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CRACKS GROWTH BEHAVIOR THROUGH WALL PIPES UNDER IMPACT LOADING AND HOT ENVIRONMENT

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Abstract: - *This search concerns study the crack growth in the wall of pipes made of low carbon steel under the impact load and using the effect of temperature (50°C). The environmental conditions were controlled using high accuracy digital control with sensors. The pipe has a crack already. The test was performed and on two type of specimens, one have length of 100cm and other have length 50cm. The results were, when the temperature was applied to the pipe, the crack would enhance to growth (i.e. the number of cycles needed to growth the crack will reduce). In addition, when the test performed on the specimens of length 50cm the number of cycles needed to growth the crack is increase due to the effect of bending stress on the pipes.*

Key words: *cracks, crack initiation, crack growth*

1. INTRODUCTION.

[3] define the cracks as a discontinuity or break, which occur in solid (rigid) body, and it branded by possessing an initiation point (start point), and by growing from this point to finite size with time. Either leading or not to the separation the original body in two or more parts. Crack growth depended on the loading conditions and the environmental conditions. Loading conditions presents the type of load, static load, dynamic load, load controlled, grip controlled. Environmental conditions like temperature and corrosive atmosphere influence crack growth.
[7] There are three types of cracks in pipes happen due to several causes associated with their types, whereby the form of a crack, its dimension and its course allows conclusions on its cause. Thus, it is possible that, on the one side, one cause results in several cracks at different places and, in the other hand, one crack can have some causes.

1- Longitudinal cracks
2- Lateral cracks
3- Crack origination at a point

2. THE BEHAVIOR OF CRACKS

[6] The behavior of fatigue cracks differs from that of long cracks because of larger sensitivity to the microstructure, a greater size of the plastic zone relative to the crack length, and a lesser level of crack finish. Advanced have been made in the understanding of the fatigue crack growth process of cracks, and this understanding has been employed in the advance of analytical treatments of short fatigue crack growth. The study of fatigue crack growth behavior of cracks is one of more active areas of research in the field of fatigue. Such cracks are of interest not only because their growth can inhabit an important portion of the fatigue life time but also because they can grow at amount much higher or lower than might be expected on the basis on long crack behavior. Below are four kinds of cracks fatigue **[6]**

1- Mechanically cracks (the crack length is less than plastic zone size)
2- Micro structurally (the crack length is less than a critical microstructural)
3- Physically (the crack length less than at which crack closure if fully developed usually less than 1 mm in length)
4- Chemically(the crack length may be up to 10 mm)

3. GOVERING DEFFERENTIAL EQUATION

Paris proposed the following equation for the correct crack propagation law **[4]**

$\frac{da}{dN} = C(\Delta k)^m$ (1)

Where C and m are constant and they depended on the material that be used
This equation seemed to have good correlation with the test data. However, if comparisons are made with the large range of data, such as a higher load ratios and crack growth rates, the correlations is not good. In fact, equation (1) does not seem to be complete. Two effect occur which are not taken into account. One of this variation in the crack growth rate owing to the load ratio, R. the other is the instability of the crack growth when the value of the maximum stress intensity factor approaches to the fracture toughness of the material, $K_{c,}$ **[4]**

4. CRACK GROWTH CRETERIA

Theoretical and experimental work contains different criteria and approaches for the study of the crack growth direction. Many of these study are based on the stress analysis of the crack tip zone. Erdogan and Sih first examined the angled crack. They suggested the MTS criteria based on the stress field existing just before the onset of fracture for prediction of the direction of the initial crack extension. According to the MTS criteria the crack extend in the radial direction agreeing to the maximum tangential stress and the crack extension occur then this maximum reaches a critical value. Some researchers study were based on the presentation of the crack tip stress field in terms of stress function derived by Williams **[8]**

$\emptyset = r^{3/2} f_1(\theta) + r^2 f_2(\theta) + r^{5/2} f_3(\theta)$ (2)

For the first term the stress are representation by:

$\sigma_\theta = \frac{1}{\sqrt[2]{2\pi r}} \cos\frac{1}{2}\theta\ (k_1 \cos^2\frac{\theta}{2} - k_2 \sin\theta)$ (3)

$\tau_{r\theta} = \frac{1}{2\sqrt{2\pi r}} \cos\frac{1}{2}\theta\ [k_1 \sin\theta + k_2(3\cos\theta - 1)]$ (4)

Erdogan and Sih proposed that the direction of crack growth is given by the condition:

$\frac{dk_\theta}{d\theta} = 0$ (5)

Where:
$k_\theta = \cos^2\frac{\theta}{2}\ (k_1 \cos\frac{\theta}{2} - 3k_2 \sin\frac{\theta}{2})$ (6)

$\cos\frac{\theta}{2}\,[k_1 \sin\theta + k_2(3\cos\theta - 1)] = 0$ (7)

A better covenant between the theoretical and experimental has been gotten by a representation of the stress field using the first two terms of the Eigen function expansion, equation (2). In addition, by using a small but finite radius to locate the maximum value of σ_θ and this was shown by Williams and Ewing. The elastic strain energy dW stored in parallel pipe of volume dV in the dominate Sih expresses zone of the strained plate:

$\frac{dW}{dV} = \frac{1+v}{4E}\ [k_{1,2}(\sigma_x + \sigma_y)^2 + (\sigma_x - \sigma_y)^2 + 4(\tau_{xy})^2]$ (8)

$k_1 = \frac{1-v}{1+v}$ For plane stress (9)

$k_2 = 1 - 2v$ For plane strain (10)

Papadopoulos used the elastic strain energy approached to propose a criterion of fracture, which takes into account the third stress invariant Determinant matrix (σ_{ij})

Det.$(\sigma_{ij}) = \begin{vmatrix} \sigma_x & \sigma_{xy} \\ \sigma_{xy} & \sigma_y \end{vmatrix}$ (11)

According to the Det. – criteria the angle of crack extension for the mixed mode loading is determined from the condition that the determinate of the stress tensor must take a maximum value. In a polar coordinate system, the relations express these conditions mathematically:

$$\left.\frac{\partial\, Det.(\sigma_{ij})}{\partial\theta}\right|_{\theta=\theta^*}=0,\ \left.\frac{\partial^2\, Det.(\sigma_{ij})}{\partial\theta^2}\right|_{\theta=\theta^2} < 0 \quad (12)$$

The critical stress for crack initiation is calculated by:

$$\mathrm{Det.}(\sigma_{ij})=\mathrm{Det.}(\sigma_{ij})_{cr} \quad (13)$$

5. CYCLIC LOAD EQUATIONS

The equations below are available for transverse crack (α = 90°) with and without internal pulse pressure **[2]**

$$p = w[1 + \sqrt{\frac{1+2hEA}{wl}}] \text{ (for impact load) } (14)$$

$$I = \frac{\pi}{64}\,(OD^4 - ID^4) \quad (15)$$

$$\delta = \frac{l^3 p}{48EI} \text{ (For simply supported beam) } (16)$$

$$\sigma = \frac{MY}{I} \text{ (Bending stress) } (17)$$

$$\sigma_{min} = -\sigma_{max} \quad (18)$$

$$\beta = \frac{a_j}{r} \quad (19)$$

$$\rho_0 = \frac{a_j}{\sqrt{rt}} \quad (20)$$

$$G_2(\rho_0) = 1 + 0.19\rho_0 + 0.01\rho_0^2 \quad (21)$$

$$C_1 = 1 + \frac{0.7071(1-\beta cot(\beta))}{\left(\frac{\cot(\pi-\beta)}{\sqrt{2}}+\sqrt{2}\cot(\beta)\right)*\beta} \quad (22)$$

$$C_2 = 1 + \frac{0.35355\left(\beta+\beta cot^2(\beta)-cot(\beta)\right)}{\left(\frac{\cot(\pi-\beta)}{\sqrt{2}}+\cot(\beta)\right)} \quad (23)$$

$$CCF_I = (G_2(\rho_0) * Sin(\beta) * C_2)/(\beta * C_1) \quad (24)$$

$$K_I = \sigma_{app.}\sqrt{\pi a_j}CCF_I = K_{Imax} \quad (25)$$

6. MATERIAL UESD AND SPECIMENS

The material used in this research is Low Carbon Steel (EN 10219 S235JRH). It is a pipe with a circular section thickness about 1.5 mm and a diameter about 75 mm. This research was done on several samples of this article. Some of these samples have a length of 100 cm **[1]**, See **Fig. 1** and other have length of 50cm See **Fig. 2**. The reason for this difference to test the effect of bending on the growth and behavior of the crack. This test was conducted under different environmental conditions to determine the effect of the moisture and heat factors on the growth of the crack.

Figure 1. Two sample of length 100cm **Figure 2**. Two sample of length 50cm

7. MATERIAL PROPERTIES

These properties from **DIN EN 10219**

1. Chemical composition

Chemical composition is in percentage by mass. See **Table 1.**

2. Mechanical properties

These mechanical properties measured at room temperature, See **Table 2**

3. Physical properties

Physical properties for this material shown in the **Table 3.**

Table 1. Chemical composition of material

carbon	silicon	Manganese	phosphorus	sulfur	nitrogen
0.17	-	1.4	0.04	0.04	0.009

Table 2. Mechanical properties of material

Yield strength in N/mm^2 min for nominal wall thickness less than 16 mm	Tensile strength in N/mm^2 for nominal wall thickness less than 3 mm	Elongation % for nominal wall thickness less than 40 mm	Impact energy in J at temperature 20°C
235	360-510	24	27

Table 3. Physical properties of material

Density at 20°C in kg/dm^3	Modulus of elasticity kN/mm^2 at 20°C	Thermal conductivity at 20°C in w/ m k	Spec. thermal capacity at 20°C J/kg k	Spec. electrical resistivity at 20°C $\Omega\ mm^2/m$
7.85	210	54	461	0.15

8. CRACK INITIATION

Fig. 5 The crack was created manually by handsaw. Because that the crack is difficult to accomplish using other machines. Where the length of the cut about 24% **[5]**, of the perimeter of the pipe. This percentage was based on previous research, where the ratio was a length of 56 mm and width of the crack is about 0.7 mm to 0.9 mm. This
difference is due to the difference in the thickness of the cutting edge in the saw as well as the hand movement. Other percentages were chosen to indicate the possibility of conducting the search on different lengths of the crack. However, these lengths of (18mm, 25mm, 30mm, and 40mm) took a long time without any continuity in the growth of the crack.

9. RESULTS

Results were obtained by using rig made for testing these specimens. See **Fig. 3**, the tests were repeated again to ensure a close test result as well as to ensure the correct functioning of the rig. The results are shown in the **Fig. 7, Fig. 8, Fig. 9** and **Fig. 10** also **table 4, table 5, table 6** and **table 7.**

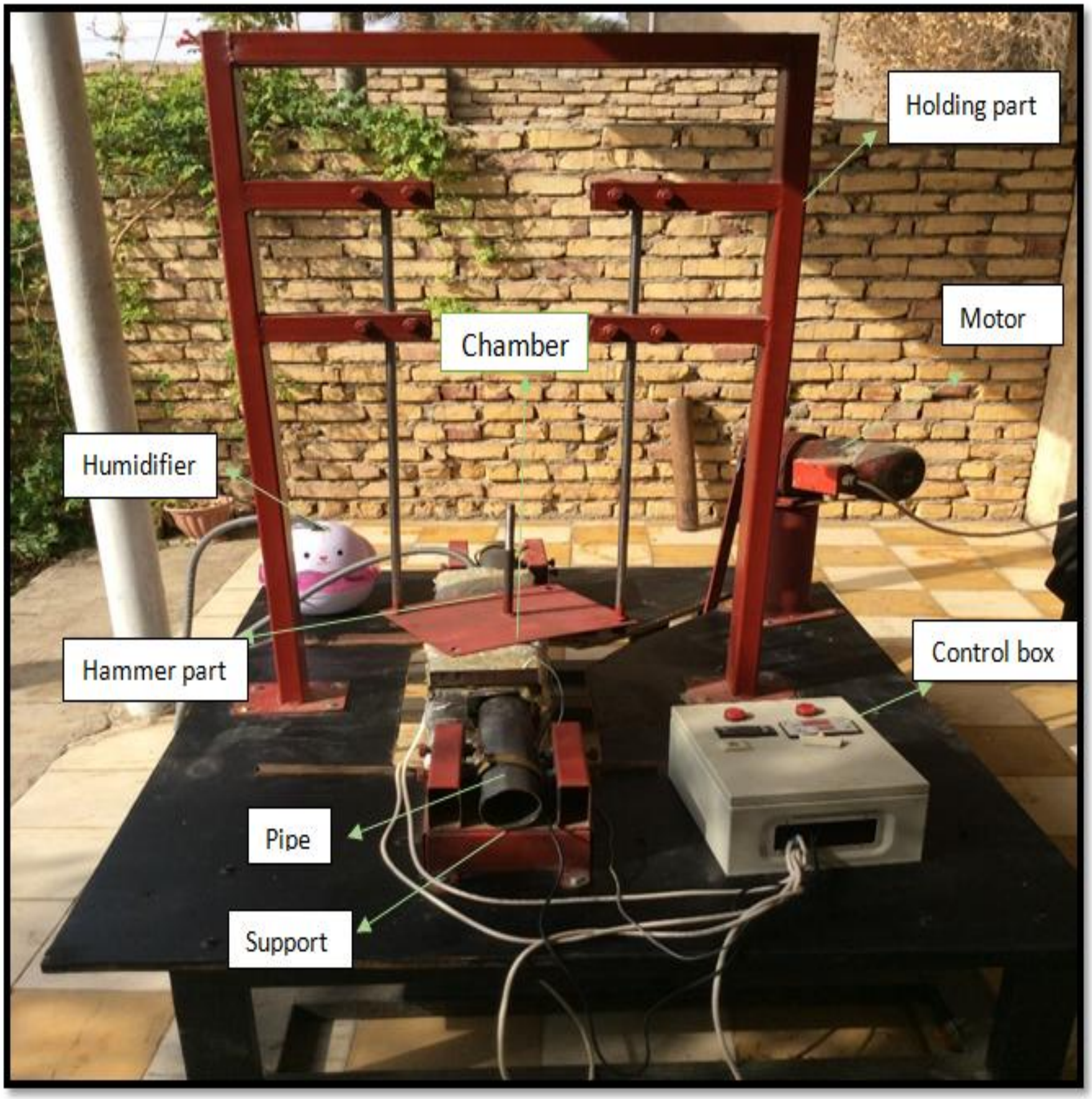

Figure 3. The device sued to test the specimens

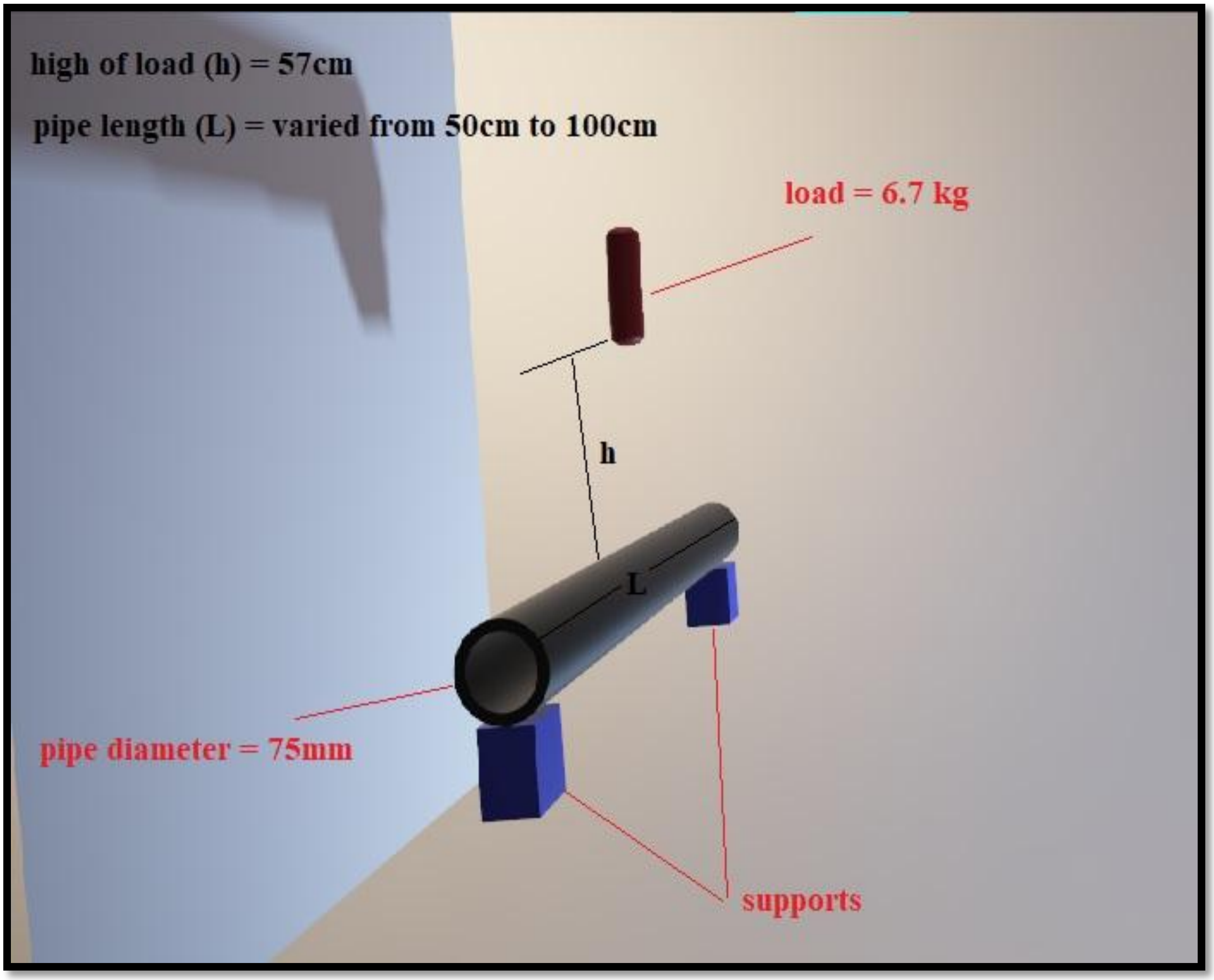

Figure 4 show the device operation principle

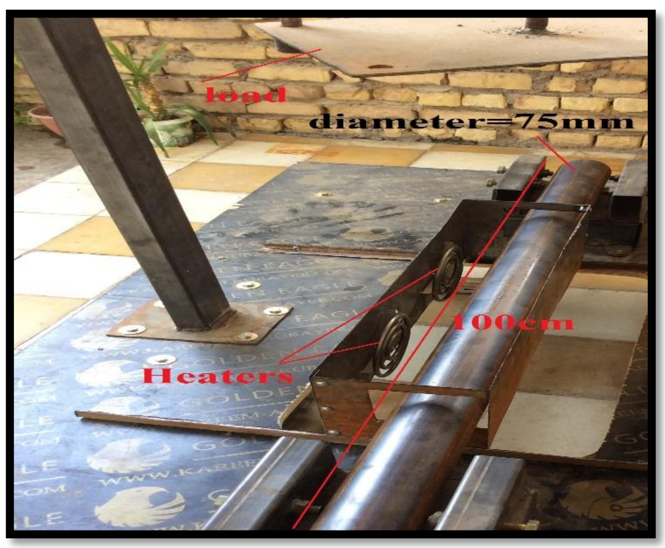

Figure 5 show the crack on pipe after test **Figure 6** show the dimensions of pipe

Table 4. Data for 100cm specimens 1 hour heat

Effective length = 100 cm **crack length** = 5.6 cm
Heat = 50°C **time** = 1 hour
Humidity = no

Number of cycles	Crack growth (mm)								
	First attempt				Number of cycle	Second attempt			
	L	∀	R	∀		L	∀	R	∀
100			Crack initiation		100			Crack initiation	
160			0.56	0°	160			0.6	0°
190	0.97	5°	1.12	0°	190	1.17	6°	1.2	0°
220	1.5	5°	2.17	0°	220	1.65	6°	1.99	1°
250	1.95	5°	3.01	0°	250	2.01	6°	2.42	1°

Table 5. Data for 100cm specimens 2 hour heat

Effective length = 100 cm **crack length** = 5.6 cm
Heat = 50°C **time** = 2 hour
Humidity = 0

Number of cycles	Crack growth (mm)								
	First attempt				Number of cycle	Second attempt			
	L	∀	R	∀		L	∀	R	∀
100			Crack initiation		95			Crack initiation	
160	0.63	0°	0.61	0°	150			0.6	0°
190	1.52	0°	1.23	1°	180	1.38	1°	1.18	0°
220	2.06	0°	1.67	1°	210	1.77	1°	1.65	0°
250	2.59	0°	1.93	1°	240	2.08	1°	2.11	0°

Table 6. Data for 50cm specimens 1 hour heat

Effective length = 50 cm **crack length** = 5.6 cm
Heat = 50°C **time** = 1 hour
Humidity = no

Number of cycles	Crack growth (mm)								
	First attempt				Number of cycle	Second attempt			
	L	∀	R	∀		L	∀	R	∀
380			Crack initiation		390			Crack initiation	
410		0°	0.74	0°	420			0.64	0°
440	0.56	0°	1.03	0°	450	0.34	0°	0.87	0°
470	1.02	0°	1.24	0°	480	0.9	0°	1.26	0°
500	1.19	0°	1.51	0°	510	1.21	0°	1.48	0°

Table 7. Data for 50cm specimens 2 hour heat

Effective length = 50 cm **crack length** = 5.6 cm
Heat = 50℃ **time** = 2 hour
Humidity = no

Number of cycles	**Crack growth (mm)**								
	First attempt				**Number of cycle**	**Second attempt**			
	L	**∀**	**R**	**∀**		**L**	**∀**	**R**	**∀**
380			Crack initiation		380			Crack initiation	
410	0.4	0°	0.56	0°	410			0.48	0°
440	0.79	0°	0.81	0°	440	0.81	0°	0.86	0°
470	1.11	0°	1.06	0°	470	1.21	0°	1.03	0°
500	1.33	0°	1.19	0°	500	1.29	0°	1.17	0°

10. Manufacturing of the device

This device was made of several parts of iron material with different sections according to the required part. Also used the technique of electric arc welding to connect these parts. The parts are cut using the cutting machine. After the cutting, the welding process is carried out to connect them together. However, most parts of this machine have the ability to switch when failure or damage occurs in one of these parts. This technique facilitated the work in many businesses on this machine for the fact that working on this device requires a change in the shape and position of the supports often to match the course of the research. A wooden plate was used to fix the parts of the machine. The dimensions of this plate are (122 cm x 244 cm) and thickness 1.5 cm. This plate has a hole in the middle to facilitate the passage of the hammer lever and to facilitate the examination of the pipe using the camera or naked eye. The dimensions of the parts of each other were developed using a laser device called (level) that allows the device to see the extent of the separation of these parts or deviation from each other, which adds the possibility of placing the parts with high accuracy. This device enables the possibility of conducting tests on pipes made of iron, carbon steel, aluminum, copper and plastic. The design of this device includes the possibility of changing the height of the hammer to suit the amount of energy necessary and strong with the ability of the metal to withstand the shocks **fig.4**, Also can work on the pipes of different length ranging from 50 cm to 150 cm and different diameters ranging from 2 to 4 inch. In addition, the researcher or worker on this device can control the environmental conditions to be operated from heat, humidity, and control where it can work in the areas of temperature ranging from 0 °C to 100 °C. Also, control the humidity, where it can work in the humidity ratio ranging from 0% to 100%.

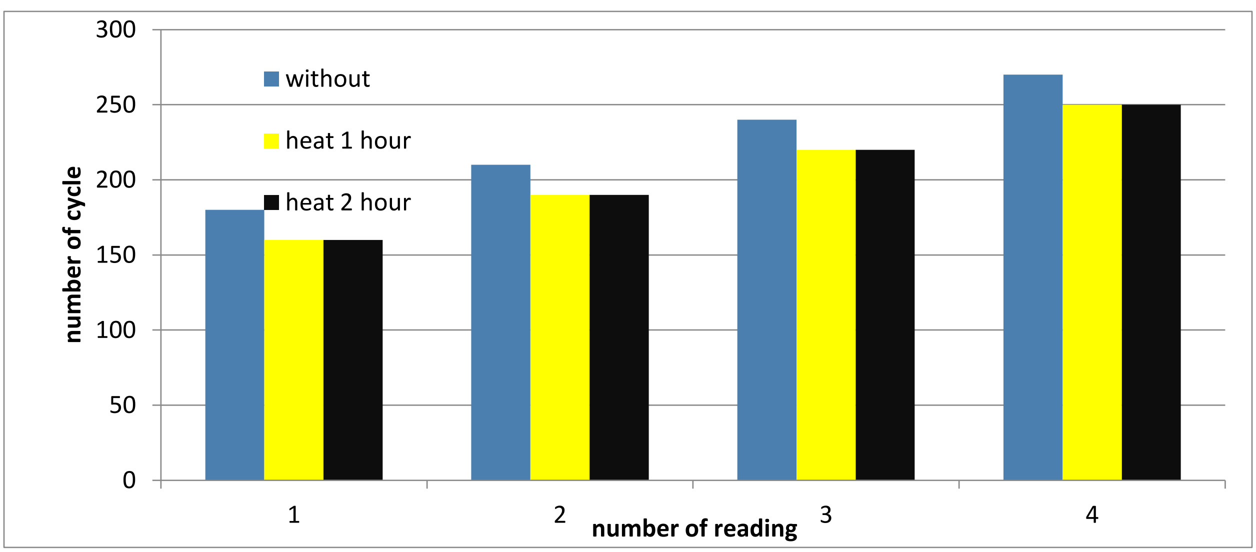

Figure 7. Show the number of cycle of every specimens of length 100cm

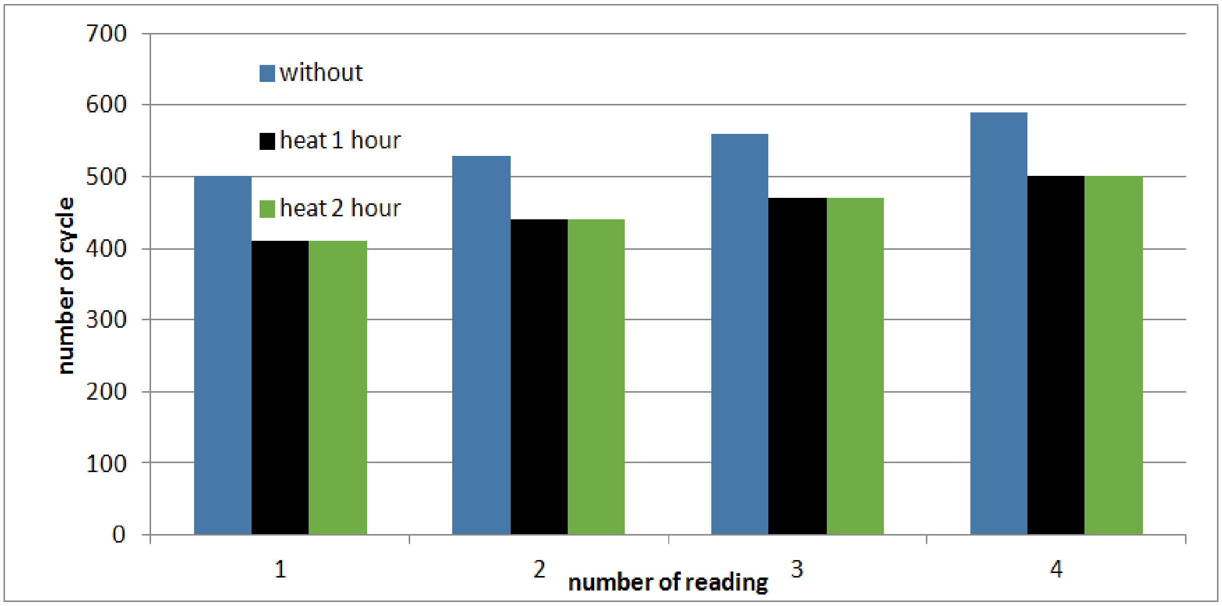

Figure 8. Show the number of cycle of every specimens of length 50cm

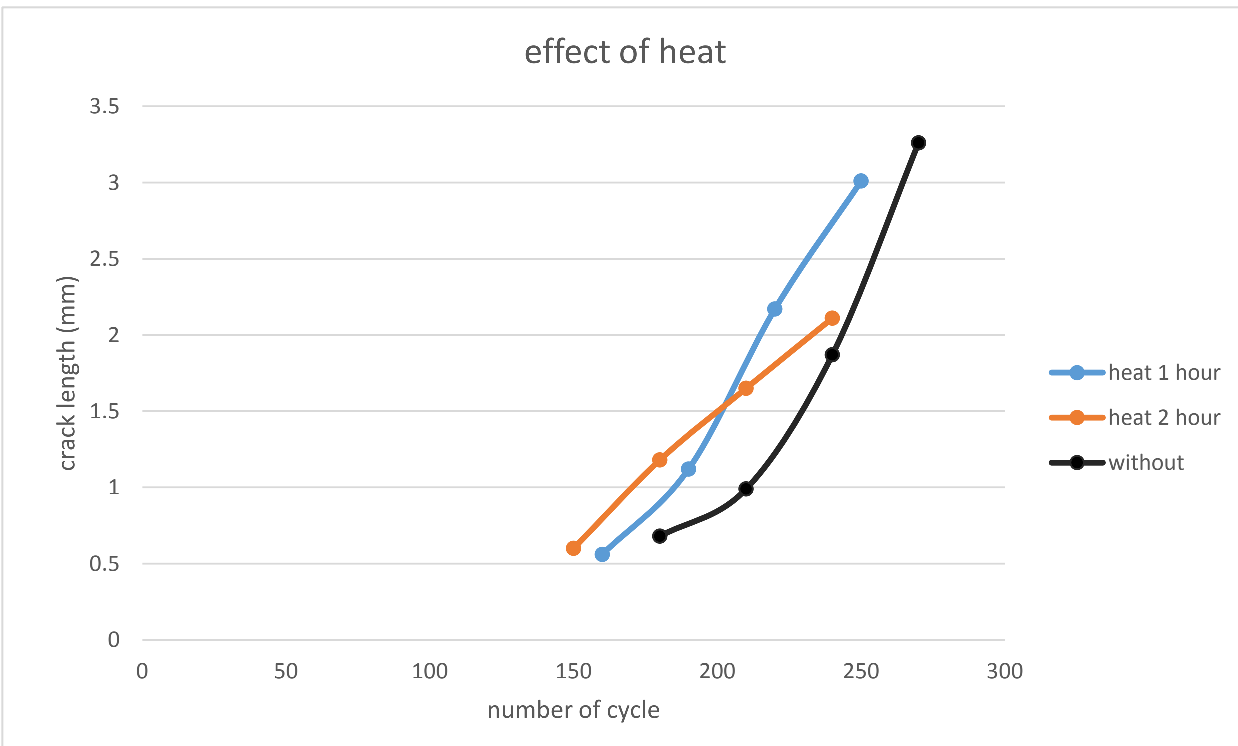

Figure 9. Show the effect of temperature on the crack growth in right side (100cm)

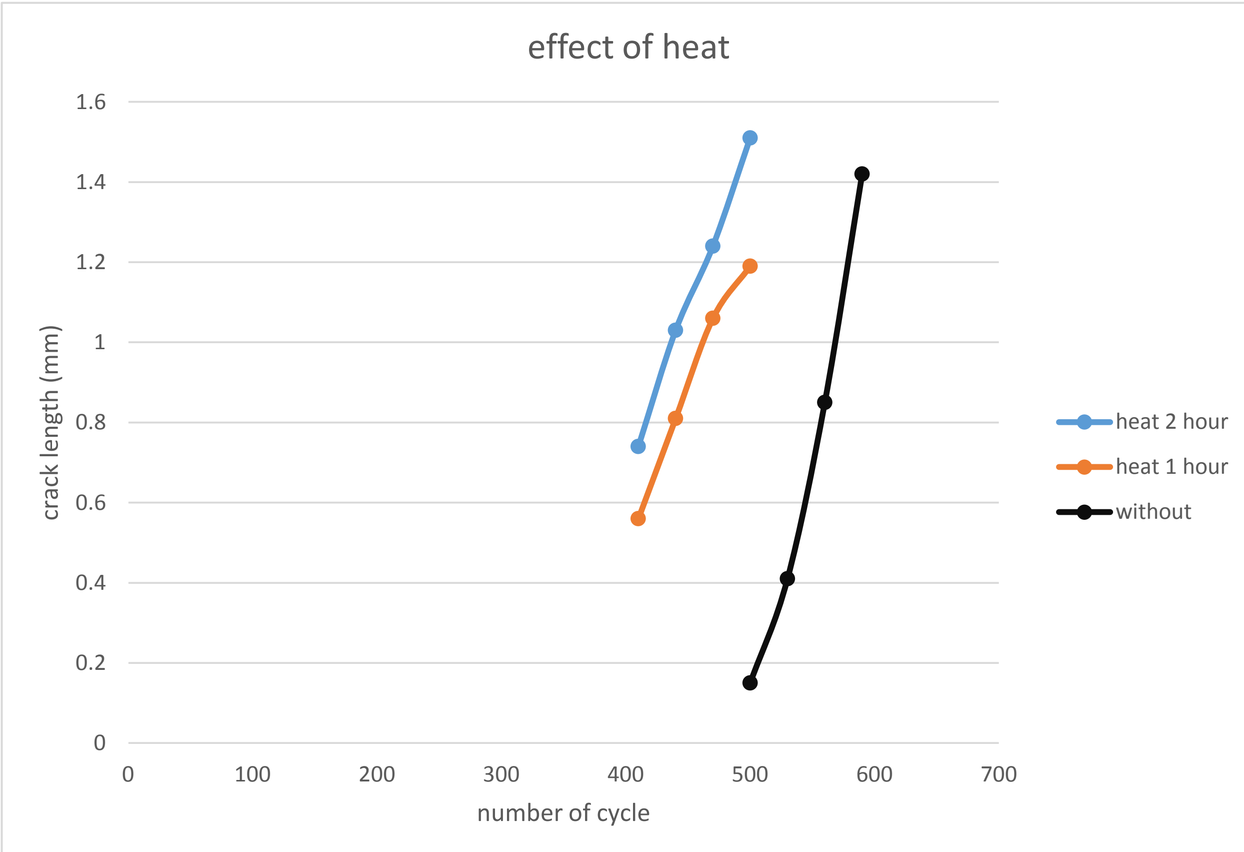

Figure 10. Show the effect of humidity on the crack growth in right side (50cm)

10. CONCLUSION

The purpose of this study is to determine the extent to which the crack is able to grow when shedding and how long it takes to grow these cracks. Some things need to be discussed to know what changes are made to these cracks and to make things better.

1- The number of cycle needed to growth the crack are reduced due to the effect of heat but it is not much because the material is made from low carbon steel. The effect may become clear when used more than 50°C
2- The number of cycle needed to growth the crack in the specimens of length 50cm are increase because the length due to the effect of bending stress in the pipes.

NOMENCLATURE

LEFM= linear elastic fracture mechanics

MTS = multi-tasking staff

da/dn = crack growth per cycle, m/cycle

r,θ = polar coordinate, dimensionless

σ_θ = circumferential stress near crack tip, Mpa

k_1 , k_2 = stress intensity factor, Mpa$\sqrt{m}$

π = mathematical constant, dimensionless
$\tau_{r\theta}$ = shear stress in cylindrical coordinate, Mpa

σ_x , σ_y , τ_{xy} = component of stress tensor, Mpa

ν = poison ratio, dimensionless

E = young modulus, Gpa

θ = angle of crack propagation, degree

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نمو الصدوع وتصرفها خلال جدران الانابيب المعرضة لأحمال صدمية تكرارية ومحيط حار

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الخلاصة
يتناول هذا البحث دراسة نمو الصدع في جدار الانابيب المصنوعة من الفولاذ منخفض الكربون تحت تأثير حمل الصدمة واستخدام تأثير الحرارة (50 درجة مئوية). تم التحكم في الظروف البيئية باستخدام جهاز تحكم عالي الدقة مع أجهزة الاستشعار. الانابيب تحتوي على صدع مسبقا. الاختبار اجري على نوعين من النماذج أحد هذه الأنواع ذو طول 100سم والأخر ذو طول 50سم. عند اجراء الاختبار فأن النتائج كانت، عند تطبيق الحرارة فأن عدد الدورات اللازمة لنمو الصدع سوف تقل. بالإضافة الى ذلك فأنه عند اجراء الاختبار على النماذج ذات الطول 50سم فأن عدد الدورات اللازم لنمو الشق سوف يزداد نتيجة لتأثير اجهاد الانحناء على الانابيب.
الكلمات المفتاحية: الصدوع، نشوء الصدوع، نمو الصدوع

