The Role of Pitting Corrosion In Reliability Assessment For Low Alloy Steels and Carbon Steel Alloys

*Lamy~a M. Dawood**

Received on: 4/8/2004
Accepted on: 15/5/2005

Abstract

Since reliability of an equipment or component is influenced through a product life cycle as a result of deficiencies occurring in design, production or due to external factors (end-environments). The effect of pitting corrosion on reliability of different low alloy steels, and carbon steel alloys are estimated in this study so as to notice the failures that may result in the end environment.

Results show that the reliability decreases dramatically as pit density and average pit depth increases for all the studied alloys, in a way that the alloys turn to non-useful from reliability point of view. Reliability is less effected by the corrosion rate of the relative alloy. These results are related to the fact that the pit depth and density better describe pitting corrosion rather than the corrosion rate.

دور التآكل النقري في تقدير المعولية لسبائك مختلفة من الفولاذ الكربوني والفولاذ المنخفض السبائكية

الخلاصة

بما إن المعولية لمعدة أو جزء تتأثر خلال دورة حياة المنتج بسبب الخلل أثناء التصميم، الإنتاج أو بتأثير عوامل خارجية (الوسط النهائي) للمنتج.

تم هذا البحث دراسة تأثير التآكل النقرى لمجموعة من سبائك الفولاذ المنخفض السبائكية والفولاذ الكربوني على معوليه هذه السبائك لملاحضة ما قد يحدث من فشل في الوسط النهائي.

تبين النتائج بان المعولية تنخفض بصورة سريعة عند زيادة كل كثافة النقر و متوسط عمق النقرة وللسبائك المستخدمة في هذه الدراسة بحيث تصبح هذه السبائك غير صالحة من حيث قيم المعولية تبين من هذا البحث بان المعولية تتأثر بصورة قليلة بمعدل التآكل وهذا يمكن أن يعزى إلى إن كل من متوسط عمق النقر وكثافة النقر يعبران عن التآكل النقري بصورة ا كثر من معدل التآكل.

* Dept. of Production & Metallurgy Eng., University of Technology.

https://doi.org/10.30684/etj.24.4.2
University of Technology-Iraq, Baghdad, Iraq/2412-0758

Introduction

Reliability is the probability of a device, or product performing its purpose adequately for the period of time intended under operating conditions encountered [1,2,3,4].

Failures occurring may be due to deficiencies in design, production, and external factors (end environments) [1]. Failures were categorized in two types [6,7]:-

1.**Element Failures**: - Due to failures in mapped functions, and

2.**pre-condition Failures**: - As a result of other behaviors in the system (external or internal). Ebeling [1] classifies three modes of failures are Electrical, Mechanical, and Chemical.

Regardless of the classification mode, it is agreed that, the impact of any failure when occurs, the system will not be immediately affected, but system reliability may decrease according to that [1,2,3].

Reliability evaluation is the most important activity of reliability activities through out the design process [5]. Probabilistic method for reliability assessment has been a mainstay of engineering system development [6,7].

Pitting corrosion is a form of extremely localized attack that produces holes in the metal. It is an especially insidious form of corrosion that causes equipment's fail after only a small percentage of designed-for weight loss [3].

Pitting damage due to the presence of aggressive environment(as the presence of chloride ions or other halide ions), and the damage is confined to small area of square millimeters or less, while other metal surface remains unaffected (passive) [8,9,10].

Pits that do not perforate parts or equipment can sometimes be accepted in engineering structure [9]. Pits can lead to an encounter fatigue and stress corrosion crack of engineering components that are subjected to external stress [9].

The aim of this study to monitor other aspects of pitting damage (fluids leakage, and loss of the component,... etc.), in a way that may help designers to increase reliability as well as quality of their design.

Reliability Assessment:-

The success of any reliability analysis depends critically on the accuracy of the

* Dept. of Production & Metallurgy Eng., University of Technology.

data used in the analysis [1]. This is why the date in reference [11] was used, these data are collected as results of the efforts of many institutes and collages [11].

The chemical composition of the alloys is shown in Table (1) as mentioned in the reference [11].

Although in most common practices Weibull function failure distribution is considered [2,4]. But since materials or equipment's failures is related to the weakest point or weakest component as in pitting corrosion case, The extreme distribution function, for the smallest value is the one usually encountered in reliability work an failures caused by corrosion [1,4].

The extreme value distribution function used in calculations is shown in equation {1} below [11]:-.

R(t)= 1-exp[[-N * (e^λt/ k-1) /(e^λD-1)]]……{1}

$$R(t) = 1 - \exp\left[\left[-N * \left(e^{\lambda t / k} - 1\right) / \left(e^{\lambda D} - 1\right)\right]\right] \quad \ldots\ldots \{1\}$$

R(t):- Reliability Function of Time

N:- No. Of Pits

λ:- Failures rate = 1/ Mean Pit depth.

K:- Corrosion Rate associated with the metal or alloy.

t:- time.

D: -Thickness of pipe or plate.

Using the data in reference [11], with the related corrosion rate of each alloy as mentioned in the same reference. Standard ASTM rating charts [12] is used to obtain the pit density values (No. Of pits per unit area) with the relative average pit depth values, the ASTM chart is shown in Fig.(1).

The calculated reliability values are shown in Table(2), using (360 days) period and, 5mm thickness for these calculations.

Discussion

Since most mechanical and electrical systems comprises collection of components. The overall reliability of the system depends on how components are arranged [2,3]. So if there are (is) component(s) of low system reliability quickly becomes very low[2,3], whether the components of the system are arranged in series or in parallel[2].

From Table_2_ it is obvious that as both, pit density and average pit depth increases the reliability of the alloy decreases sharply, and for all the estimated alloys. The corrosion rate (indication for the general corrosion) increase is noticed to be ineffective on the reliability values. This result may be related to the fact that mass is very small, but can provide information about metal loss, and may be of value with visual comparison [8,12].

It is important to determine the extent of pitting in service applications in order to predict the remaining life of the metal structure, or to predict the most pitting resistance material for service [12]. So For pitting corrosion the maximum pit depth is more significant than the average pit depth [10,12], but in this research it is desired to use the ASTM standard of pitting density as well as the average pit depth for assessments of the reliability values using the same standard data. Also the resulted data may be beneficial for comparison purposes.

The remained values of the pit density, and related average pit depth is not used because of the very low values of reliability values resulted for the calculated values shown in Fig.(1), sometimes pit average depth is almost the thickness of the tested metal.

. Its important here to mention that the used alloys in this study have different applications for engineering products, so these data can add new dimension for designers in order to have good, reliable, and quality of their designs.

Conclusions

1. The reliability information are important to the designers early in the design stage, where pitting environment is expected in order to choose the proper material, also to estimate time to failure in case that a part, or equipment could replaced.
2. Reliability values are greatly affected by pit density, and the average pit and with less extent effected by corrosion rate, this is for all the estimated alloys in this study.
3. In a moderate pit density, the reliability of low carbon steel alloys were very low in a way that these alloys cannot be used for engineering purposes in pit media.

References

1. Charles Eyeballing "An Introduction to Reliability and Maintainability Engineering" McGraw-Hill Companies. INC (1997).
2. Roy Billinton and Ronald N. Allan "Reliability Evaluation of Engineering Systems".
3. George Dieter "Engineering Design", McGraw-Hill (1983).
4. K.C. Kapur, and L.R. Lamberson" Reliability in

Engineering Design", John Wiley and Sons, (1977).
5. Ben Wang, "Integrated Product, Process, and Enterprise Design" Champman and Hall, 1st ed. (1997).
6. WWW. Steven Kementa, and kosuke Ishii, 1998 ASME Design Engineering Conferences, Atlanta.
7. WWW. Steven Kementa, and Peder Fitch, and Kosuke Ishii, 1999 ASME Design Engineering Conferences, Nevada.
8. Simialowska. S.Z., "Pitting Corrosion of Metals" NACE (1987).
9. Galvale, "Pitting Corrosion", (1982).
10. Fontana. G. Mars. and Greene D. Norbert., "Corrosion Engineering", Mac Graw-Hill Book Company, (1978).
11. WWW. Corrosion Network, Avesta Sheffield AB, Sweden, BASF,Germany,
12. British Steel Plc,Swindon Technology Center,UK, Denmark's ,EDF,France
13. Insttituto Per La Corrosione Marine,Italy, Sintef,NORWAY, Swedish
14. Corrosion Institute,Sweeden, and University of Portsmouth, UK (2002).
15. 12. 1989 ASTM Annual Book, G-46,pp172_176.

Fig.(1). Standard ASTM rating charts [12]

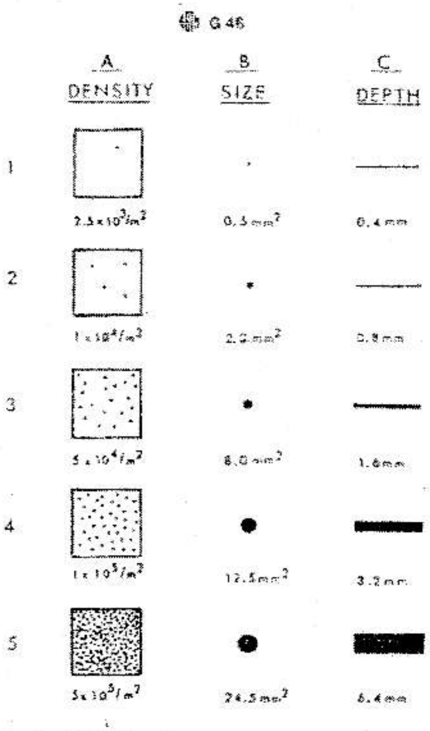

Table No.1. Low alloy steel and carbon steel-laboratory tests Material

Nominal composition	C	Si	Mn	P	S	Cr	Mo	Ni	Cu
1%Cr	0.066	0.27	0.95	0.005	0.005	1.02	<0.005	0.04	<0.02
2%Cr	0.081	0.24	0.93	0.006	0.005	1.96	0.006	0.06	<0.02
0.5%Mo	0.069	0.25	0.91	0.006	0.004	0.02	0.490	<0.02	<0.02
0.5%Cu	0.066	0.25	0.97	0.006	0.004	0.03	<0.005	0.04	0.51
1.85%Si 0.25Cr	0.080	1.35	1.00	0.015	0.005	0.56	-	-	-
1.35%Si 0.55%Cr	0.080	1.35	1.00	0.015	0.005	0.56	-	-	-
CrNiCu	0.057	0.43	0.74	0.012	0.005	0.90	-	0.23	0.29
Mild steel	0.110	0.04	0.53	0.012	0.007	0.02	-	0.02	<0.02

Table No._2_Reliability Assessment.

Alloy [11]	Corrosion Rate K hr/mm [11]	% Reliability		
		Pit Density [12] N=2.5*10^3 / m^2 Average pit Depth = 0.4mm[12].	Pit Density[12] N=10^4 / m^2 Average Pit Depth 0.8mm[12].	Pit Density[12] N=5*10^4/m^2 Average pit depth 1.6mm[12].
1% Cr	1.8*10^5	99.99	96.0	9.0
2% Cr	1.84*10^4	99.95	67.19	6.0
0.5% Mo	5.5*10^4	99.98	87.68	4.3
0.5% Cu	5.5*10^4	99.98	87.68	4.3
1.85%Si 0.26%Cr	3.8*10^4	99.98	82.68	4.1
1.35%Si 0.55%Cr	5.5*10^4	99.98	87.68	4.3
Mild Steel	9*10^4	99.98	92.24	7.07