# Cyanide in salt bath Applied to ASTM A-517 Steel: Effects on Hardness, Wear and Microstructure

### Victor Alcántara Alza

*Abstract: The effects of the cyanide treatment (CN) in a salt bath at elevated temperatures on the hardness; adhesive and abrasive wear; of ASTM A-517 steel, were investigated. For abrasive wear, 1" x 3" x 5/16" samples were prepared according to ASTM G-65 standard. For adhesive wear, specimens wit ring-shaped: φ ext. = 40 mm, φ int = 20 mm and 10 mm thick, according to ASTM G -77. The CN treatment was carried out, at high temperatures: 800 – 850 – 900 – 950 °C, immersing the samples in a salt bath: 6% NaCN + 80% BaCl₂ + 14% NaCl before entering the muffle furnace, with soaking time of 3 hr. Hardness tests were performed on a Rockwell Durometer taking measurements on the HRC scale. The adhesive wear tests were carried out on a parallel lathe coupling the Amsler device, following the ASTM G-77 standard. The abrasive wear tests were performed according to the ASTM G65 standard. Microscopy was done at the optical level. A maximum hardness of 63.5 HRC was found in all samples, representing an increase of 11.3% with respect to the state of supply (T&R). In abrasive wear, its value increased to 66%, compared to supply samples. The most suitable microstructure is presented by cyanide samples at 850ºC, with a layer of compounds (hard layer) formed by: massive cementite; tempered martensite and carbide. It is concluded that when applying cyanide to ASTM A-517 steel, the hardness and wear properties are increased to optimal values, if the cyanide treatment (CN) is carried out at 850 °C.*

*Keywords: Cyanide, adhesive wear, abrasive wear, wear steels, surface hardening*

## I. INTRODUCTION

The phenomenon of wear, like corrosion and fatigue, is one of the most important forms of degradation of parts, mechanical elements and industrial equipment [2]. This has created the need to search for new steels, as well as to investigate the mechanisms of surface hardening to improve their hardness and resistance to wear (WR).

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Wear can be defined as the surface damage suffered by materials after certain working conditions to which they are subjected. This phenomenon manifests itself on the surfaces of the materials, affecting the sub-surface. The result is, the loss of material and the subsequent decrease in dimensions and loss of tolerances [1].

First proposal, to improve WR of equipments was the use of new materials developed for this purpose (alloys and coatings) [2]. Another proposal to improve WR was the use low carbon alloy steels, to which thermochemical surface hardening treatments can be applied. Its advantage is the lower cost compared to the indicated materials. Within these treatments, there are established methods, that improve the surface hardness of steels that include: carburizing, nitriding, carbonitriding, cyaniding and boronizing. These methods change the chemical composition of steels. Carburizing by adding carbon, nitriding, by adding nitrogen, cyaniding; both by the addition of carbon and nitrogen and boronizing by adding borides [3]. Compared carburizing and nitriding, B. Selcuk, et all. [4], revealed that carbonitriding treatment is an effective surface hardening method for low carbon alloy steels; although boronizing is the most effective of the thermochemical treatments for all ferrous materials.

Recently, the salt bath cyanide treatment, also called liquid carbonitride, is preferred compared to the other conventional thermochemical methods used to improve the hardness and WR of steels, due to the circulation of molten salts that provides a uniform temperature in the whole component giving more uniform results with a low oxidation and decarburization surface; also presenting a good surface finish [5]. On the other hand, the cracks and distortions inherent in conventional heat treatment methods are eliminated through controlled cooling with molten salts. In particular, cyanide salt baths offer a workpiece change with a high rate of surface hardening, since carbon penetration is faster using this process [5].

Cyaniding is a kind of mixed carburizing and nitriding process, when the process is carried out at high temperatures, it approaches carburization and at low temperatures to nitriding. Therefore, it is divided into: cyaniding at low temperatures: 500-600 ºC, and high temperatures in the range: 800-950 ºC.

# Cyanide in salt bath Applied to ASTM A-517 Steel: Effects on Hardness, Wear and Microstructure

In this process, steels of medium and low carbon content, simple or alloyed are used, and it is carried out in a molten salt bath, which is a mixture of salts, whose composition is approx. as follows: 6% NaCN, 80% BaCl$_2$ and 14% NaCl, for the case that the temperature range is between 850-950 ºC. The main component of cyanide baths is the CN group, which favors the content of carbon and nitrogen in the surface layer, but not in its depth [6]. There are many research works regarding how to increase the surface hardness and the WR of the different grades of steels, using various thermochemical processes with various technologies that include carburizing, nitriding, gaseous nitriding, plasma nitriding etc, [3], [4], [5], [7], [8].

S.P. Ayodeji, et all, [9] conducted a study of Carbonirided in four types of steels: low carbon, medium carbon, low-alloy, and high-alloy. The treatments were carried out using a salt bath with high: 790-920 ° C, and soaking times: 30 - 120 min. The samples were cooled in different media: air, oil and brine. The results revealed that the surface hardness of steels treated by liquid cyanide is related to the temperature of the treatment and the quenching medium used. I. Ilerio et all [10], studied the behavior of AISI 8620 steel in dry abrasion with samples subjected to quenching - tempering, cyaniding and boronizing. The results showed that boronized AISI 8620 steel obtained a hardness of 800HV, the highest of all; followed by cyanide and quenchig - tempering, respectively. Boronized samples obtained the best resistance to abrasión. C. Bohórquez [11], carried out another study on austenitic nitrocarburizing of AISI 1020 and 8620 steels, applying traditional nitrocarburizing processes in structural profiles using alcohols and liquid nitrurants (urea and triethanolamine) to replace ammonia (NH$_3$). The advantage was the low or almost zero distortion of the profiles, with a significant increase in hardness, thus providing an alternative at lower cost. Thermochemical treatments are not always used in their traditional way. New technologies are currently being used on the basis of traditional methods. We can report on the studies of Z. Zhou, et. al [12], who proposed a new technology for low temperature salt bath cyaniding (575 ° C), additionally applying a direct current (DC) electric field, based on the traditional technique. It was found that by applying 7.5 V (DC), a 29 mm thick layer of compounds was obtained, much thicker, compared to the 18 mm layer obtained by the traditional method. The results showed that this new technique significantly improves the efficiency of the process by improving its tribological properties. A.P. García, et all, [13] studied the microstructural evolution of the surface of oxy-nitrocarburized AISI 304L stainless steel using a cyanide-free salt bath. The treatments were carried out at 600 °C from 5 to 60 min. The salt bath chemistry played a key role in the microstructural evolution of the observed surface. The simultaneous oxidation and nitrocarburization that occur during thermochemical treatments led to the formation of an outermost oxide compound layer under which an extensive nitrided diffusion zone developed. The composite layer was made up of intermixed crystals of the Fe$_3$O4, Fe$_3$C and ε-Fe$_3$N phases, as well as an innermost sublayer made up of spinel oxide FeCr$_2$O$_4$.

The present work aims to find the effects of surface hardening of low carbon and low alloy steels, subjecting them to a liquid cyanide process (salt bath), in the high temperature range (800-950 ° C), to which has taken Steel ASTM A-517 as a model, widely circulated in the metal mechanical sector.

## II. MATERIALS AND METHODS

### A. Study material

ASTM A-517 steel was used in the experiment, whose commercial name is: (CHRONIT T1 500), supplied by the company "Aceros Böhler del Perú". It was distributed with a pre-quenching - tempering (T&R) with hardness: (38.8-46.5) HRC. It is an alloy steel with good resistance to abrasion, impact and sliding wear [14]. Table I shows the chemical composition of the material.

**Table I. Chemical Composition of ASTM A-517 steel (% w) [14]**

| C | Si | Mn | Ni | Mo | Cr | V | Nb |
|------|------|------|------|------|-----|------|------|
| 0.30 | 0,50 | 1,80 | 0,80 | 0,50 | 1,0 | 0,08 | 0,05 |

### B. Experimental Procedure

### B1. Specimens

For both abrasive and adhesive wear, 27 specimens were prepared for each type of test corresponding to 4 temperature levels and 03 replicates for level.

For abrasive wear test, prismatic specimens, with dimensions: 1"x 3" x 5/16", were machined following the ASTM G-65 standard. For adhesive wear test, specimens in the form of a hollow ring were used whose dimensions were: outer diameter = 40 mm, inner diameter = 10 mm, thickness 20 mm; following the ASTM G-77 standard. A slight excess thickness was left in all the samples. the specimens are shown in Fig.1.
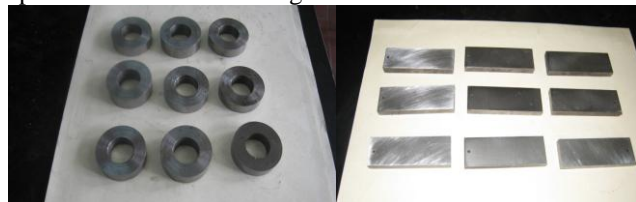


**Fig.1. Adhesive wear specimens (round) and abrasive wear specimens (plate)**

### B.2. Cyanide Treatment.

It was carried out in a muffle furnace in a salt bath according to the following composition:

**6% NaCN + 80% BaCl2 + 14% NaCl.**

This composition was determined following the recommendations established in the ASM Metal Handbook [15]. The salts were acquired in the powdered state, then they were placed in a stainless steel tank, and then placed in the oven until they are completely melted. Subsequently, the oven was closed until reaching the temperatures of the experiment: (**800- 850 - 900 - 950 °C**). These temperatures were selected, considering that it is a cyanide in a salt bath with high temperatures [15].

The soaking time was **03 hours,** for all temperature levels. After this time, the specimens were extracted and then quenched in oil and subsequently **tempered at 200 °C** for 30 min of permanence to eliminate residual stresses.

### B.3. Hardness Test

First, an average hardness was measured for the supply samples and then measurements were made for the cyanidated samples at their respective temperature levels. All tests were performed using the IDENTEC digital durometer, and measurements were taken on the Rocwell "C" scale (HRC). Before conducting these tests, the faces of the specimens had to be ground and polished to maintain tolerances for flatness and parallelism. After being rectified, sandpaper: 280, 360 and 600 were used, to then proceed to the measurement. Three replications were made in each indection and the average of the measurements was taken.

### B.4. Adhesive Wear Test

For the performance of the adhesive wear test, a parallel MHASA lathe was used with an Amsler-type coupled device that was mounted on the lathe, as shown in figure 2a). The load that must reach the contact point must be determined based on the loads located on the Amsler device by a ratio of moments.

The test was carried out under the block-on-ring configuration using a tungsten carbide plate as an abrader. The plate is the wear bar and the ring is the specimen to wear, as shown in Figure 2b).

Each test lasted 30 minutes, and in each of them a load of 90 N was applied, and a rotation speed of 355 rpm. As an abrader of 19x19x6.2 mm tungsten carbide prismatic plate with a hardness of 1800 Hv and 24.25 g of weight, was used.

Before the test, the specimens were cleaned to leave them free of foreign substances and thus make the correct measurement and record the initial and final weight. The final weighing after the test was carried out on an H. W. Kessell Analytical Balance, with 0.0001g precision.

### B.4.1. Adhesive wear test device

The TIMKEM device is based on the ASTM D2714 standard. This standard describes in detail an apparatus for sliding contact wear tests in the: plane - cylinder mode, the test method of which is explained in the same standard. All Amsler equipment, coupled with the specimen holder device, worked together on the horizontal lathe to carry out all the tests, as shown in figures 2a) and 2b).
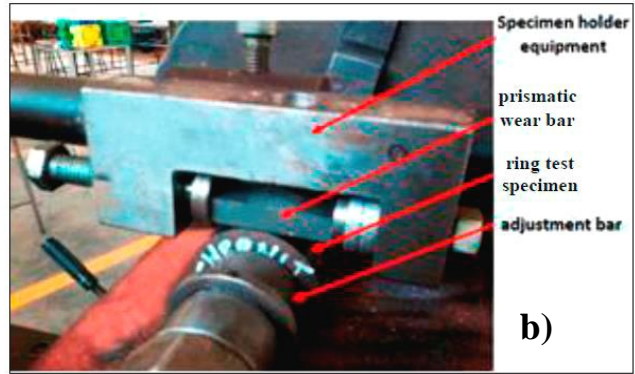
**a)**

**b)**

**Fig.2. Wear equipment coupled to the parallel lathe to perform adhesive wear tests; a) Amsler equipment installed on the lathe; b) Timken ASTM D2782 specimen holder device coupled to Amsler equipment indicating how the tests are performed.**

### B.5. Abrasive Wear Test

It was done under a standardized dry test with a rubber wheel and sandblasting, whose specifications are given by the ASTM G65 standard, where the loss of mass was the parameter that was measured. The procedure was done with the rubber wheel rotating at a speed of 200 rpm, applying a load of 130N per counterweight.

A medium grain size AFS 30/50 (300–600 mm) silica flow was used on the wear surfaces at a flow rate of approximately 310 g / min. The total test time was 30 min.

### B.6. Wear measurement

The direct way that wear is measured is in units of lost volume (mm3) based on any parameter; which allows to compare materials with different densities. It is directly measured by mass loss, linear measurement, or wear area. In the present study, it has been adopted to measure wear due to loss of mass. The specimens were weighed before and after the tests, and the change in mass was determined with the difference in weight. The measurement of the loss of mass for each test, both adhesive and abrasive, was carried out on the H. W.

KESSELL analytical balance, 0.0001 gr. precision.

### C. MICROSCOPY TESTS

It was made transversely, after removing the lateral hard layer to be able to observe the thickness of the radial or peripheral layer, its microstructure and the matrix. The specimens were encapsulated with epoxy resin for polishing, starting with sandpaper 280, up to 2000 and then passing through a cloth with alumina up to 0.1μ. Then they were etched on the polished surface, with 3% Nital reagent, to proceed with the metallographic analysis and take the necessary photos. The ZEISS 1000X microscope will be used for developing the photos.

## III. RESULT AND DISCUSSION

### A. Hardness

Hardness results are shown in table II and in the comparative graph of Fig. 3. It can be seen that the hardness values are decreasing as the cyaniding temperature increases.

The maximum hardness (63.50 HRC) is found for samples cyanide at 800 ° C and the minimum: (61.5 HRC), for cyaniding samples at 950 °C.

The decrease in hardness does not follow a constant rate. Thus it is noted the following: In the entire temperature range (800-950 °C) the hardness decreases by 2.4 HRC, which represents a fall of 3.7% between these two values, but with respect to the state of supply (T&R) hardness decrease 7.2 HRC; representing a fall of 11.3%.

In the range (800-850 ° C), the hardness only decreases by 0.5 HRC; in other words, it almost remains constant. The same happens in the interval 900-950 ° C where the decrease is 0.4 HRC; almost constant. However, in the range: 850-900 ° C a more appreciable drop is observed (1.5 HRC). From the previous results, it can be observed that the cyanide temperature itself increases hardness a little, within the study temperature range under a constant immersion time of 3 hrs. But if these values are compared with the hardness that the material brings in the supply state (T&R), it is observed that the cyanide treatment increases the surface hardness of the material significantly, reaching up to 11.3%. This phenomenon can be explained based on the diffusion that occurs in the process, which in turn depends on time and temperature. If the time is kept constant, the temperature in itself, can give rise to unexpected structures.

Table II shows that the surface hardness of the cyanide samples in all the treatments had close or similar values. This is due to the fact that on all the surfaces of the cyanided layers they presented an appropriate microstructure, either with the presence of massive carbides or tempered martensite and carbides as shown in table 6. However, in all the treatments it is observed that the hardness it is significantly increased compared to the samples in the supply state.

**Table II. Surface hardness in ASTM A-517 steel samples, subjected to liquid cyanide treatment with different temperatures.**

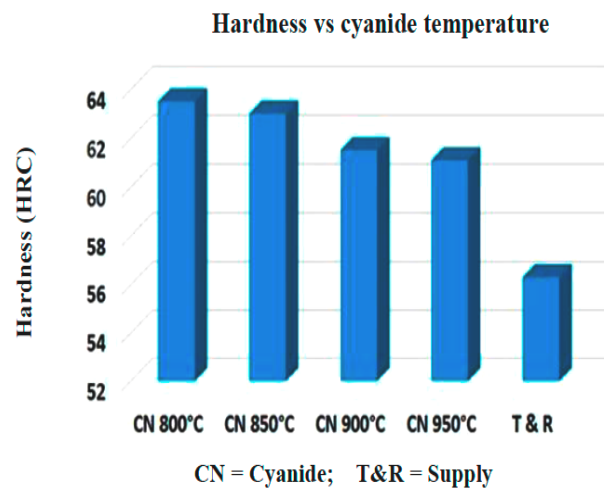| Test T° Cyanide | Cyanide surface | | | Matrix |
|---|---|---|---|---|
| | Hrc (1) | Hrc (2) | Hrc(Pr) | Hrc |
| 800°C | 63,00 | 64,00 | 63,50 | 45,50 |
| 850°C | 62,50 | 63,50 | 63,00 | 45,00 |
| 900°C | 62,00 | 61,00 | 61,50 | 41,10 |
| 950°C | 61,50 | 60,7 | 61,1 | 39,80 |
| supply | 57,00 | 55,60 | 56,3 | ------ |



**Fig. 3. Hardness graph for samples obtained with different cyanide temperatures. T&R (supply) is for reference only.**

**B. Adhesive Wear.**

The adhesive wear results are found in Table III as a function of mass loss. Figure 4 shows a graph of the evolution of adhesive wear with the treatment temperature as a function of the average mass loss. In Figure 5, a trend curve is observed considering all the tests, observing that the adhesive wear presents oscillating values of the approximately sinusoidal type. Furthermore, it is observed that for almost all the tests the loss of mass is much lower than for the samples in state of supply (T&R). In other words: The liquid cyanide in this material increases its resistance to adhesive wear. It is also observed that in some cases the loss of mass is very considerably with respect to the material supplied. In any case, the advantage of the liquid cyanide treatment over conventional T&R is noted.

**Table III. Results of adhesive wear tests of cyaniding samples of ASTM A517 steel**

| Ensayo | 1 | | | 2 | | | 3 | | | Promedio ΔP (mg) |
|---|---|---|---|---|---|---|---|---|---|---|
| T° | Pi (g) | Pf (g) | ΔP (mg) | Pi (g) | Pf (g) | ΔP (mg) | Pi (g) | Pf (g) | ΔP (mg) | |
| 800 °C | 73.4365 | 73.4318 | 4.7 | 76.1832 | 76.1761 | 7.1 | 75.6662 | 75.6581 | 8.1 | 6.63 |
| 850 °C | 76.2712 | 76.2672 | 4,0 | 76.1827 | 76.1795 | 3.2 | 73.3433 | 73.3395 | 3.8 | 3.67 |
| 900 °C | 73.5025 | 73.4976 | 4.9 | 75.6965 | 75.6913 | 5.2 | 75.2493 | 75.2406 | 8.7 | 6.27 |

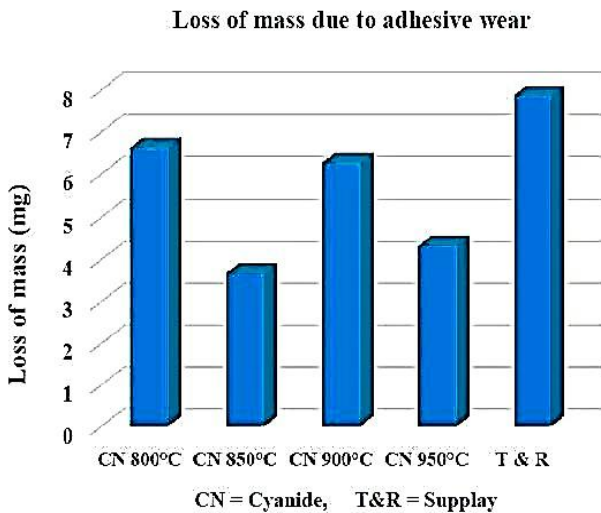| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **950 °C** | 75.7954 | 75.7916 | 3.8 | 75.6836 | 75.6781 | 5.5 | 73.5935 | 73.5898 | 3.7 | 4.33 |
| **T&R** | 76.2692 | 76.2633 | 5.9 | 76.6675 | 76.6583 | 9.2 | 76.7746 | 76.7661 | 8.5 | 7.87 |



**Fig.4. Bar graph illustrating the variation of average adhesive wear loss as a function of cyanide temperature.**

From the results it is observed that the loss of mass is not directly related to the increase in cyanide temperature. Its values are oscillating with temperature. For cyanidated samples, it was found that the maximum mass loss: $\Delta P = 6.63$ mg corresponds to cyanide samples at 800 °C; and the minimum: $\Delta P = 3.67$ mg, corresponds to cyanide samples at 850 °C. Therefore, it follows that the maximum decrease due to loss of mass: $\Delta P = 6.63 - 3.67 = 2.96$, represents a reduction of 44.6% for these extreme values; difference due exclusively to a change in process temperature. Then, for a cyanide in a salt bath at high temperature, it is recommended to do it at 850 °C, to obtain the highest resistance to wear of this material, as long as the process time remains constant.

If we take into account the samples in the state of supply (T&R), the data and graphs indicate that over the entire temperature range, cyanide samples have greater resistance to adhesive wear than samples with T&R. It is also observed that if we compare the mass loss of the cyanide samples at 850 ° C with respect to the T&R we have a mass loss: $\Delta P = 7.87 - 3.67 = 4.2$ mg; which represents a 53% greater wear resistance compared to the samples in the supply state (T&R), resulting in a considerable increase in the wear resistance due to the treatment.

The samples with wear resistance closest to the T&R, are the samples treated with temperatures of 800 ° C and 900 ° C, which would not be recommended temperatures for this purpose. It is inferred that to obtain optimum resistance to adhesive wear, the cyanide of the material must be carried out at a temperature of 850 °C.
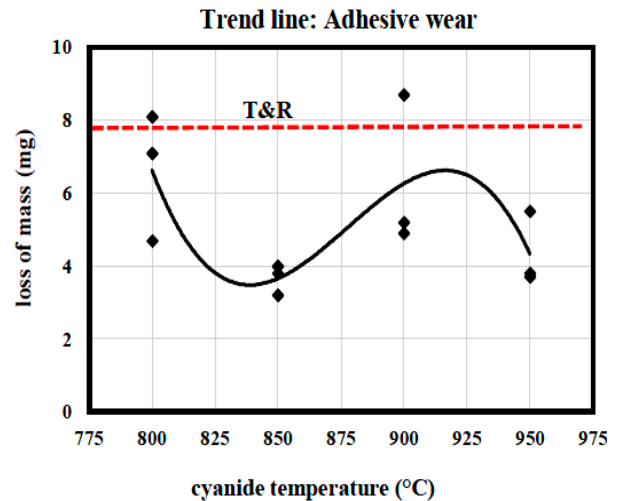


**Fig.5. Graph illustrating the trend curve of adhesive wear mass loss as a function of cyanide temperature.**

**C. Abrasive Wear.**

The results of abrasive wear are observed in table IV and their respective trend graphs in figures 6 and 7. From these results it is observed that, as in the previous case: The loss of mass is not related to the increase in temperature cyaniding; their values are oscillating.

As shown above; the increase in temperature increases the hardness, but not the resistance to wear that goes up and down, even though the layer of compounds increases. However, a higher layer thickness does not mean that it results in greater resistance to both adhesive and abrasive wear. This will be discussed later when the results of microscopy tests are shown, where the results can be justified based on the structures formed in the compound layer.
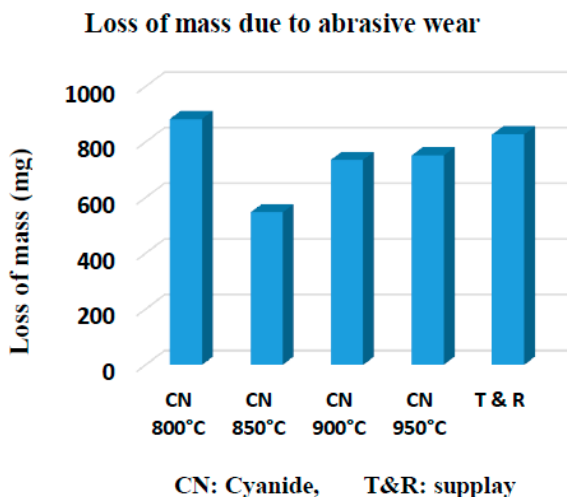
**Table IV. Abrasive wear test results of cyanide samples of ASTM A517 steel**

| **Test** | **1** | | | **2** | | | **3** | | | **Average $\Delta P$ (mg)** |
|---|---|---|---|---|---|---|---|---|---|---|
| **T°** | **Pi (g)** | **Pf (g)** | **$\Delta P$ (mg)** | **Pi (g)** | **Pf (g)** | **$\Delta P$** | **Pi (g)** | **Pf (g)** | **$\Delta P$** | |
| **800 °C** | 114.0177 | 112.8033 | 1214.4 | 115.1213 | 114.5558 | 565.5 | 115.6107 | 114.7418 | 868.9 | 882.93 |
| **850 °C** | 116.3282 | 115.8466 | 481.6 | 114.0302 | 113.8175 | 212.7 | 115.1227 | 114.1769 | 945.8 | 546.70 |
| **900 °C** | 114.3024 | 113.2784 | 1024.0 | 115.2409 | 114.3863 | 854.6 | 114.2092 | 113.8787 | 330.5 | 736.37 |
| **950 °C** | 115.8781 | 115.1512 | 726.9000 | 113.9828 | 113.1411 | 841.7 | 115.6104 | 114.9228 | 687.6 | 752.07 |
| **T&R** | 114.8582 | 113.8471 | 1011.1 | 113.8553 | 112.9842 | 871.1 | 115.5142 | 114.9148 | 599.4 | 827.20 |

Loss of mass due to abrasive wear

**Fig.6.** Graph that illustrates the variation of the loss of mass due to abrasive wear as a function of the cyanide temperature.

The maximum mass loss: $\Delta P = 882.93$ mg, corresponds to samples cyaniding at 800 ° C and the minimum $\Delta P = 546.70$ mg, for samples cyaniding at 850 °C. Therefore, the maximum decrease due to loss of mass: 336.23 mg represents 38% of the total; then, samples cyaniding at 850 °C have the highest resistance to abrasive wear, and those cyaniding at 800 °C the least. Therefore, for high temperature cyanide it is recommended to do it at 850 °C; as long as, the process time is constant (3hrs). Likewise, the values shown indicate a decrease in resistance to abrasive wear of 38% due only to the change in process temperature.

Comparing the results with the samples in the state of supply (T&R) we have the following relationships: 1) Maximum mass loss with respect to the T&R: $\Delta P = 882.93 - 827.2 = 55.73$ mg (6.5%), which means that the increase in resistance to cyanide abrasive wear for this material is not very high compared to the supply. 2) According to fig. 7 it is observed that throughout the entire temperature range, cyanide samples are not always more resistant to abrasive wear than T&R samples. If you look at fig. 6, samples cyaniding at 800 °C, are less resistant to abrasive wear than samples with T&R, and samples treated at 900 and 950 °C also show a value closer to samples in the as-delivered state. You can say; that for this material in the study temperature range, the cyanide process, under constant time (3 hr), does not increase the resistance to abrasive wear as the temperature increases; even in some cases, such as samples cyaniding at

800 °C, it has values close to those with T&R, but in other cases it is significant; as is the case with cyanide samples at 850 °C. The reason for these results is probably attributed to the carbon content (0.30%); due these treatments are recommended to be applied to low carbon steels up to 0.25% C; but it must be taken into account that the manufacturer supplies this steel in a reduced form; that is, with a pre-quenching and tempered (T&R) for direct use on parts subject to wear.

The intention of the treatment proposed in this research was, to increase the resistance to abrasive wear that the material brings with itself, to provide it with more demanding applications, such as earth removal in the mining industry, etc. In this sense, it has been possible to significantly increase abrasive wear compared to T&R, but for certain specific temperatures (850 °C) as shown in Fig. 6., where resistance to abrasive wear is quite significant.
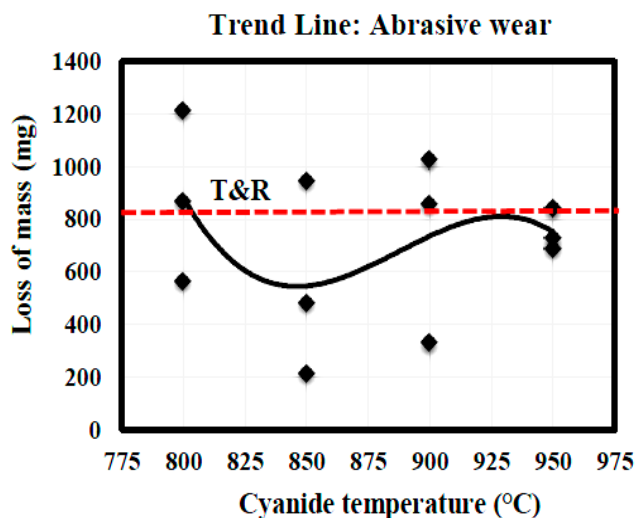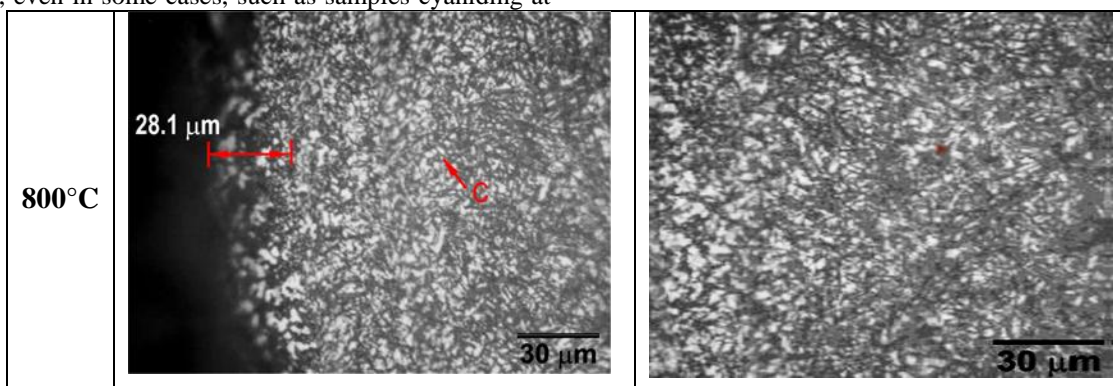


**Fig.7.** Graph illustrating the trend curve of abrasive wear mass loss as a function of cyanide temperature.

The results obtained are in agreement with the studies of K.H. Zum Gahr, who states that the intensity of abrasive wear depends on the ratio of the hardness of the abrasive used to the hardness of the worn surface [16]. Furthermore, the abrasive particles can be the roughness of the surface itself or the product of their wear; that tend to cut and / or tear material from the surface [17], [18], [19], [20].
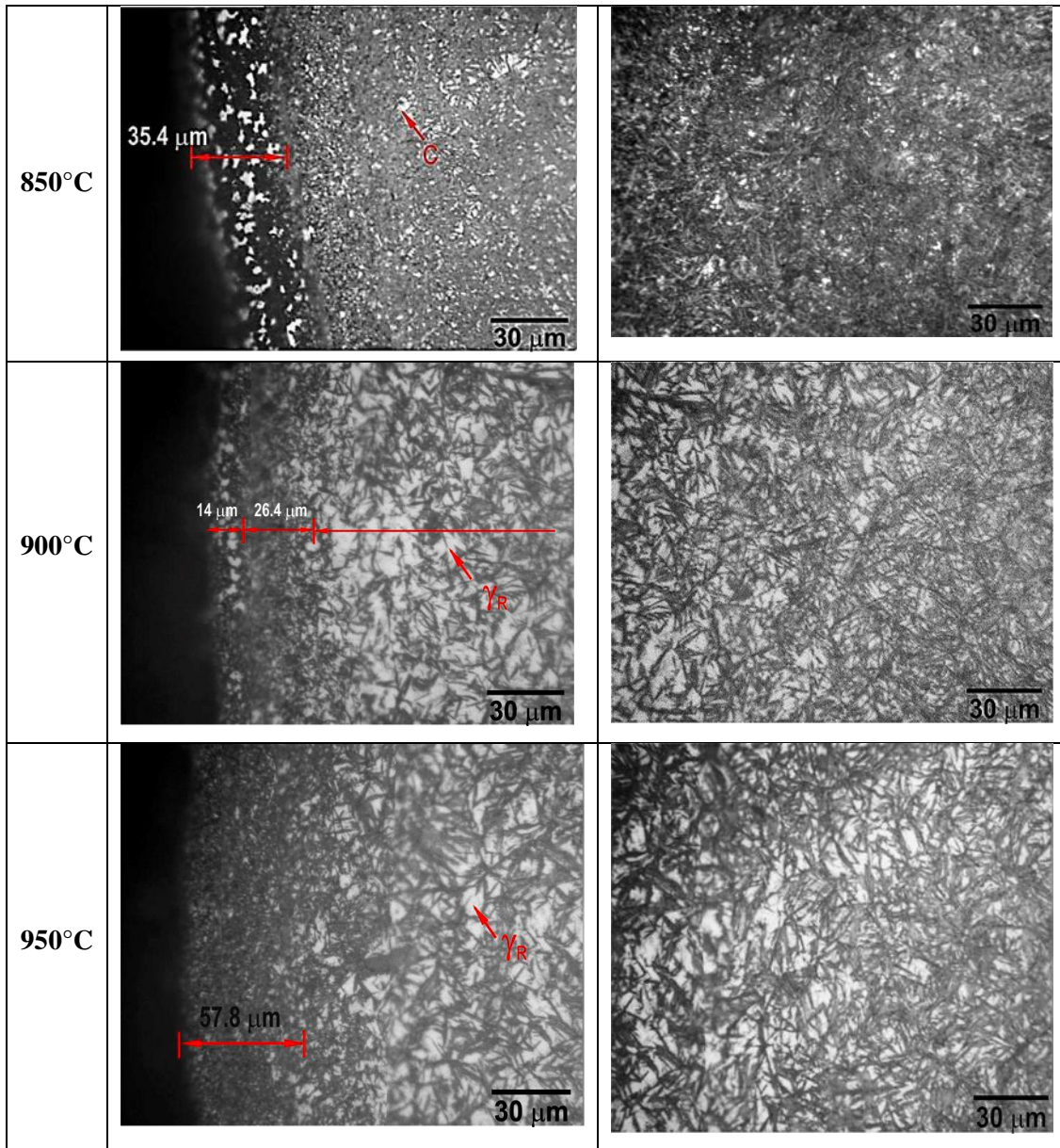
**Fig.8. Microstructures of cyanide samples at experiment temperatures. On the left, the hard layer or zone of compounds is observed, indicating the average thickness of each one of them. The corresponding diffusion zone is shown on the right. [ $\gamma_r$ = retained austenite; C = Carbides]**

## A. Microstructure.

Figure 8 shows the microstructures of the samples for the four selected temperatures. The figures on the left show the structure of the composite layer with their respective thicknesses, and those on the right show the diffusion zone. The average thickness indicated for each layer corresponds to the sum of the three sublayers that are formed in the process. The hard outer layer is shown to the left of Figure 8 and the diffusion zone is shown to the right of each ones.

The technique used for the measurement of sublayers is shown in Fig. 13, and the results of the measurement of the layer thicknesses are shown in Table 5, from which the graphs of Figures 9-12 are derived. Fig. 9 reports that the thickness of the layer increases as the treatment temperature increases. A drastic drop in surface hardness is also observed, at a layer thickness of 250 μm.

**Table 5. Cyanide layer thickness measurements as a function of temperature. The measure includes the three sublayers formed before reaching the core.**

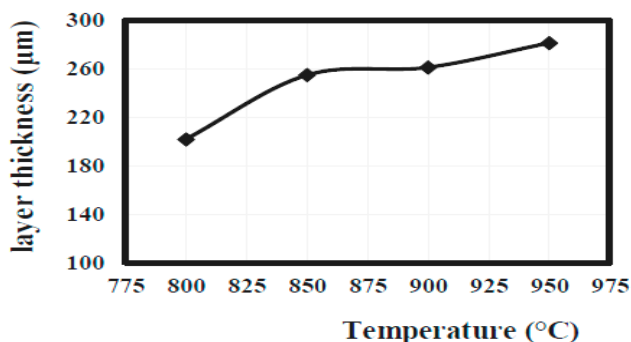| Temperature | Measurements (µm) | | Average layer thickness (µm) |
|---|---|---|---|
| | 1 | 2 | |
| **800 °C** | 203,5 | 200,7 | 202,1 |
| **850 °C** | 248,5 | 261,7 | 255,1 |
| **900 °C** | 266,7 | 256,4 | 261,5 |
| **950 °C** | 289,5 | 274,0 | 281,7 |

**Fig. 9. Graph showing the relationship between cyanide temperature and the thickness of the layer formed.**
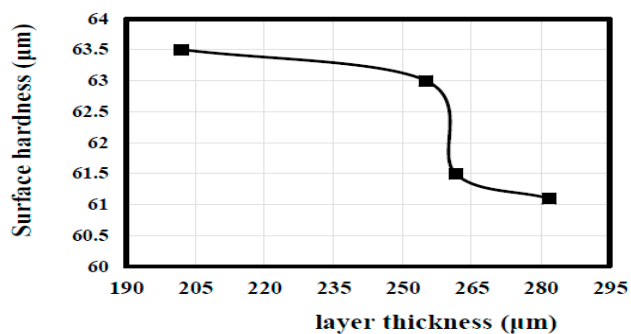


**Fig.10. Graph showing the relationship between layer thickness and surface hardness obtained by cyanide.**

In Fig. 10, it can be seen that for the two types of wear, the loss of mass is minimal for the samples with a layer thickness of approx. 250 μm; which corresponds to samples cyaniding at 850 ° C, that is, the best wear resistance in both cases will be found in samples cyaniding at 850 °C.
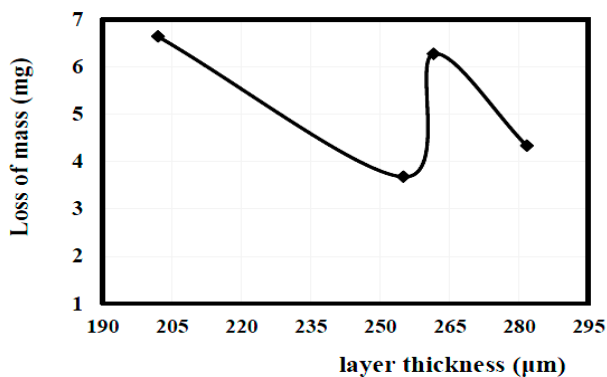


**Fig. 11. Graph showing the relationship between layer thickness and loss of mass due to adhesive wear**
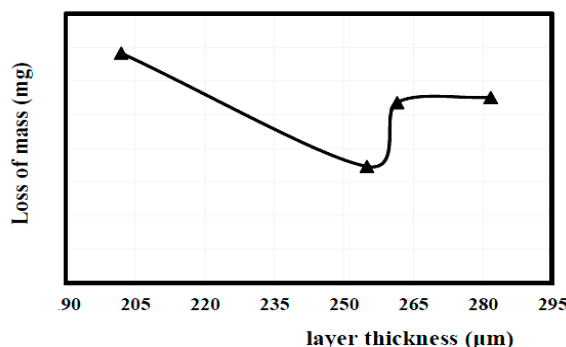


**Fig 12. Graph showing the relationship between layer thickness and loss of mass due to abrasive wear**

Observing the graphs of figures (9 -12); Table 5, and taking into account the microstructures of Fig. 8 we can infer the following:

The cyanided specimens in the range of 800 - 900ºC, during their treatment were in the intercritical range A1 - Acm (for the cyanide layer); This caused the structure of its massive cementite layer to be present.

The cyaniding specimens at 800 and 850ºC, presented a minimum amount of retained austenite. The low presence of austenite retained in the cyanide layer is due to the fact that at these temperatures the carbon potential is lower, which does not drastically decrease the Ms and allows obtaining a structure with a high martensite content after quenching than with tempering. it will transform into tempered martensite.

The cyanided specimens at 900 and 950ºC, presented a high amount of retained austenite; because a higher cyanide temperature (coupled with the average carbon content of the steel) caused the cyaniding layer to present more carbon content on the subsurface, lowering the temperature Ms, and generating after hardening the appearance of retained austenite.

**Table 6. Measurements in the cyanide layer for the different cyanide temperatures and properties obtained: [Cm = massive cementite]; [MR + C = tempered martensite and carbides]; [MR + C + $\gamma_R$ = tempered martensite, carbides and retained austenite].**

| T° de cianurado | Dureza Promedio (HRC) | Peso Promedio (mg) | Réplicas | Mediciones en micrones (μm) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Cm | MR + C | MR + C + $\gamma_R$ | Medida Total |
| 800ºC | 63.5 | 6.63 | A | 28.1 | 175.4 | | 203.5 |
| | | | B | 28.5 | 172.2 | | 200.7 |
| 850ºC | 63.0 | 3.67 | A | 35.4 | 213.1 | | 248.5 |
| | | | B | 36.4 | 225.3 | | 261.7 |

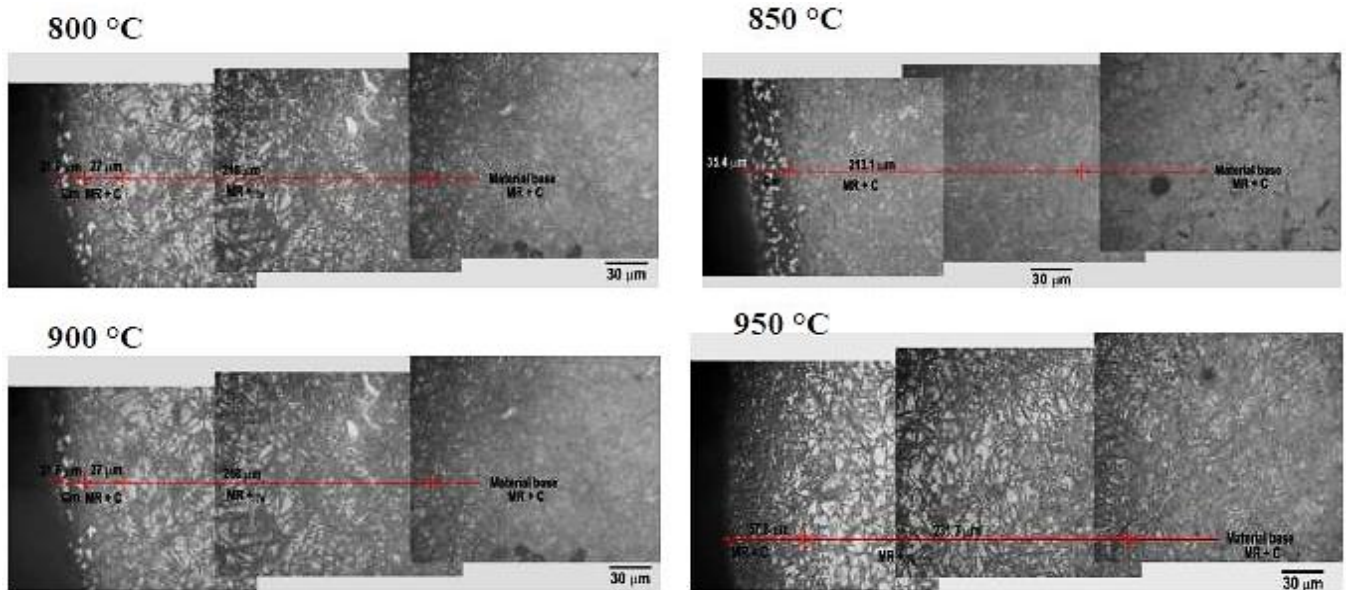| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **900ºC** | 61.5 | 6.27 | A | 21.6 | 27.1 | 218.0 | 266.7 |
| | | | B | 14.0 | 26.4 | 216.0 | 256.4 |
| **950ºC** | 61.1 | 4.33 | A | | 57.8 | 231.7 | 289.5 |
| | | | B | | 53.5 | 220.5 | 274.0 |



**Fig. 13. Superimposed photomicrographs to determine the penetration depth of the carbonitrided hardened layer at different temperatures. The zones and thicknesses of the sublayers are shown. Nital 3%.**

The presence of retained austenite inside the cyanide layer, and not on the surface, is a product of the carbon profile that forms through the layer during the liquid cyanide treatment and the direct quenching treatment from temperatures of 900 and 950 °C.

The specimens that were carburized at 950ºC, did not present massive cementite on their surface, this due to the fact that the temperature was above Acm, for the cyanide layer.

The specimens that were cyanide at 950ºC, did not present massive cementite on their surface, this because the temperature was above Acm, for the cyanide layer.

However, in the specimens treated at 800ºC, the size of the [Cm + (MR + C)] layer was smaller than for the specimens treated at 850ºC. Likewise, the specimens treated at 900 and 950ºC, although they present a surface layer of [MR + C], underneath it, they present a wide layer of [MR + C + $\Upsilon_r$] with a high content of retained austenite with low properties to the wear. The above mentioned would explain the wear behavior observed in these specimens.

According to the results obtained, the microstructure of the cyanide layer more appropriate for its resistance to wear, is presented by the cyanide specimens at 850ºC, with a layer composed of: [$C_m$+( MR + C)].

## IV. CONCLUSION

The effects of cyanide in a salt bath on the hardness and wear of ASTM A-517 medium carbon steel have been studied. The conclusion can be summarized in the following points:

1. The surface hardness of the cyanide samples does not follow a regular trend, but it does have close or similar values, but with respect to the T&R samples they are up to 11.3%

2. The maximum resistance to both adhesive and abrasive wear was obtained with the cyaniding samples at 850 °C. For adhesive wear, the mass loss was: 2.1 times greater than for T&R and for abrasive wear it was 1.5 times greater.

3. Microstructure of the cyanide layer more appropriate for wear resistance, is presented by the samples cyaniding at 850ºC, with a layer composed of massive cementite; tempered martensite, and carbides.

4. It is concluded: when applying the cyanide treatment in a salt bath to the ASTM A-517 steel, it should be done at 850 °C, to optimize the indicated properties.

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