization at 950°C for 15 min then quenched in oil). It should be noted that the temperature Ac3 was calculated according to formula 1 (http://micro.icaunais.free.fr/05_trait_therm.pdf). The quenched steel was tempered for a 15 min at various temperatures of 550°C, 600°C, and 700°C (Figure 1). The microstructural characterization and the wear mechanisms were revealed by scanning electron microscope type Quanta 250/FEI. A load of 187.5 kgf was used for Brinell hardness test.

Low alloy steels (C<0,6%) :

$$Ae1 \sim Ac1 = 723 - 10{,}7Mn - 16{,}9Ni + 29{,}1Si + 16{,}9Cr + 6{,}38W + 290As$$

$$Ae3 \sim Ac3 = 910 - 203\sqrt{C} - 15{,}2Ni + 44{,}7Si + 104V + 31{,}5Mo + 13{,}1W - 30Mn - 11Cr - 20Cu + 700P + 400Al + 120As + 400Ti\ldots \quad (1)$$

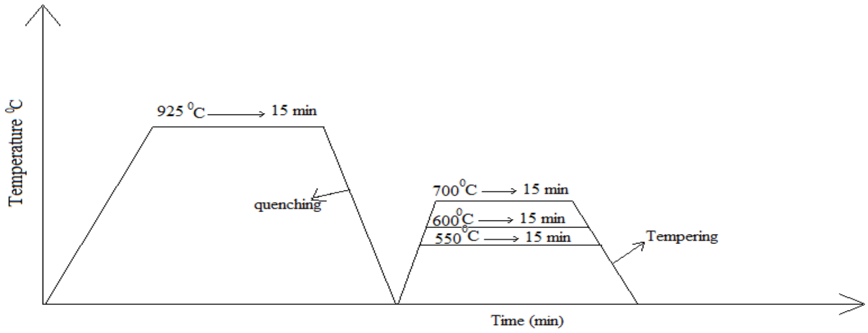


Figure 1. Schematic illustration of heat treatment (Quenching and Tempering).

For the friction tests, samples of size (1cmx1cmx1cm) were previously prepared by mechanical polishing. These friction tests were carried out using a typical tribometer ball/pin-on-disk, CSM Instrument according to ASTM G99-95 at ambient temperature using a 100C6 ball of 6 mm in diameter, under the following conditions: Load 8N, linear speed 2cm/s, distance traveled 50m. The friction coefficient was recorded automatically during the test using the Tribox 4.49 data acquisition software. The roughness parameters were measured (bearing surface) using a 3D laser source profiler of Cyber-Technology type, CT100 scan according to DIN ISO 25178. The wear rate is calculated according to the Archard ( 1961) formula (Eq.2), after calculating the worn surface.

$$Ws = V/PL \tag{2}$$

-W (mm3/N/m) is the wear rate;
-V (mm3) is the wear volume;
- P (N) the applied load;
- L (m) the sliding distance.

## Results and Discussion

### Microstructural Evolution

The microstructure of the different samples is shown in Figure 2. The sample produced has a Ferrito-pearlitic structure (0.33% C), after a normalization treatment at 900°C for 1 hour, and cooling in air. After austenization at 925°C and water quenching, the microstructure obtained is lower bainite, which is in the form of lath.

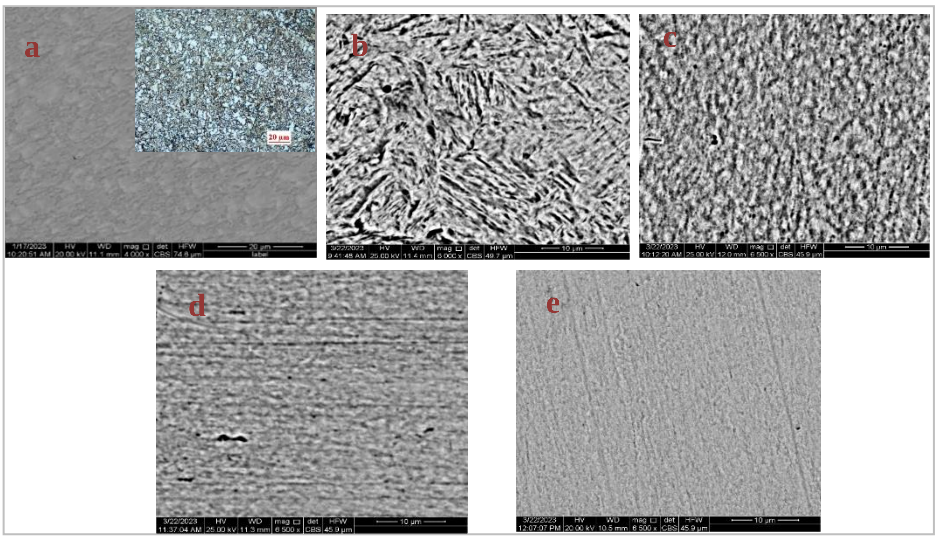


Figure 2. Microstructural evolution: a) Initial structure (B), b) Quenched, c) Tempering 550°C, d) Tempering 600°C, e) Tempering 700°C.

The carbon precipitates in the form of cementite which appears in the form of sticks of the same orientation within the bainitic ferrite supersaturated with carbon then in the austenite enriched with carbon (Élodie Boucard , 2014). The microstructure of the sample tempered at 550°C and 600°C - 15 min reveals the nucleation of fine carbides and the tendency for the bainitic morphology of lath to disappear. For the microstructure of the sample tempered at 700° C.-15 min, the microstructure obtained is globular pearlite including spheroidized carbide.

**Hardness Evolution**

Figure 3 displays the variation in hardness after the various quenching and tempering heat treatments. It can be seen that the hardness depends on the treatment temperature. However, the highest hardness is recorded for the sample quenched at 925°C which has a bainitic structure. Whereas, the decrease in hardness occurs at higher tempering temperatures. The same result is observed in the work of Mosayebi et al. (2021) and Hafeez et al. (2020). At 700°C, there is coalescence of the carbides (change in their morphology, globulization and a more homogeneous structure), which leads to a softening of the structure, and consequently a reduction in hardness.

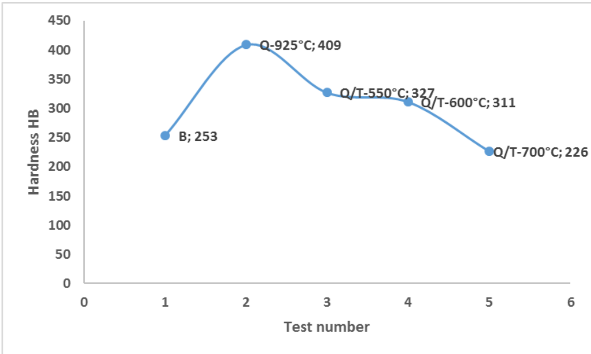


Figure 3. Hardness evolution during quenching and tempering.

**Evolution of Friction Coefficient and Wear Rate**

Analysis of the curves illustrated in Figure 4 show the variation of the friction coefficient for the tribological couple Chromoly steel (Q, Q/T)/100C6 as a function of the distance travelled. These curves clearly indicate the existence of three phases (Meddah, 2022). Friction begins with a break-in period during which the friction coefficient increases rapidly to reach a maximum value. This period is characterized by a plastic deformation of the surface asperities. The second phase is the transition phase, which is characterized by a slight decrease in the friction coefficient. This is due to the formation of the third body (wear debris), which acts as a solid lubricant. During the third period, the friction coefficient stabilizes and its value remains constant regardless the distance traveled. The friction coefficient reaches a maximum value of 0.567 for the quenched sample and a minimum value of 0.383 for the quenched sample and tempered at 700°C.

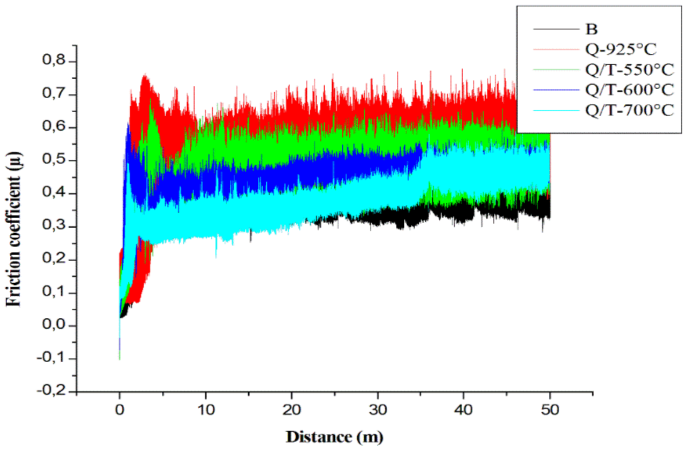


Figure 4. Evolution of friction coefficient as a function of heat treatment (Quenching/Tempering).

The evolution of the wear rate according to the heat treatment (quenching/tempering) is presented in the histogram of Figure 5. From this histogram, it is observed that the sample quenched at 925°C/water recorded the lowest wear rate equivalent to $1.192\times10^{-5}$ $mm^3/N/m$. Whereas, the sample after normalization treatment recorded the highest wear rate equivalent to $3.864\times10^{-5}$ $mm^3/N/m$. This result indicates that Archard's law is validated, where the volume of material lost is inversely proportional to the hardness value of the material (Meddah, 2020; Archard, 1953).

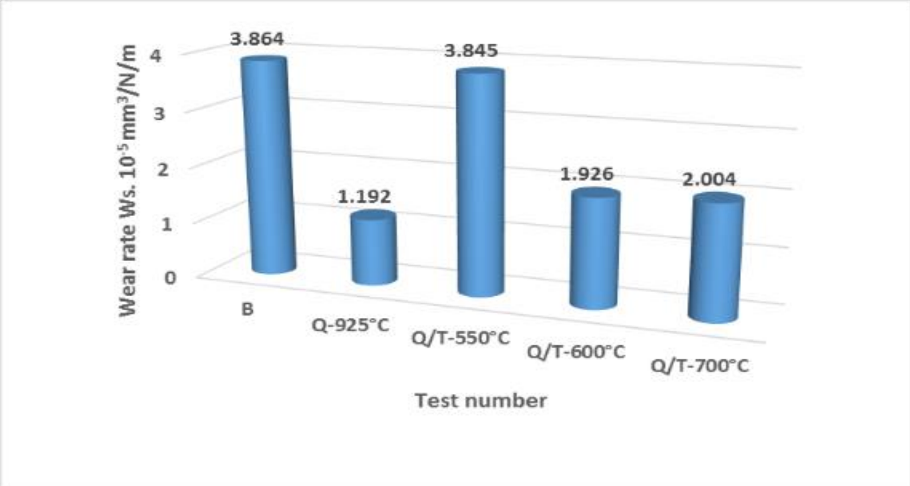


Figure 5. Evolution of wear rate as a function of heat treatment (Quenching/Tempering).

According to these results, it can be seen that the quenching and tempering treatment has provided an improvement in the wear resistance, which is manifested by the lower value of the wear rate. This behavior depends on the microstructure formed after treatment, the volumetric fraction, the morphologies, the size and the nature of the carbides formed. Moreover, the wear debris detached from the surface results in the formation of an adherent oxide film during the wear process which prevents the direct contact of the two rubbing bodies (Meddah, 2022).

## Wear Track Morphology

Figure 6. show the SEM micrographs from the worn surfaces for tested samples . The micrograph for sample 1 (after normalization treatment) reveals the parallel grooves to the sliding direction, and the flakes confirming the presence of abrasive and adhesive wear mecanisms, with predominance of abrasive wear favoring the delamination of the rubbed surface. These observations are confirming by the highest wear rate. However for samples that have undergone the quenching and tempering treatment at different temperature, their micrographs reveals the parallel deep grooves to the sliding direction, signes of delamination, and wear debris resulting from the destruction of surface roughness. These observations confirm the abrasive and adhesive wear mechanisms with predominance of the adhesive mechanism. The latter is manifested by the lower wear rate recorded by the heat-treated samples, compared to the untreated one. This may be related to the structural state and to the adhesion of iron oxide to the contact surface. Hence, the good ductility of these iron oxides means that the non-abrasive particles promote wear by adhesion (Meddah, 2022).

## Evolution of Bearing Surface

The evolution of the upper Sr1 and lower Sr2 bearing surface ratios for the friction test carried out after different heat treatments is illustrated in Figure 7. From witch, we note an improvement in the Sr1 parameter varying from 1.15% to 40.63%. This improvement shows the beneficial effect of heat treatment. It is explained by the distribution of the carbides formed, as well as their volume fractions, hence the homogenization of the microstructure which increases the bearing surface. On the other hand, the parameter Sr2 decreases, this phenomenon is explained by the detachment of the debris from the surface which causes a degradation of the latter; hence a reduction in the bearing surface.

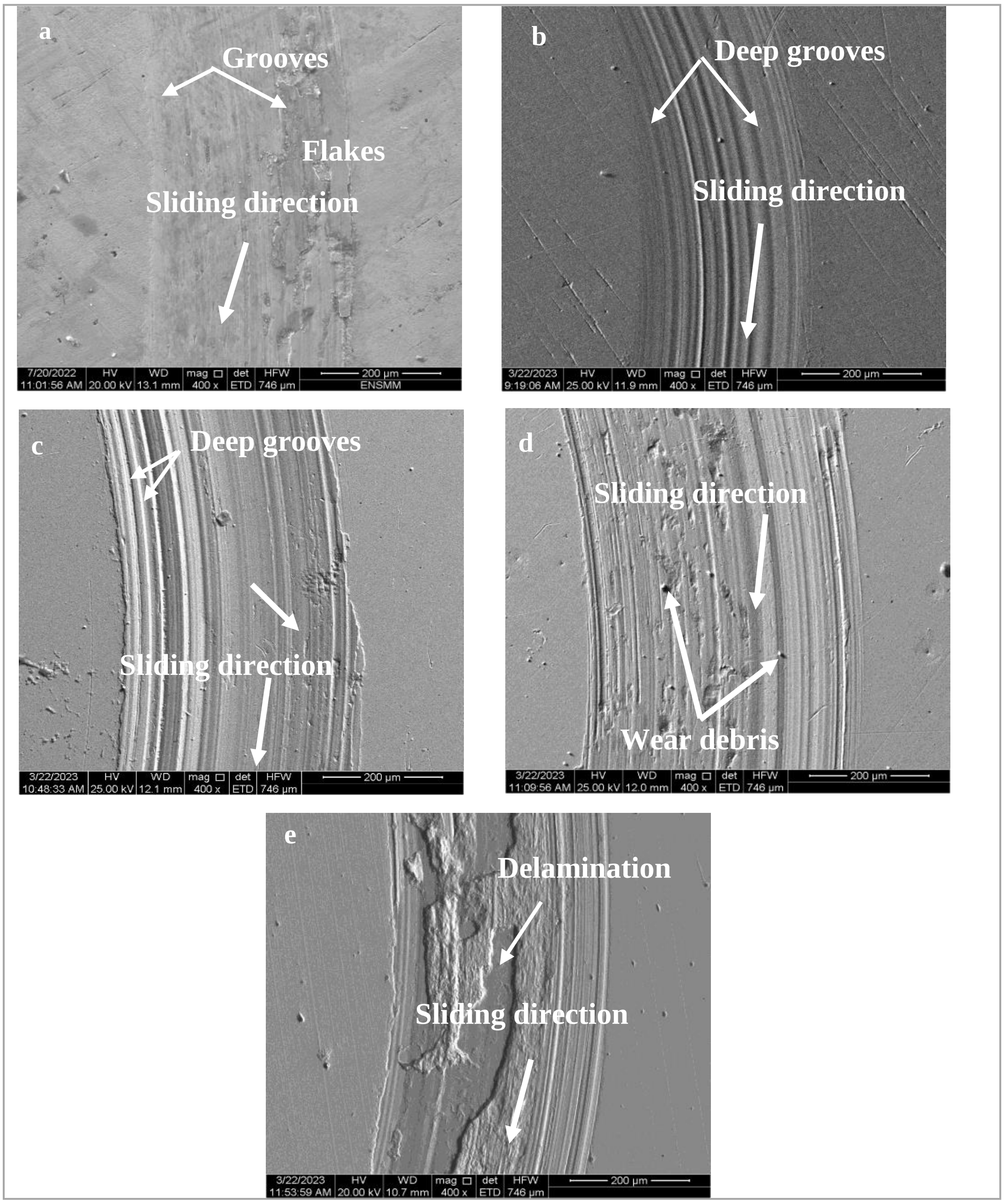


Figure 6. Wear mechanisms after friction test : a) Initial structure (B), b) Quenched, c) Tempering 550°C, d) Tempering 600°C, e) Tempering 700°C.

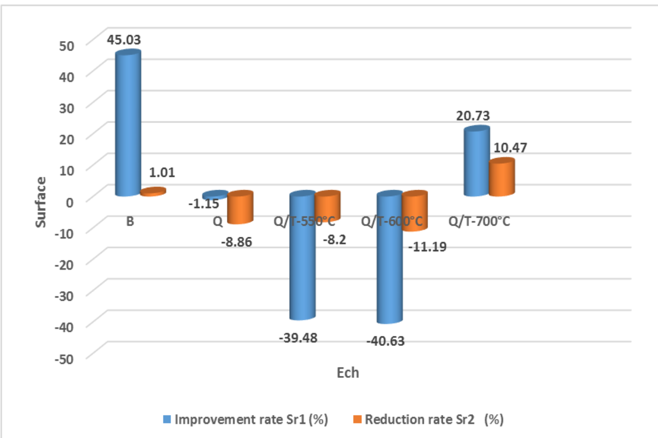


Figure 7. Evolution of improvement and reduction rate.

## Conclusion

The effects of quenching and tempering heat treatment parameters on the microstructural evolution and the mechanical properties of a medium carbon steel have been studied. The main results can be summarized as follows:

Quenching resulted in the formation of lower bainite, while the microstructure after tempering at 700° C.-15 min is globular pearlite including spheroidized carbide. By increasing the tempering temperature, the hardness decreases to reach minimum values of 226HB. The highest friction coefficient is recorded for the quenched sample with a value of 0.567. The lowest wear rate is recorded for the quenched sample with a value $1.192 \times 10^{-5}$ $mm^3/N/m$, indicating improved wear resistance. Predominance of the abrasive wear mechanism for untreated sample, while the adhesive wear mechanism is dominant for the heat-treated samples. An improvement in the rate of upper bearing surface Sr1with a rate varying from 1.15% to 40.63% during the running-in period. A reduction in the rate of the lower bearing surface Sr2 with a rate that varies between 8.2% and 11.19%.

## Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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## Author Information

**Soumaya Meddah**
Research Center in Industrial Technologies (CRTI), P.O.BOX 64, Cheraga 16014 Algiers, Algeria
Contact e-mail: *s.meddah@crti.dz*

**Mounira Bourebia**
Research Center in Industrial Technologies (CRTI), P.O.BOX 64, Cheraga 16014
Algiers, Algeria

**Taleb Ahlem**
Research Center in Industrial Technologies (CRTI), P.O.BOX 64, Cheraga 16014
Algiers, Algeria

**Boumacheta Wafa**
National Higher School of Technology and Engineering
2000 places pedagogic Sidi Amar, Annaba, Algeria

**Latifa Kahloul**
National Higher School of Technology and Engineering
2000 places pedagogic Sidi Amar, Annaba, Algeria

**Sihem Achouri**
Research Center in Industrial Technologies (CRTI), P.O.BOX 64, Cheraga 16014
Algiers, Algeria

**Amel Oulabbas**
Research Center in Industrial Technologies (CRTI), P.O.BOX 64, Cheraga 16014
Algiers, Algeria

**Samia Lemboub**
National Higher School of Technology and Engineering
2000 places pedagogic Sidi Amar, Annaba, Algeria

**Ahlem Taleb**
Research Center in Industrial Technologies (CRTI), P.O.BOX 64, Cheraga 16014
Algiers, Algeria

**Wafa Boumacheta**
National Higher School of Technology and Engineering
2000 places pedagogic Sidi Amar, Annaba, Algeria

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