INFLUENCE OF THE FORMING PROCESSES ON THE RATE OF CORROSION OF GALVANIZED HIGH STRENGTH LOW ALLOY STEEL SHEETS

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ABSTRACT:

The effect of deformation on the corrosion of galvanized high strength low alloy steel sheet is studied. Specimens in the uniaxial, plain and biaxial strains were stretched by a hemispherical punch to three different punch heights for each path of strain. After each deformation, The deformed specimens together with a fourth non deformed specimen were subjected to a corrosive medium for the same sequential times. To determine the effect of corrosion, all the specimens were weighted before and after each corrosion stage and the hardness was also measured It was found that corrosion in the deformed specimens was higher than in the non-deformed ones. Also it was found that corrosion increased by moving from the uniaxial to the biaxial strain passing through the plain strain path and by increasing the punch heights. The results were verified by the hardness measurement.

KEYWORDS: galvanized HSLA steel, corrosion, deformation, strain path

أثر عمليات التشكيل على معدل تآكل صفائح الصلب عالي المقاومة منخفض العناصر السبائكية المغلون

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مستخلص

تمت دراسة أثر التشكيل على معدل التآكل الكيميائي لصفائح الصلب عالي المقاومة منخفض العناصر السبائكية المغلون. شكلت نماذج ذات الانفعالات الاحادية الاتجاه و البسيطة والثنائية الاتجاه بواسطة الخرامة نصف الكروية الى ثلاثة اعماق مختلفة ولكل نوع من الانفعالات السابقة . بعد كل تشكيل عرضت النماذج المشكلة إضافة الى نموذج غير مشكل الى وسط ذو قابلية تآكل لفترات زمنية متعاقبة و متساوية لكافة النماذج. وجد أن التآكل الحاصل في النماذج المشكلة كان أكثر من ذلك الحاصل في النماذج غير المشكلة. كما وجد بأن التآكل ازداد بتغيير مسار الإنفعال من الأحادي الى الثنائي الاتجاه مرورا بالإنفعال البسيط وكذلك بزيادة عمق التشكيل لكافة النماذج. تم التحقق من النتائج بواسطة قياس الصلادة.

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INTRODUCTION:

High strength low alloy steel (HSLA) is a type of alloy steel that have been developed since 1960. The requirement was better mechanical properties than carbon steel. In the 1970s the reduction in vehicle size, weight and fuel consumption was started. Types of galvanized sheet steels were developed and began to be used in the second half of the 1970s. Therefore the percentage of coated products increased reaching more than 2/3 of all automotive panels in the 1990s [1].

Improved-formability HSLA steels were developed primarily for the automotive industry to replace low carbon steel parts with thinner crossection parts for reduced weights without sacrificing strength and hardness. HSLA steels are usually 20 to 30% lighter than carbon steel with the same strength [2].

Since sheets made from HSLA steels can have thinner crossections than equivalent parts made from low carbon steel, corrosion can significantly reduce strength decreasing the load bearing crossection. While additions of elements such as copper, silicon, nickel, chromium and phosphorus can improve corrosion resistance of these alloys, they also increase cost. Galvanizing and other rust preventive finishes can help protect HSLA steel from corrosion at lower prices.

A typical hot-dip galvanized steel coating consists of four layers [3], figure (1), the

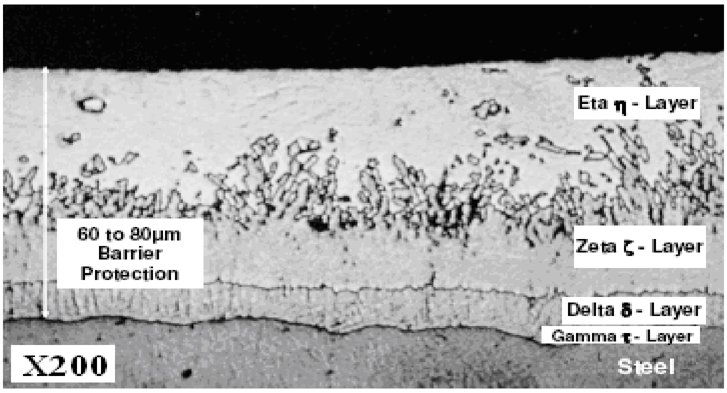


Figure (1): The four layers of the zinc coating [3]

1st layer, the gamma layer, results due to the intermetalic reaction between Zn and Fe. This layer improves the hardness and reduce flaking and cracking during forming [4]. The 2nd layer is the delta layer. The 3rd layer is the zeta layer and the outer layer is the etta layer. Table (1) shows the chemical percentage composition and the hardness of the four layers [5].

Table (1): the percentage composition and the hardness of the layers of Zn coating [5]

Eta	100 % Zn	70 HV
Zeta	94% Zn 6% Fe	179 HV
Delta	90 % Zn 10 % Fe	244 HV
Gamma	75 % Zn 25 % Fe	250 HV
Basesteel		159 HV

Zinc coating protects steel in two ways; 1- it acts as a physical barrier between a potentially corrosive environments and the steel substrate, 2- The zinc coating gives cathodic protection to steel at cut edges and scratches.

Series of researches concerning the performance of hot-dip zinc coating were carried out around the world. Keeler [6] studied the effect of galvanizing on the formability of sheet steels. Stevenson [7] studied the effect of the thickness of the intermetalic layer on the limiting punch height in punch stretching. Meuleman et al [8] studied the effect of changing the strain path on the formability of Galvanized sheet steels. Nanayakkara et al [9] studied the interaction between the coating characterstics of galvanized steel and forming parameters. Rangaravan et al [10] studied the effect of removal of the coating of galvanized steels on dies in the deformation processes. Krzywicki [11] performed a number of tests including salt fog test, damp sulpher dioxide test, cathodic protection and temperature test to determine the resistance and performance of hot-dip galvanized steel against these corrosive mediums. Johnson et al [12] and Townzend et al [13] studied the dissolution rate of the zinc coating in industrial environments.

The objective of this work is to study the effects of deformation, the strain path, and the depth of deformation on the rate of corrosion of galvanized HSLA steel sheet.

MATERIAL PROPERTIES:

The metal used in this work is the galvanized high strength low alloy steel A606 whose chemical composition was analyzed in Badosh cement factory and is shown in table (2).

Table (2): chemical composition of the tested HSLA A606 steel sheet

Alloying Element	C	Mn	P	S	Cu
%	0.22	1.35	0.04	0.05	0.2

The mechanical properties of the HSLA steel sheet were determined by the tensile test using specimens prepared according to the ASTM E 8M- 04 [14]. The engineering stress- strain diagram is shown in fig. (2). The values of the strain hardening exponent (n) and the stress coefficient were determined from the log true stress-true strain diagram shown in figure (3). Table (3) shows the mechanical properties of the tested metal.

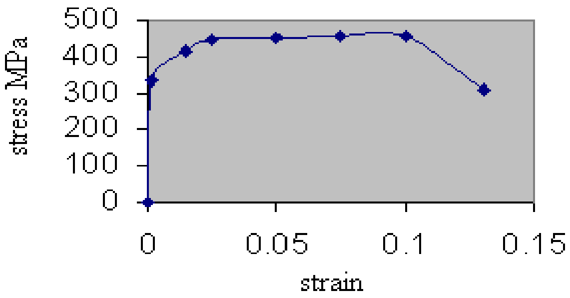
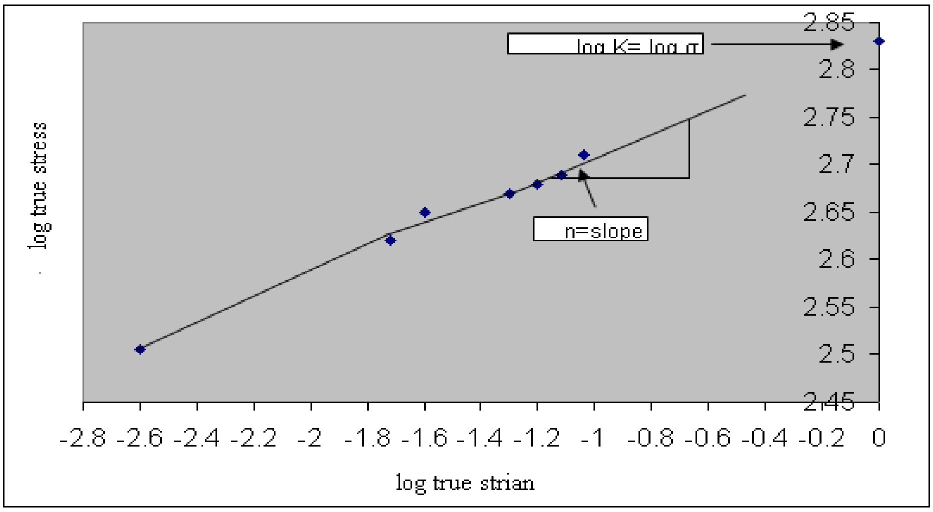
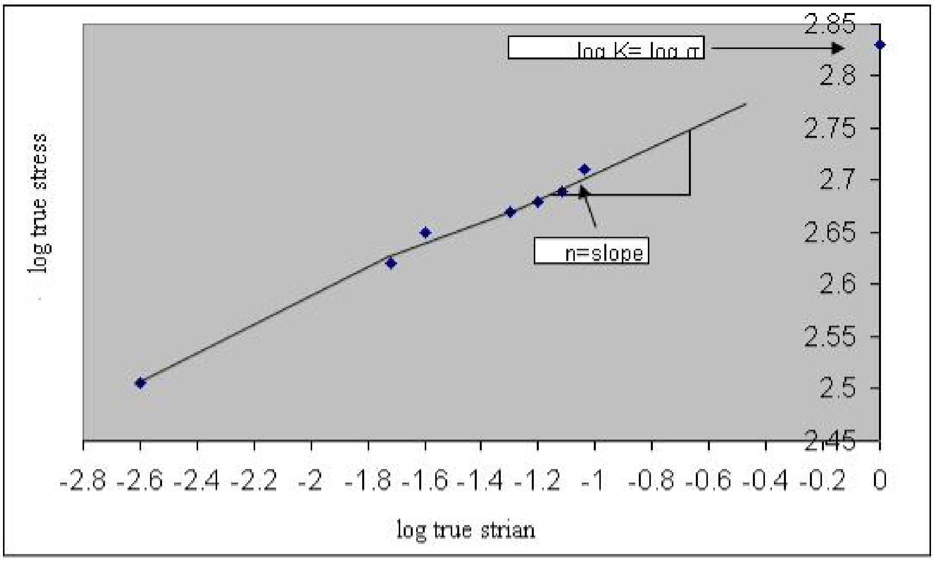


Figure (2). The engineering stress-strain diagram for HSLA A606

Table (3):the mechanical properties of the HSLA A606 steel sheet

Modulus of elasticity E GP	Yield stress MP	Ultimate tensile stress Mp	Density Kg/cm^3	Elongation %	Strain hardening exponent n	Stress coefficient K MP
208	387	420	7.77	11.3	0.125	616





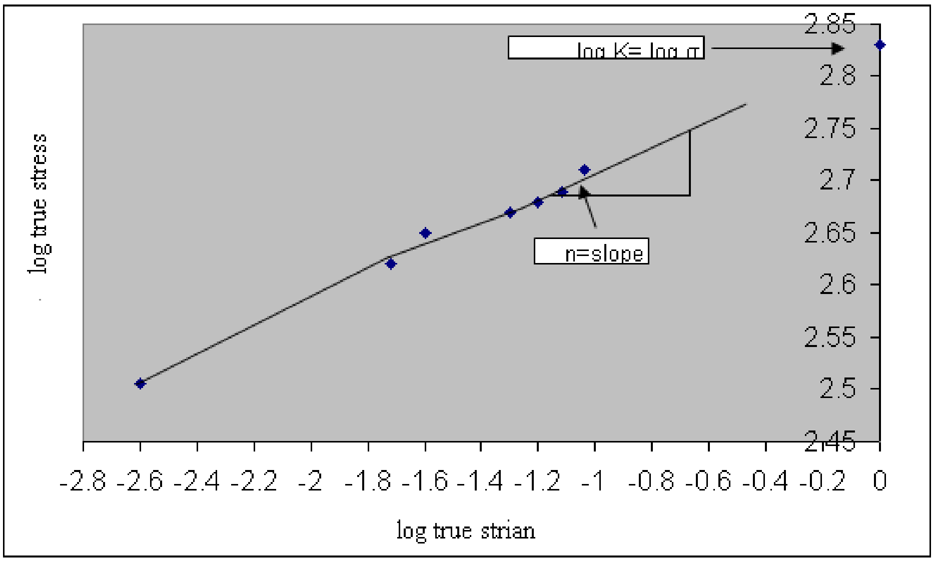


Figure (3). The log true stress- true strain diagram

PROCEDURE AND TEST SPECIMENS:

The different processes of deformation of sheet metal are complicated and may consist of a number of strain paths. Since the Hecker hemispherical punch stretching test [15] includes a wide range of strain paths starting from uniaxial to equibiaxial strain paths, it was chosen in this work to produce different strain paths . Schematic representation of the set up is shown in figure (4) with the necessary dimensions.

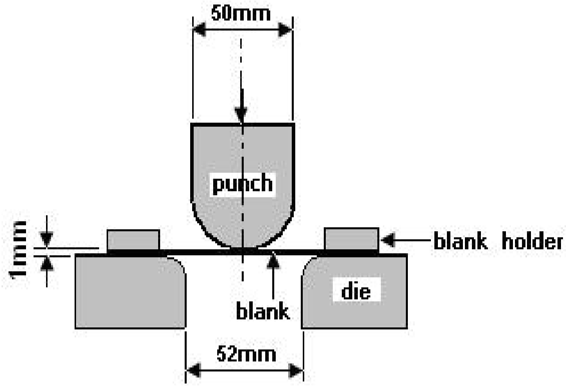
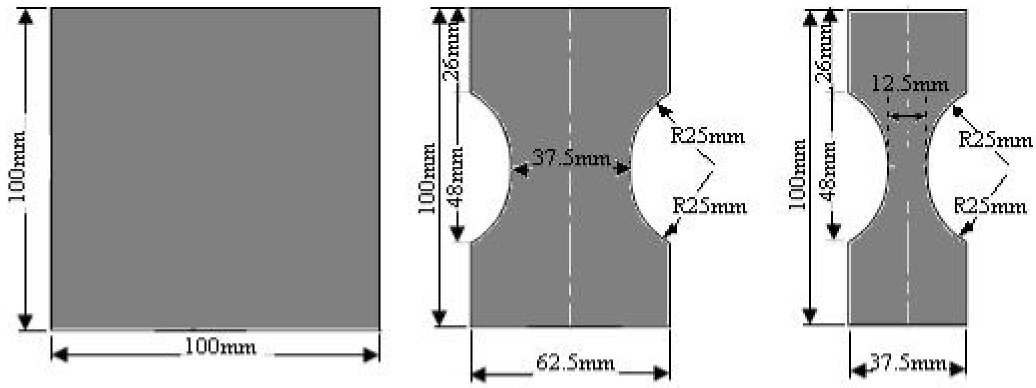


Figure (4): The stretching set up

In order to verify the effect of the strain path on the rate of corrosion, three different shapes of specimens among the eight shapes described by Hecker [15], shown in figure (5), were chosen and prepared to result in uniaxial, plain strain and biaxial strain paths.



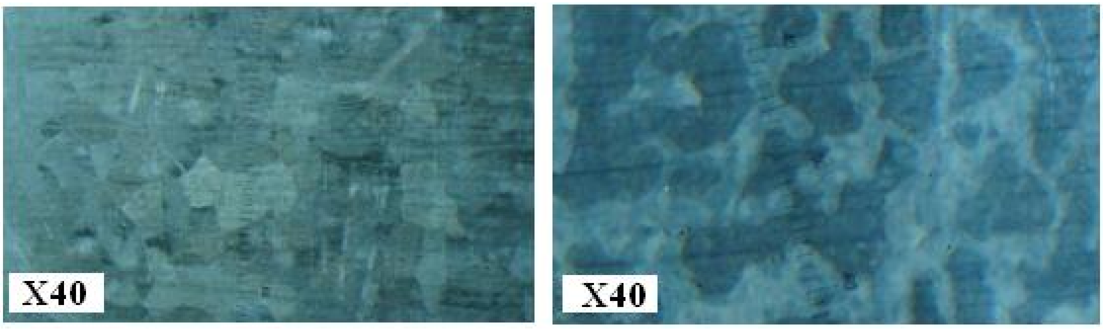
Biaxial plain strain uniaxial

Figure (5): the three specimens for the three different strain paths

To find the effect of the punch height in addition to the strain path, the specimens for the mentioned three strain paths were formed to three different punch heights (8 mm, 10 mm, 12 mm). Half of the deformed specimens as well as a non deformed one were subjected to corrosion by immersing them into a salty water composed of 3% NaCl for three sequential periods (5, 10, and 15 days). The other half of the deformed specimens were left without corrosion. After each period the corroded specimens were taken out and weighted. The surface hardness was measured by the equipment of the type (V-tester 2) for measuring the micro hardness, at different points on a meridian of each deformed specimen before and after corrosion.

RESULTS AND DISCUSSION:

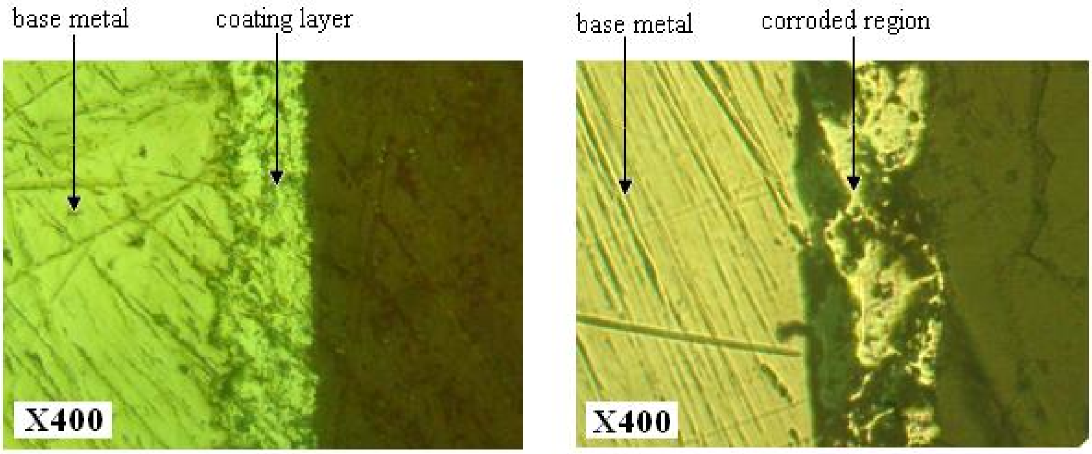
A macrograph of the HSLA steel as received sheet is shown at the left of figure (6) where the grains of zinc are easily recognized, and to the right a corroded sheet with the corrosion results is shown.



as received corroded

Figure (6). A micrograph of the as received and the corroded HSLA sheets

Figure (7) shows the micrographs of the as received crossection on the left and the corroded one on the right. The right micrograph shows different rate of corrosion within the coating without reaching the substrate metal. No cracks in the coating layer, as a result of deformation, is recognized so that sacrificial corrosion is excluded.



As received crossection corroded crossection

Figure (7). Micrograph showing the as received crossection and the corroded crossection of the HSLA steel sheet

The technique followed to measure the rate of corrosion is by weighing before and after the corrosion [16]. Samples were degreased with ethanol and weighted before exposure to the salty water. After exposure for the indicated periods, samples were cleaned to remove corrosion products and dried so that no excess fluids remain on the part and finally weighted to determine loss of coating due to corrosion. Figure (8) shows three graphs representing the relation between the loss of weight per unit area of the sheets versus the time of exposure to the corrosive medium for the three different strain paths and for three increasing punch heights(8,10 and 12 mm). For the sake of comparison, the results of the non-deformed corroded sheet is also shown on the three graphs. It is clear that all the specimens have lost weight due to corrosion and the loss in weight has increased by the increase of exposure time. The loss in weight in the deformed sheets is higher, to different degrees, than the non-deformed one. By comparing the three graphs, it can be noticed that the loss in weight increases, which means higher corrosion rate, by changing the strain path from uniaxial to biaxial passing by the plain strain path. Also, for all the strain paths, the loss in weight is higher when the punch height is increased i.e. the corrosion rate was increased by further deformation.

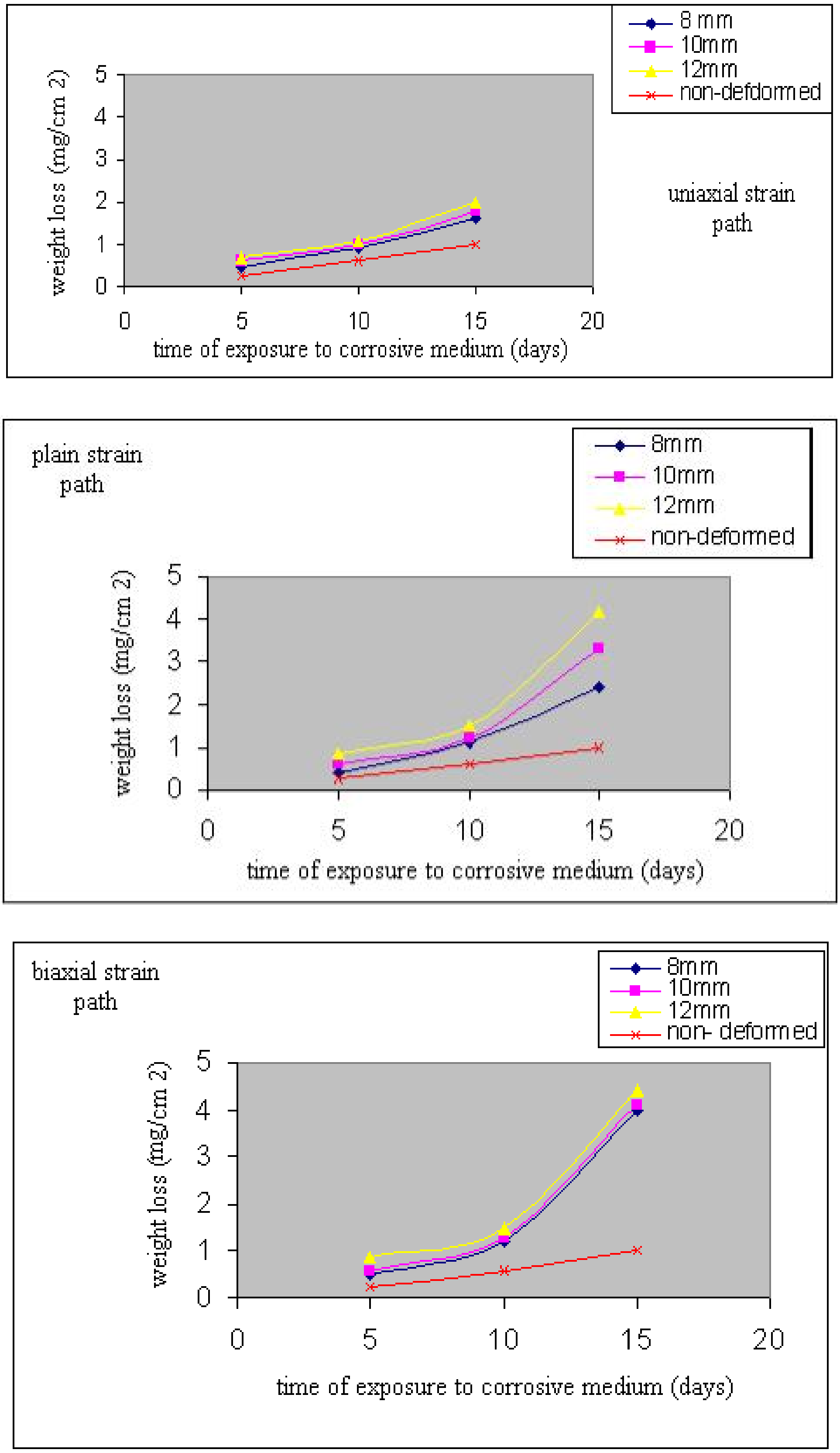


Figure (8). The loss of weight versus the time of exposure to the corrosive medium, for three different stain paths

The hardness was measured, by the equipment of the type (V-tester 2) for measuring the micro hardness, for all the specimens at the same three points (1, 2 and 3), figure (9), located at different distances along a meridian of the formed sheets.

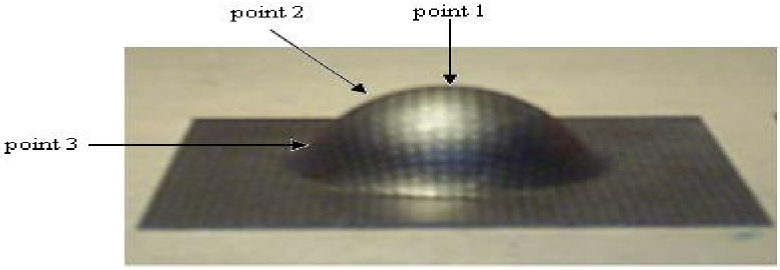


Figure (9). The location of points (1,2,3) along the meridian of a deformed sheet

The graphs shown in figures (10), (11) and (12) are for the deformed non-corroded and the deformed then corroded sheets. They show the variation of the hardness at the three points (1,2,3) for three different punch heights (8, 10, 12) and for the three strain paths (uniaxial, plain strain and biaxial) consequently.

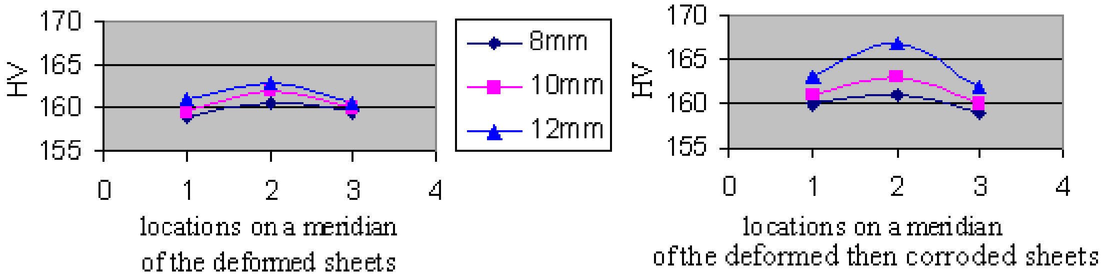


Figure (10). The hardness at points 1, 2 and 3 of a deformed non-corroded sheets (on the left) and the deformed then corroded sheets (on the right) for a uniaxial strain path

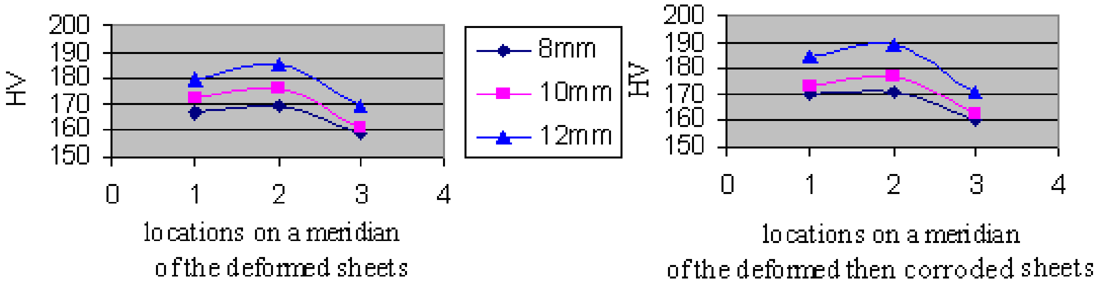


Figure (11). The hardness at points 1, 2 and 3 of a deformed non-corroded sheets (on the left) and the deformed then corroded sheets (on the right) for a plain strain path

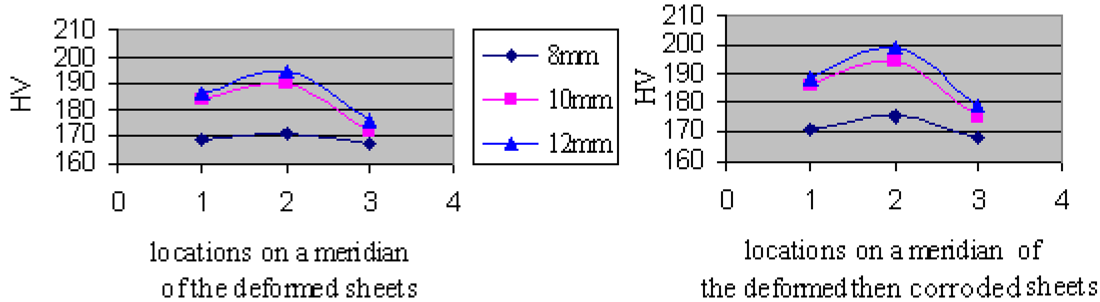


Figure (12). The hardness at points 1, 2 and 3 of a deformed non-corroded sheets (on the left) and the deformed then corroded sheets (on the right) for a biaxial strain path

By comparisons between the two graphs in figure (10) it can be noticed that the hardness has increased after corrosion in the three locations (1,2,3) for the three punch heights. This increase in hardness is due to the fact that the layers of coating which remain after corrosion are the inner layers whose hardness is higher than that of the outer layers (table 1). This result enhances the result obtained previously that the deformation increases the rate of corrosion. Also it can be noticed that the hardness has increased by increasing the punch movement from 8 to 10 then to 12 mm which indicates higher rates of corrosion and strain hardening of the metal.

The same results can be obtained from figures (11) and (12), but by comparison between the three graphs it can be easily noticed that the increase in hardness in the biaxial strain path is higher than that in the plain strain path and in the later it is higher than that in the uniaxial strain path. This also enhances the fact, obtained previously, that the rate of corrosion increases by changing the deformation path from the uniaxial to the biaxial passing by the plain strain path.

For all the specimens in figures (10), (11) and (12) the hardness at point (2) is the highest. Point (2) is at the ring of contact between the punch and the sheet. At the ring of contact, because of friction, the maximum deformation occurs [17] hence maximum strain hardening which means highest hardness values.

CONCLUSIONS:

To study the effect of forming processes on the rate of corrosion of the HSLA steel sheet, specimens were deformed in three different strain paths then immersed into a corrosive medium for certain time intervals. The results showed that:

1. Certain amounts of the coating were corroded and no corrosion of the substrate was noticed.
2. No cracks within the coating were generated so that galvanic protection did not take place.
3. The deformation process has increased the corrosion rate as the deformed specimens were corroded more than the non-deformed ones.
4. The rate of corrosion increased by changing the strain path from uniaxial to biaxial passing through the plain strain path.
5. The rate of corrosion increased by increasing the punch height.
6. The hardness measurement verified all the preceding results.

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