Study the (Wear, Roughness, Micro hardness) of the Electroplated Layers on Low Carbon Steel Improved by Shoot Penning

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ABSTRACT

In this study an electroplating method has been employed (with zinc, nickle). Studying of mechanical, surface, metallurgical properties for each coated systems and made a comparison among them and with shoot penned coated systems. Low carbon steel alloy has been selected as a substrate. Studying of specified properties including coating thickness and dry corrosion properties (oxidation at high temperature) and comparison the results of each treatment with other treatment results. Coated samples with nickel and zinc by electroplating methods are used in order to compare among the resulting coating layer properties. Shoot penning method also has been employed to the two coatings in order to determine the compression residual stresses role in the variation of studied properties. Results showed that nickel coating layer has higher oxidation resistance than zinc coating layer at high temperature, but has lower roughness, micro hardness, wear resistance and density. Microstructure inspection results showed ferrite- pearlite phases in the treated samples for all coated systems, This ensures that this treatment will not subject to any phases transformation, and formation of coating layer with a different thickness as illustrated by micro structure images.

Keywords: Shoot penning, Electroplating, Zinc, Nickel, Low Carbon Steel.

دراسة (البليان،الخشونة،الصلادة الدقيقة) لطبقات الطلاء الكيميائي الكهربائي على سبيكة الصلب منخفض الكربون المطورة بالقصف بالكريات الفولاذية

الخلاصة

في البحث الحالي تم توظيف طريقة الطلاء الكيميائي- الكهربائي(بمعدني النيكل والخارصين). وذلك لغرض دراسة الخواص السطحية والطورية والميكانيكية لكل طلاء ومقارنة نتائج كل معاملة بعد أجراء القصف بالكرات الفولاذية .وقد تم اختيار سبيكة الصلب منخفض الكربون كمادة أساس و تمت دراسة الخواص المحددة متضمنة سمك الطلاء وخواص التآكل الجاف (الأكسدة) عند درجات الحرارة العالية ومقارنة نتائج كل معاملة مع نتائج المعاملات الأخرى. تم استخدام الطلاء بالنيكل والخارصين بطريقة الطلاء الكيميائي- الكهربائي للمقارنة بين طبقات الطلاءالمنجزة.

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وكذلك تم توظيف طريقة القصف بالكرات الفولاذية لكلا الطلاءين وذلك لتحديد دور الإجهادات المتبقية الضغطية في تطوير الخواص المدروسة، وقد بينت النتائج أن طبقة الطلاء بالنيكل تمتلك مقاومة للأكسدة أفضل من طبقة الطلاء بالخارصين في درجات الحرارة العالية،بينما تكون خواص الخشونة، الصلادة الدقيقة، مقاومة البلى ،الكثافة بقيم أقل .كما أوضح فحص البنية الدقيقة ظهور طوري الفرايت والبرلايت في العينات المعاملة مما يؤكد أن هذه العملية لا تؤدي إلى إحداث تغيرات طوريه، وأظهرت تكون طبقات طلاء بأسماك مختلفة ظهرت في صور البني الدقيقة.

INTRODUCTION

Electroplating is an electrodeposition process for producing a dense, uniform, and adherent coating, usually of metals or alloys, upon a surface by the act of electric current.[1] The coating produced is usually for decorative and, or protective purposes, or enhancing specific properties of the surface. The surface can be a conductor, such as metal, or nonconductor, such as plastics. Electroplating products are widely used in many industries, such as automobiles, ships, air space, machinery, electronics, jewelry, defense, and toy industries. The core part of the electroplating process is the electrolytic cell. In the electrolytic cell a current is passed through a bath containing electrolyte, the anode, and the cathode. In industrial production, pretreatment and post treatment steps are usually needed as well.[2]

Electroplating is achieved by passing an electrical current through a solution containing dissolved metal ions and the metal object to be plated. The metal object serves as the cathode in an electrochemical cell, attracting metal ions from the solution. Ferrous and non-ferrous metal objects are plated with a variety of metals, including aluminum, brass, bronze, cadmium, copper, chromium, iron, lead, nickel, tin, and zinc, as well as precious metals, such as gold, platinum, and silver. The process is regulated by controlling a variety of parameters, including the voltage and amperage, temperature, residence times, and the purity of bath solutions.[3]

The process of electroplating takes place as metals in ionic form move from a positive to negative electrode. An electric current passing through the solution causes objects at the cathode or work piece to be coated by the metal in the solution.[4] Electroplating is done for many reasons, usually to beautify, insulate or to protect and to increase the corrosion resistance, conductivity of metal objects. Plating protects by one of two ways, either sacrificially or mechanically. Zinc and cadmium protect the base metals they cover sacrificially.

They are more reactive to corrosion than iron or copper alloys so they corrode first, before the base metals. Copper, nickel, chromium and most other metals protect the base metals mechanically. They protect the base metals by forming a protective coating; therefore the protection is good only as long as that coating is intact. If there is defect or break in the protective coating the base metal will corrode before the plating. The most common metals used in plating are copper, nickel, gold, silver, chromium, zinc and tin [5]. For over a century, zinc has enhanced the longevity and performance of steel. Zinc coatings provide the most effective and economical way of protecting steel against corrosion. Zinc-coated or galvanized steel offers a unique combination of high strength, formability, light weight , corrosion resistance , beautifulability , recyclability , low cost. That is not obtained by any other material. For this reason, galvanized steel sheet is an ideal material for a multitude of building and manufacturing applications - from automobiles to household appliances to residential. [6] Nickel Plating, is a yellowish white, hard, reflective finish used for wear resistance, solderability, or dimensional restoration. Nickel plating often used over copper or under chromium for a decorative finish. Nickel is a very hard metal with poor ductility, therefore parts that to be plated by nickel should be bent into their final shape before plating whenever possible. Nickel should be plated on copper before gold plating to reduce the corrosion or darkening of the gold [7].

Plastic deformation due to cold work (shoot penning) causes changes in material density (a rise in volume to approximately 0.3 to 0.8) [8], correlated to the rise of compressive stresses. Plastic stretching of the superficial layer by forces of friction and by machining chips also causes the formation of compressive stresses. Residual stresses caused by mechanical factors are sometimes termed as mechanical residual stresses; the stresses are compressive if the specific volume is increased and tensile is decreased. In turn, all volumetric changes within the volume of a given component are accompanied by changes in neighboring zones [9]. Residual stresses in the superficial layer usually occur in texture zones, plastic deformation, and elastic deformation, but it is in the textured zone that they assume their highest values. Their distributions and values depend on the type of material and its three-dimensional and metallographic structure, on strength and thermal characteristics, on external factors (e.g., rate of heat extraction) and on the associated strain-hardening of the superficial layer, as well as on wear deformation. [8].

EXPERIMENTAL PROCEDURES

The substrate material used for the investigation was a low carbon steel with a nominal composition as in table (1). Specimens were cut to dimensions of approximately (10× 20, 10×10 , 4×10) mm and then manually ground using SiC abrasive paper to a 600-grade finish. The specimens were then degreased before being coated by electroplating with the selected two metals (nickel, zinc), The coating times reported were the holding times at coating temperatures. For zinc coating the hydrochloric acid was used HCl (30%) and doped for (20gm\lit zinc) sodium cyined (50gm/lit.), sodium carbonate (100 gm/lit.) sodium cyanide- zinc ratio (2.5 gm/lit, sodium hydroxide (110 gm/lit). For nickel coating boric acide (40 gm/lit), nickel sulfate (240 gm/lit), nickel chloride (18.20 gm/lit). Another set of the coated specimens were surface treated by shoot penning for 15min.,The hardness values were measured using a micro –hardness testing device with 100gm load and a profile will give, wear resistance values were measured using pin on disc wear testing device and the wear rates was obtained , roughness to the surfaces of samples were measured by roughness tester ,Microstructure of the cross section of the coated specimens was analyzed using optical microscopy (OM) (Hitachi S-2400). Dry cyclic oxidation test was made by the variation in specific weight after coated samples were subjected to a thermal cycle in a furnace for (1hr.) by running different temperatures (250,350,450,550,650)^{o}C ,and weight gain curves were drawn by using sensitive balance with four digit accuracy . The thickness of the electroplated layer was estimated from element concentration depth profiles measured by optical microscopy.

RESULTS AND DISCUSSIONS

From the observation of external appearance for the treated systems, we can notice that the coating process was successful (so the coating layer will appear uniform and have a good external appearance. From the results of micro hardness Vickers test type , observation of an increment in its values as illustrated in figures (1) and (2) .The formation of hardness profile which indicates variation in hardness at the sample edge ,improvement for the zinc coated systems ,this will attributed to role of hard phases like zinc compounds, also for shoot penning treatment the hardness will be increased as a result of residual compressive stresses role , this behavior is correlated with mind of **Mozley**[11] when he was achieved very interesting results by penning hard steel, Without preening, Rockwell C reaches about 42 hardness." of un peened parts, while of penned parts increases to 53.6. Nickel systems were showed a drop in hardness as a result of low hardness of nickel coating layer.

From the observation of wear results in figs. (3,4) ,all the selected nickel and zinc electroplating treatments improve wear resistance and decreasing the weight loss in wear test. This does attribute to the formation of hard surface for zinc coated systems, and the sliding effects – ((low friction coefficient)) - for nickel coated systems. This behavior was correlated to microstructure images which demonstrates the successful establishment of the coating layer as a thick layer for the two selected metals (nickel ,zinc), all these lead to increase in resistance and reduction in wear rate . This behavior was illustrated in fig. (3) which showed a decrement in weight loss to the coated systems, Also fig. (4) gives the wear rate which ensures the above behavior, zinc coated system illustrates optimum improvement in wear resistance, the penned zinc coated systems was attained the optimum improvement ,this will be correlated with **Tarasov and Grover** [12] when they will be studied the Effect of Grinding and Other Finishing Processes on mechanical properties of Hardened Steel springs, they will be concluded that without peening, these springs had a very low fatigue life, wear resistance ; with penning they lasted longer than penned springs of the highest commercial hardness in conjunction with improved wear resistance.

The second improvement degree is for shoot penned surfaces of as received alloy – (without coating)-, but nickel coated systems has the lower values.

From the observation of roughness results in fig. (5), the two selected electroplating treatments, and shoot penning caused decrease in roughness. This will be attributed to the formation of new coating layer and give low surface roughness as illustrated in fig (6) ,the decrease in roughness can be assist the improvement in surface mechanical properties ,this was correlated with **Almen** [13] when he will be studied fatigue loss and gain by electroplating ,he showed that landing-gear parts, are chrome plated after shot penning so that cracks which form in the chrome do not propagate into the steel and cannot harm fatigue life of the part, this was distinguished the importance of roughness effect on the surface mechanical properties . Also fig. (5) Illustrates that nickel coated systems have lowest roughness values. From fig. (7) it is shown that the coating density for all the selected treatments were decreased, this will attributed to the formation of a new layer having a low density than the substrate material .But shoot penning treatment increased density values ,this will be attributed to the role of compressive residual stresses and compacting effect .

From the results of cyclic oxidation shown in fig. (8) , it is concluded that all the selected electroplating treatment increased oxidation resistance . This is attributes to the formation of a new stable ,high adhesion oxide layer which prevents the oxygen from passing to the coating layer and contacting to the original substrate that protect the original surface of metal substrate . The same figure shows that the increase in temperature is leading to the decrement in weight gain; this will be attributed to the increase in spilling and tearing of coating layer at higher temperatures.

From microstructure, coating layer thickness was measured, this was illustrated in table. (2). All coated systems give an observation of ferrite, pearllite in core of any tested samples, that will be established a little carbon percent and absence of any phase transformation.

CONCLUSIONS

1. Nickel electroplated system have better wear properties than the substrate, this in conjunction with low roughness and high sliding effect.
2. Zinc electroplated system have better wear properties than the substrate, this in conjunction with hardness increment.
3. Zinc electroplated system has micro hardness higher than the substrate but nickel coated system illustrate lower values.
4. Electroplated coated systems have lower roughness than the shoot penned and the as received conditions, this in conjunction with wear resistance improvement.
5. The increase in oxidation temperature showed a sever effect on the coated system.
6. Lower roughness of electroplated coated systems make ensures that these coating layers have a high uniformity.

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Table(1) chemical composition of selected low carbon steel alloy.

Elements	*Weight percentage*
C	0.197
Si	0.186
S	0.025
P	0.006
Mn	0.564
Ni	0.100
Cr	0.270
Mo	0.017
Cu	0.198
W	-0.011
Ti	-0.000
Sn	0.006
Co	0.009
Al	0.005
Pb	0.003
Zr	0.002
Mg	0.001
Zn	0.005
Fe	98.407

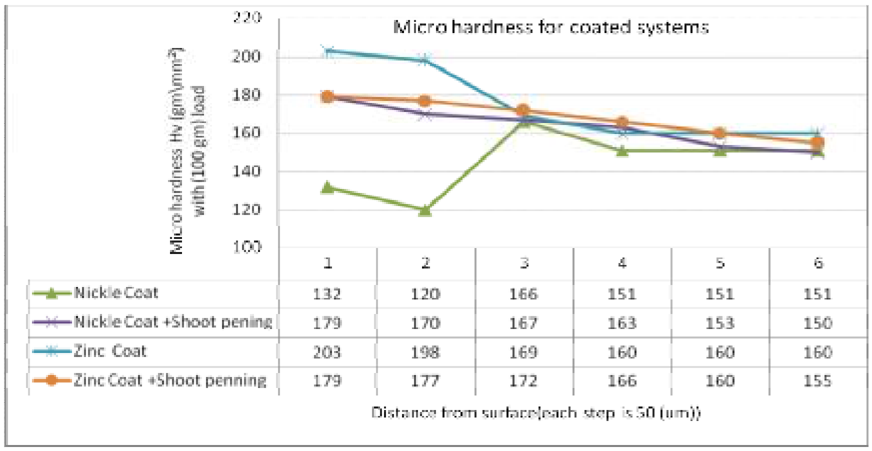


Figure. (1) Micro hardness profiles curves of electro plating coated systems including (Nickel, Zinc) . (each step in X-axis represent 50 um towards the core of coated samples, the optimum depth is 30um).

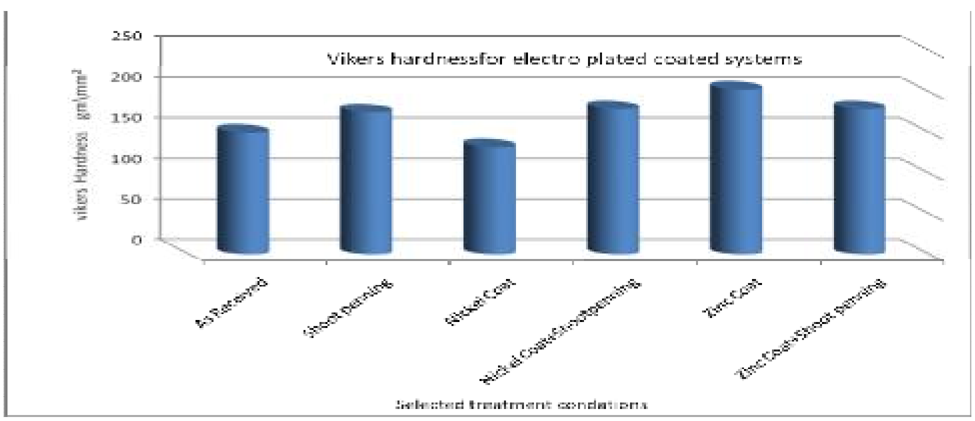


Figure (2) A block diagram showing the behavior of hardness for all the selected treatments.

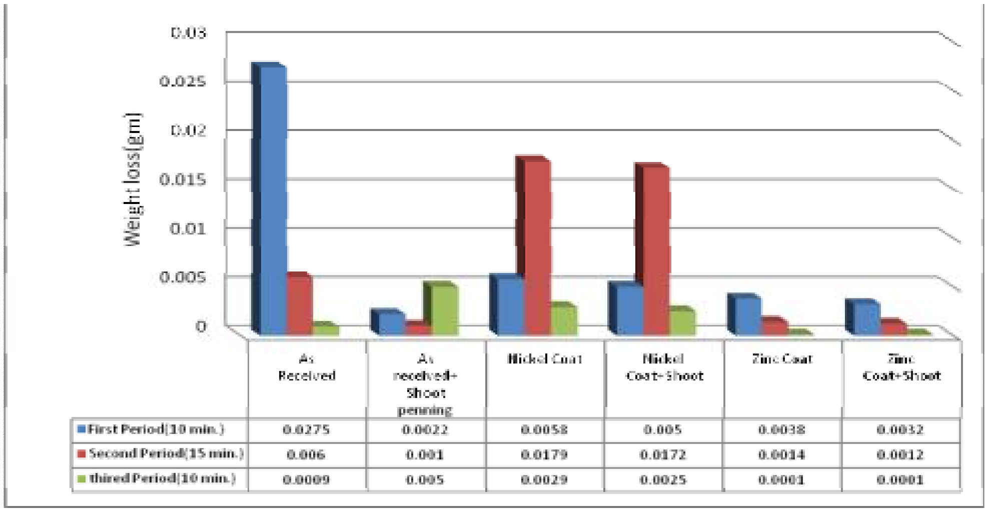


Figure (3) A block diagram illustrating surface treatment Influence on a weight loss in wear resistance test.

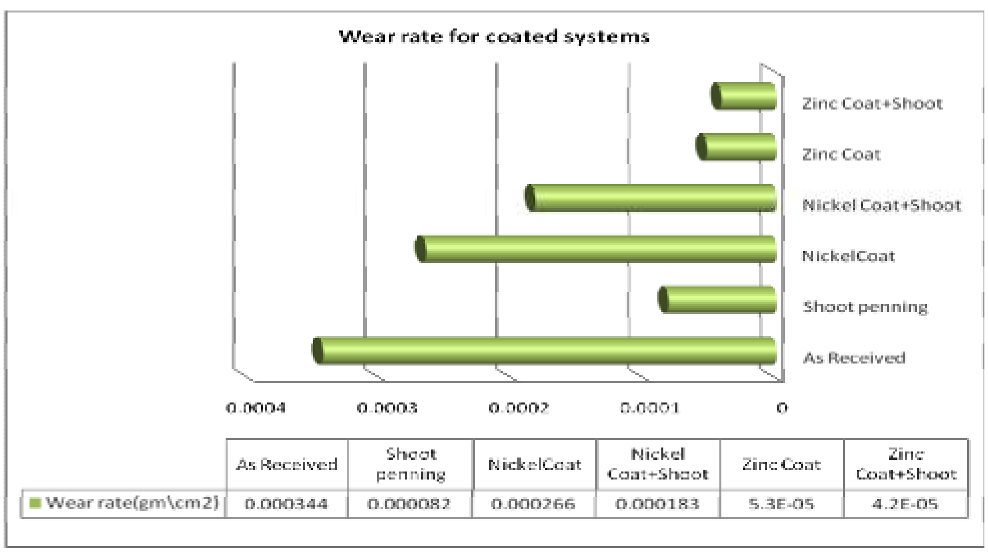


Figure (4) A block diagram illustrating surface treatment influence on a wear rate for 35 minutes.

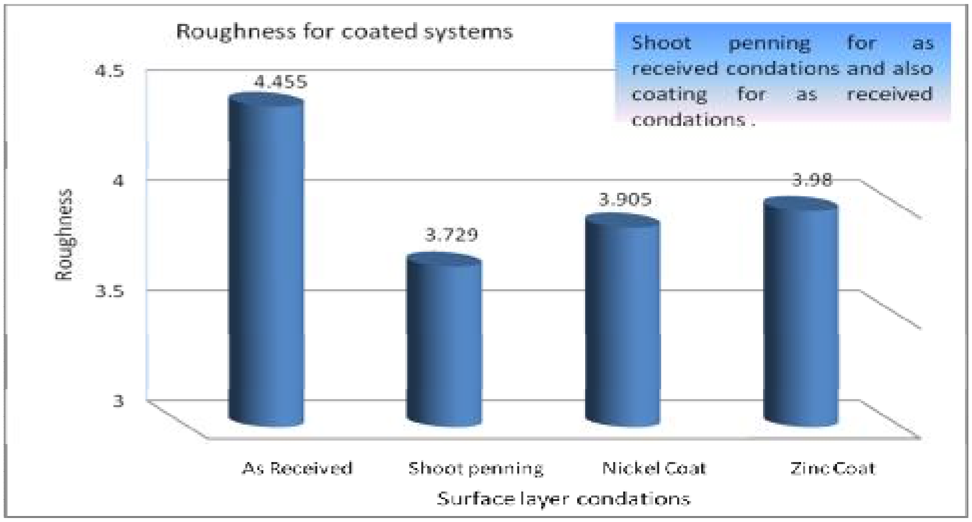
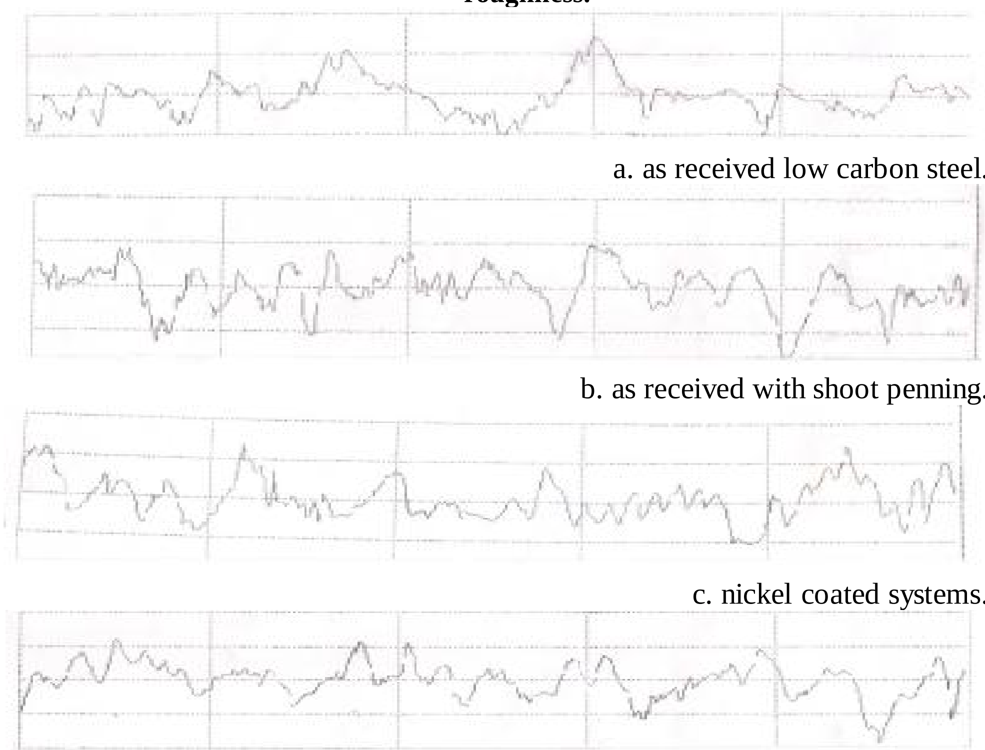


Figure (5) A block diagram illustrating surface treatment influence on a roughness.



a. as received low carbon steel.

b. as received with shoot penning.

c. nickel coated systems.

d. zinc coated systems.

Figure (6) Diagram illustrating roughness behavior for coated systems.

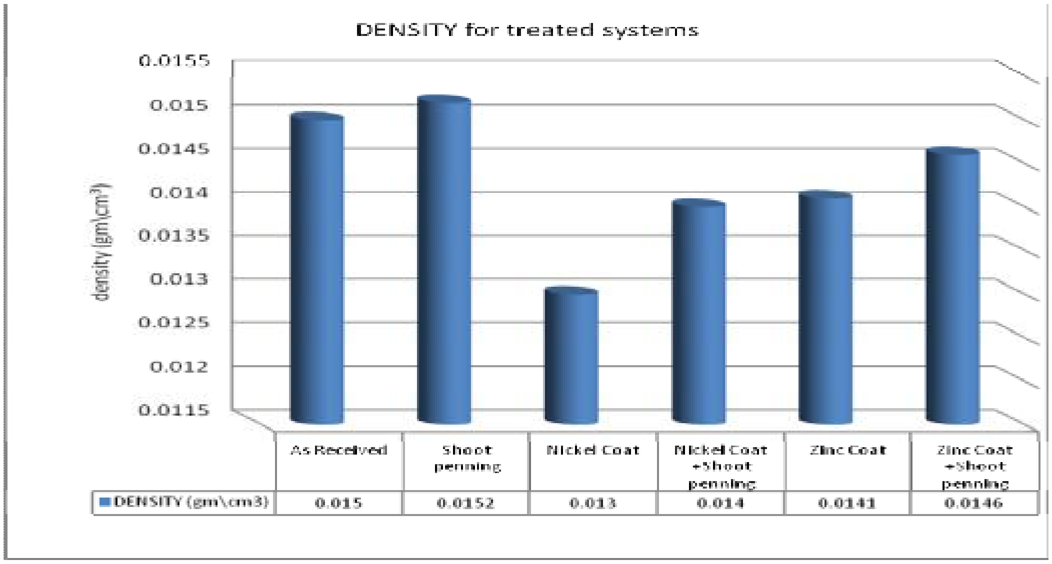


Figure (7) a block diagram illustrating surface treatment influence on a Density.

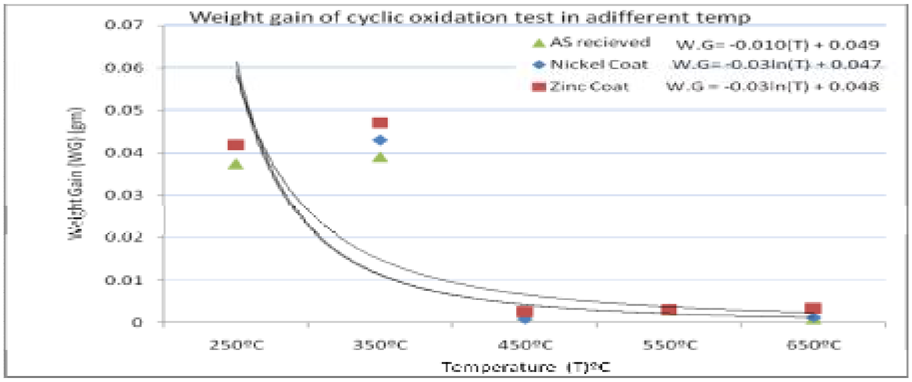
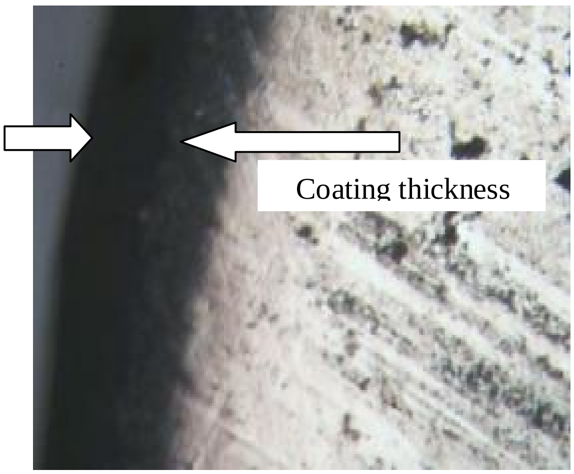
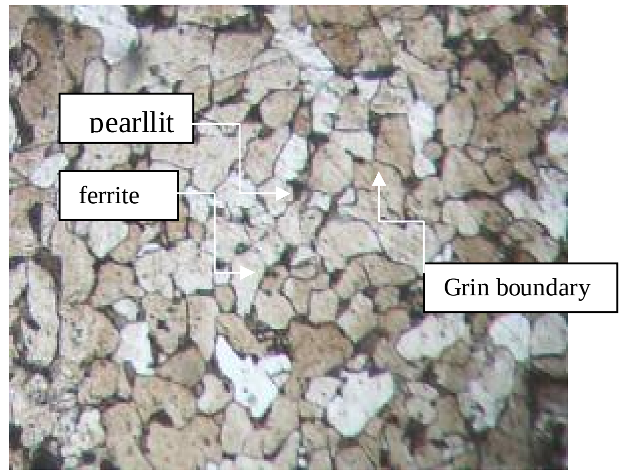


Figure (8) Relation between weight gain and oxidation temperate °C .

Tale (2) show the coating thickness (in µm) for each selected treatment.

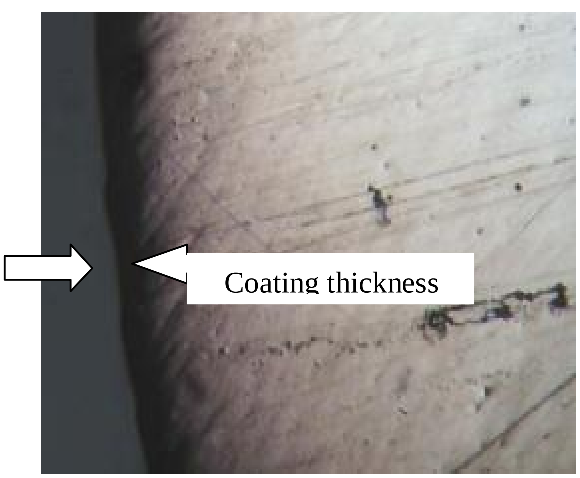
Coating Type	Zinc Coat	Nickel Coat
Coating thickness(µm)	97	117

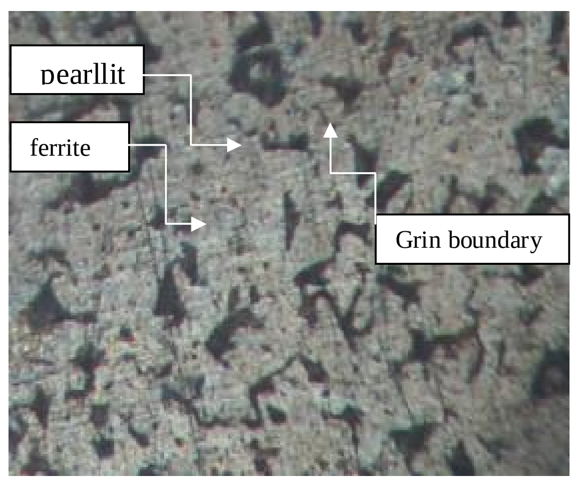




Surface (X50) core(X200)

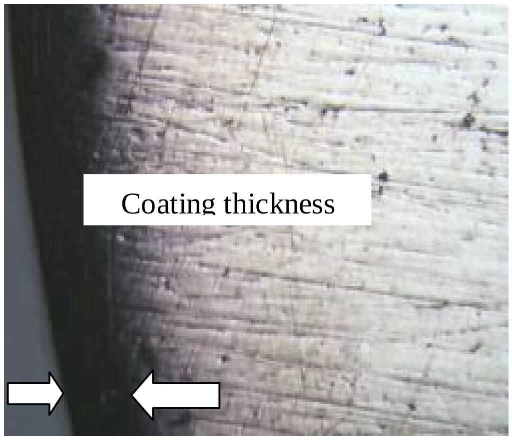
Micro structure for nickel coated systems

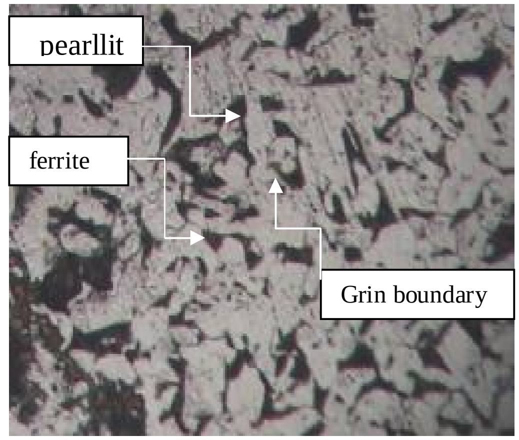




Surface (X50) core (X200)

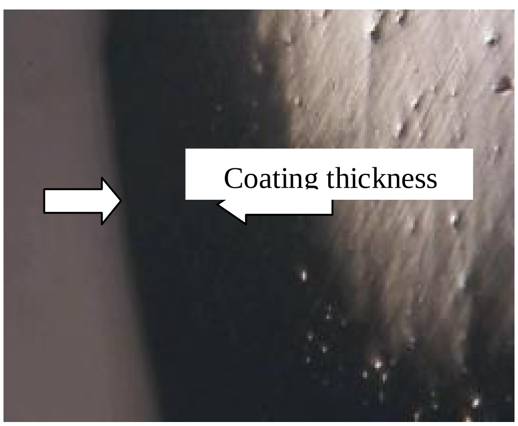
Micro structure for nickel coated systems with shoot penning

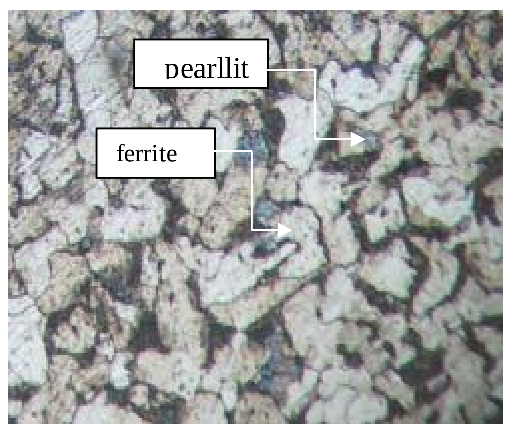




Surface(X50) core (X200)

Micro structure for zinc coated systems





Surface (X50) core (X200)

Micro structure for zinc coated systems with shoot penning

Figure (10) the microstructure.