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Pitting Stochastic Study in Airframe Aluminium Alloy using Non-linear Ultrasonic

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Abstract:

Pitting corrosion is considered to be one of the principal degradation mechanisms for high-strength aluminum alloys. The aircraft airframe has been the most demanding application for aluminum alloys. The combined effects of corrosion and cyclic loading have been shown to produce cracks from corrosion pits and pits have frequently been the source of cracks on aircraft components operating in fleets. Once the pit or group of pits form, the rate of pit growth is dependent mainly on the material, environmental conditions and type and state of stress. Therefore, to estimate the total corrosion fatigue life of a component, it is of great importance to develop realistic models to establish the component life in these situations and to formulate methods by which designers and operators know likely sources of pitting early in the design and fleet operation. There are certain gaps in knowledge with regards to life prediction for pitting initiated fatigue. The need is to gauge the extent of pitting damage of a component or material non-destructively and predict the remaining life through superimposition of the pertinent operational, environmental and material parameters. However, a foolproof non-destructive means to characterize and three-dimensionally map pits is not available. The pitting phenomenon has to be analyzed statistically and the kinetics of pitting assessed through a change in the statistical distribution parameter of pits rather than deterministic equations relating pit dimensions to time. In this work we have applied high frequency ultrasonic and non-linear ultrasonic to assess the damage due to pitting and attempt has been made to establish correlations between this non-destructive tools and pit stochastic.

Key Words: Pitting, Al-alloy, ultrasonic, non-linear ultrasonic, pit stochastic

Introduction:

Pitting corrosion is a localized form of corrosion by which cavities or "holes" are produced in the material. Pitting is considered to be dangerous than uniform corrosion damage since it is more difficult to detect and predict. Moreover, apart from localised loss of thickness, corrosion pits also act as the source of stress risers. Fatigue and stress corrosion cracking may initiate from the base of corrosion pits. The combined effects of corrosion and cyclic loading have been shown to produce cracks from corrosion pits. Pitting corrosion is considered to be one of the principle degradation mechanisms for high strength aluminium alloys and the aircraft airframe has been the most demanding application of aluminium alloys. Hence early detection of hidden corrosion in aging aircraft aluminum structures is a major safety concern.

The pitting phenomenon has been well studied in 2XXX and 7XXX alloys. One of the first investigations of pit growth kinetics on aluminum was made by Godard [1] who found that pit depth was proportional to $t^{1/3}$. By predicting the pit depth from this relationship, he obtained a good agreement with the pitting in service. Surface observations and serial sectioning techniques are most often used in the study of pitting. These techniques provide essentially two-dimensional information and can be tedious to apply. Furthermore, the information is limited (or inadequate) and can be misleading. Serial sectioning, on the other hand, can provide useful information, but requires careful polishing and reconstruction. It is most effective for isolated large pits of hundreds of micrometers, and is impractical for smaller pits or clusters of pits because of imprecision in pit location and polishing control. A technique has been developed for studying the 3-dimensional shapes of corrosion pits by C.M. Liao et al. [2]. They provide a 3-dimensional perspective that was heretofore missing from surface observations and serial sectioning techniques, and can aid in the quantitative assessments of the kinetics and the mechanistic understanding of pitting corrosion. A novel digital fringe projection (DFP) technique has been developed for the detection and quantitative evaluation of corrosion on engineering structures. DFP detects and evaluates corrosion by measuring surface topographical changes caused by corrosion. This technique has the potential of providing rapid on-site inspection and evaluation of corrosion on large structures [3]. But with the increasing number of civil and military aircrafts, there is a growing need for faster non-destructive corrosion inspection techniques.

Recent research in NDE has led to the development of a number of techniques for detecting and measuring hidden corrosion, which could be used to underpin life extensions for aircraft structures. The possibility of using ultrasonic Lamb waves to detect hidden corrosion in platelike aircraft structures is well established for piezoelectric ultrasonic generation and detection [4]. High frequency ultrasonic and laser ultrasonic have also been used to map the hidden corrosion. Using the existing ultrasonic technique, it is required to map the wall loss due to corrosion but the quantification of pitting density in a localised area is not possible [5]. More importantly, a wall thickness reading at a given point depends on good through thickness echoes to measure accurately the time of flight. Rough corroded internal wall surface make it difficult to obtain valid readings. In this present work, we have attempted to apply NLU to image the pitting corrosion in 7075 Al alloy with different pitting exposure time.

Experimental:

7075 Aluminium alloy in T6 temper condition was chosen for this pitting stochastic study. Chemical composition of the alloy is given in table 1.

Table 1: Chemical composition of 7075 T6 Al alloy

Cu	Fe	Si	Mg	Mn	Ti	Zn	Cr	Al
1.88	0.3	0.11	2.57	0.15	0.03	5.96	0.23	Bal

Aluminium samples were mechanically polished with silicon carbide papers and in the final stages, with 0.05 µm Al_2O_3 polishing powder and then in silvo. The specimens were subjected to pitting in a corrosive media (0.1N NaCl) with different exposure time (1hr, 6hrs, 16hrs, 48hrs and 72hrs). The microstructures of the unexposed and exposed samples were taken, for comparing the images.

After exposing, the samples were first rinsed with water. The oxide layer (or corrosion product) on the specimen was cleaned by a mixture of 50ml phosphoric acid & 20g chromioum trioxide (CrO_3) acid, then rinsed with water, dried and then ultrasonically cleaned.

At each exposure time, Optical microscopy, high frequency ultrasonic imaging and NLU measurements were carried out to establish this new technique to detect the pitting in material which could be useful for structural health monitoring.

Ultrasonic measurements were carried out using 100MHz immersion probe with a spatial resolution of 25µm.

For NLU measurement, a high power ultrasonic signal analysis device, RAM 5000 (Ritec, Warwick), was used. The NLU measurements were performed on the samples at various interrupted cycles along the gage length. A 5 MHz longitudinal transducer was used as a transmitter, and a longitudinal broadband transducer with a centre frequency at 10 MHz was used as a receiver. The waveform of the transmitting signal was a tone burst with five cycles. The received signal from the 10 MHz broadband sensor was filtered using a band pass filter and then amplified by a low-noise preamplifier. The transmitted signal was fed in one channel of the oscilloscope and amplified received signal was fed to the other channel. The oscilloscope was interfaced with the computer through GPIB.

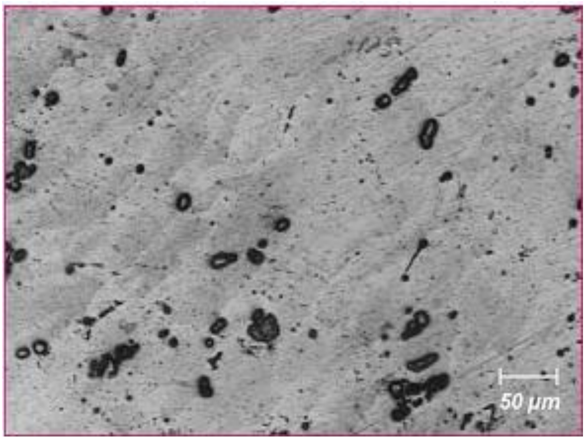
To improve the signal to noise ratio (S/N) of the received signal, a Matlab program was developed at our laboratory for windowing the required reflected echo, digital filtering of the windowed signal corresponds to the frequency of the fundamental (f) and the second harmonic (2f) then to perform FFT of each filtered signal to determine A_1 (amplitude of the fundamental) and A_2 (the amplitude of the 2^{nd} harmonic) and then to measure the nonlinear ultrasonic parameter (β) from the relation,

$\beta = A_2 / A_1^2$. Detailed derivation of the equation is given in reference [7]. Figure 1 shows the experimental setup for NLU measurement. Results of NLU were correlated with the results obtained from image analysis and high frequency ultrasonic imaging.

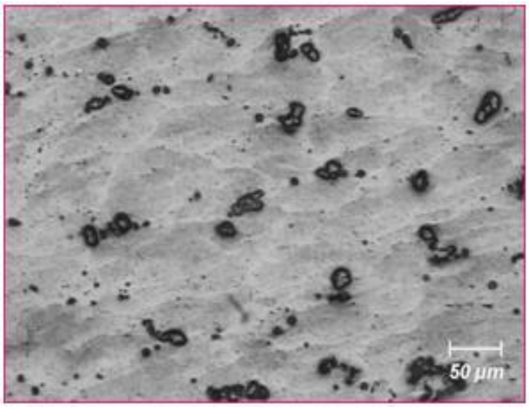
Results and Discussion:

Figure 2(a) - (d) shows the optical micrographs of the virgin, 6 hrs, 16hrs and 48 hrs pitted samples. Corresponding 3-D views of the high frequency ultrasonic imaging of the same specimens up to 500 micron depth are depicted in figure 3(a) – (d).

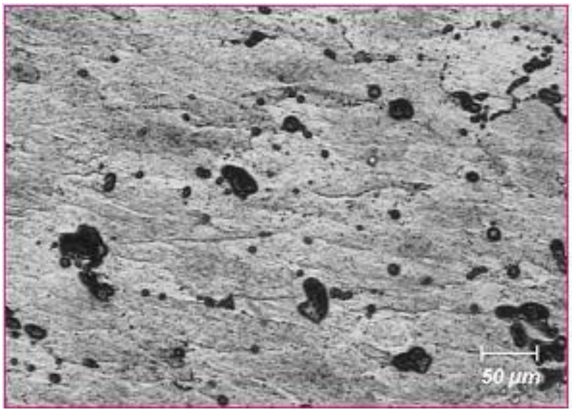
(a)



(b)

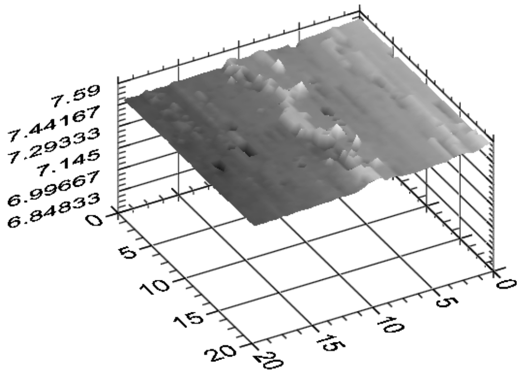


(c)

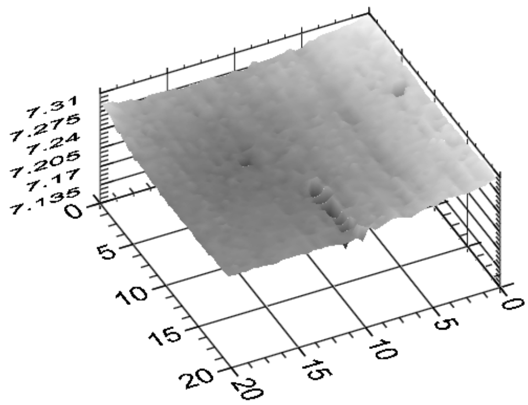


(d)

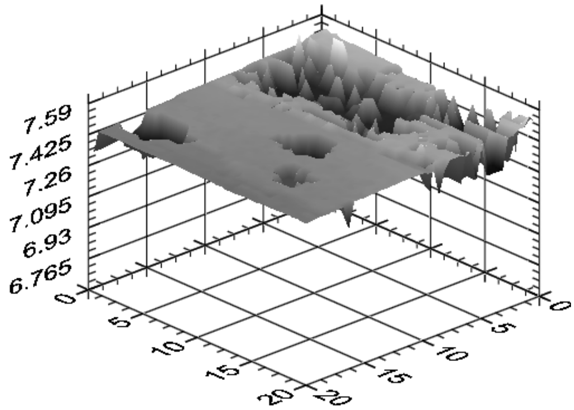
Figure 2: Optical micrographs of (a) virgin, (b) 6 hrs, (c) 16 hrs, and (d) 48 hrs pitted specimens



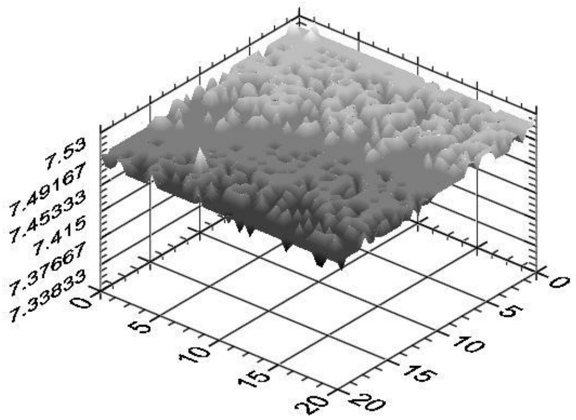
(a)



(b)



(c)



(d)

Figure 3: 3-D views of the ultrasonic scanning of (a) virgin, (b) 6 hrs, (c) 16 hrs and (d) 48hrs pitted specimens

The pitting morphology of each sample was analyzed statistically by the image analyzer. For each specimen, twelve images were separately analysed. The pitting kinetics was studied by observing the change in the pit size and number distribution with time for a specific heat treatment.

The variation of pit number density with the pitting exposure time is plotted in figure 4.

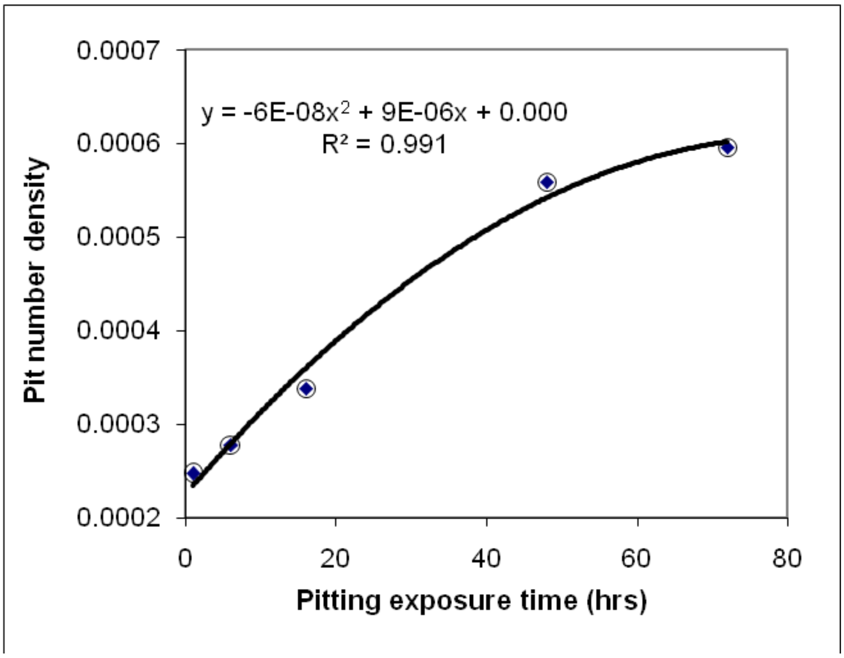


Figure 4: Variation of pit number density with pitting exposure time

From NLU measurement, non-linear parameter β was determined at different positions on virgin as well as on pitted specimens. It has been found that the value of relative β varies at different positions and the maximum of β corresponds to the position where ultrasonic imaging shows the maximum pitting. This work reveals the applicability of non-linear ultrasonic in corrosion pitting detection. Figure 5 shows the variation of β with pitting exposure time which follows the same trend as that of pit density with pitting exposure time.

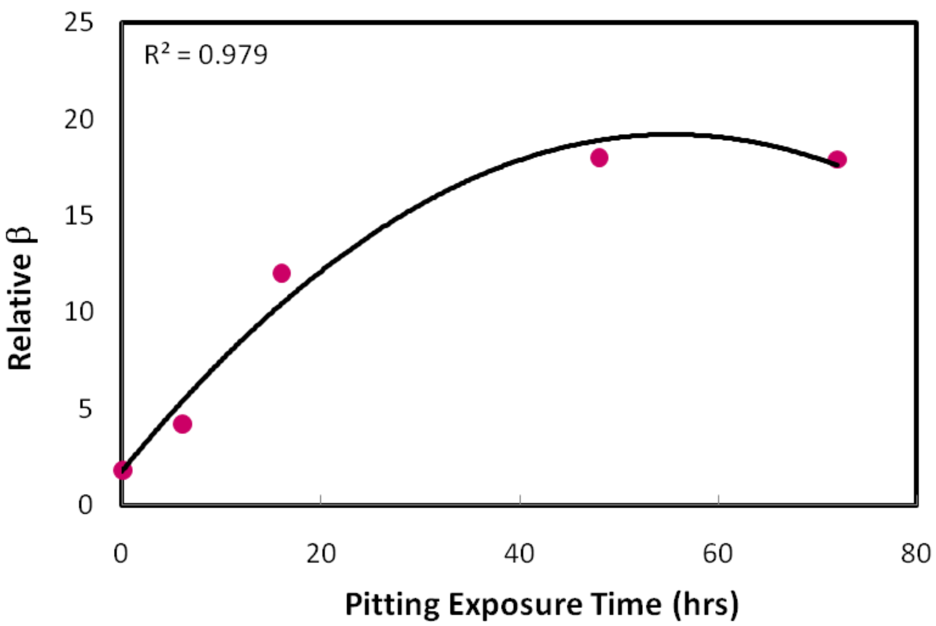


Figure 5: Variation of relative β with pitting exposure time

Till 48 hrs of exposure time, there is increase in β thereafter it saturates. Work has also been extended to evaluate the corrosion pitting in T73 Al alloys with different exposure times and a definite correlation of β with pit number density has been observed. From this study it has been found that non-linear parameter β could be a definitive parameter in hidden corrosion detection in structural components.

Conclusion:

In this paper, non-linear ultrasonic technique has been used to evaluate pitting corrosion in airframe Al-alloy. Results of NLU have been compared with high frequency ultrasonic imaging and optical imaging. It has been found that the non-linear parameter β could be a definitive parameter in pitting corrosion detection in structural components.

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