I －90 ACCURACY IMPROVEMENT OF FATIGUE CRACK DETECTION BY ULTRASONIC INSPECTION

Toshiyuki OSHIMA F JSCE Kitami Institute of Technology
Tomoyuki YAMAZAKI M JSCE Kitami Institute of Technology
Muhammad S.RAHMAN M JSCE Nakagami Civil Design Office
Takao HIGETA ZUKOSHA
Hideo KUDO Taiheiyo Sogo Consultants
Hideaki TANAKA M JSCE Japan Steel Works Ltd.

1.INTRODUCTION

Ultrasonic inspection for detection of surface and sub-surface defects has advantages over other techniques in nondestructive testing. Internal fatigue crack detection is important when evaluation of remaining life and durability of structure is needed. Generally fatigue crack is very sharp in nature. Fatigue crack initiation and propagation are estimated by cycle number of repeated stress, stress concentration factor and type of structure or member.

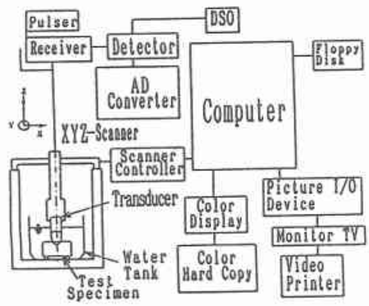
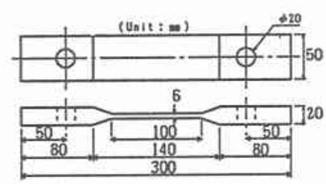
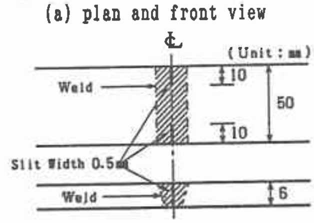


Fig.1. Measurement System

If it is possible to monitor this propagation in real time, the measured quantities could be used as indicators of the extent of fatigue damage. In the present study as a continuation of this research, this paper will focus on visualization of fatigue crack propagation due to cyclic loading. Here ultrasonic immersion acoustic wave technique has been performed on previously damaged specimen for studying the growth behavior of small fatigue cracks. For analysis of microcrack propagation in detail angle beam scanning was performed. By calculating arrival time from crack tip echo here measured crack length and observed crack propagation nature. From precise wave analysis of crack process zone and 3D image of defect of crack we can estimate fatigue crack growth and evaluate the remaining life time for civil structures.



(a) plan and front view



(b) cross-sectional view

Fig.2. Specimen No.1

2.EXPERIMENTAL PROCEDURE

2.1 Equipment Set-up

Fig.1 illustrates the ultrasonic immersion scanning system(AT5000) for this study. The system function as automatic scanning with controller unit and image display has some sub-systems. Their details are as follows;

I) Ultrasonic transducer:

a)Frequency - 10 MHz

b)Spherical diameter - 9.525 mm

c)Focal length - 80 mm.

II) Automatic scanning control unit:

a)Scanning range(mm)- 500(W)* 500(L)* 250(D)

b)Scanning pitch(variable,mm)- 0.005 ~ 9.95

c)Scanning speed - 10 ~ 150 mm/sec

III) Ultrasonic wave recorder system(Dual channel digital storage oscilloscope,DSO):

a)Sampling speed - 500 mega samples/second

b)Resolution of amplitude - 10 bits

c)Frequency range up to 30 MHz

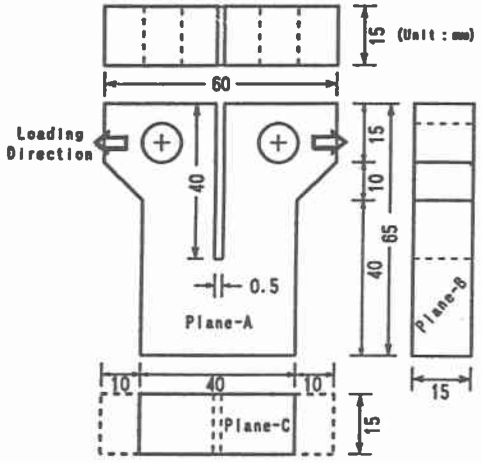


Fig.3. Specimen No.2

2.2 Test Specimen

Specimens are shown here in figs No.2 and 3. Specimen No.1 is a flat horizontal steel plate of varying thickness. Defect shape is slit opening of 0.5 mm width, 6 mm thick and 10 mm length which is filled with welded material of 1~ 2 mm thick. Specimen No.2 is a Y-shaped steel specimen(SS400), also slit width of 0.5 mm opening and 40 mm in length from upper portion. Detail dimensions are shown in figure respectively.

2.3 Ultrasonic Measurements

2.3.1 Scanning Tomograph

Working principle - During scanning the echo heights and time of flight data are stored in memories corresponding to positions of the transducer at predetermined intervals. The sampling gate of time axis is set to receive first boundary and bottom echo of the reflection wave. C-scan image is obtained by synchronizing flaw or discontinuity signals as the transducer is moved across the entire surface of the specimen. It shows the location of defects, but in the simplest form it does not show their depth. The digital voltage data with the reference voltage gives image data to represent a 2D shape of crack and other subsurface condition on a real time basis. DSO(Digital Storage Oscilloscope) can receive the whole reflection waves as 4096 point digital values for every wave. The reflection waves in the time gate and its FFT spectrum as frequency verses echo amplitude are stored in floppy disk for detail analysis.

2.3.2 Angle Beam Testing

Angle beam scanning provide larger reflection from the defect when the defect is normal to the surface. Angle beam inspection is accomplished mostly with SV(shear vertical) waves. The refraction angle is the key parameter specified in angle beam inspection which is a function of the material properties and the incident angle. Scanning direction and transducer position is shown in fig.4. Incident angle is 19° so that under water refracted angle becomes 45°.

3. EXPERIMENTAL METHOD

Firstly, normal beam scanning performed on virgin specimen and obtained C-scan image. Then during finished with cyclic loading scanning tomograph and waveform are recorded from cracked zone. Repeated loading and scanning tomograph done on both specimen simultaneously before breaking. For crack initiation and propagation in specimen No.1 applied loading range is between min. 2.33 KN to max. 31.0 KN of frequency 10 Hz. Stress amplitude of total cross sectional area is 95.6 MPa. The specimen was broken at repeated load number of 380000 cycles. Image and waveform of cracked portion with transducer normal and inclined position, recorded around 1 mm inner side from slit corner as transducer center on area 10mm*20mm, so that wave from slit corner to crack tip is recorded. For specimen No.2 cross-sectional stress amplitude is 12.5 MPa, loading range min. 1.33 KN to max. 6.00 KN of frequency 10 Hz. For detecting crack propagation specimen finished with 150000 cycles, then normal and angle beam scanning performed on the plane A, B and C as shown in Fig. 3.

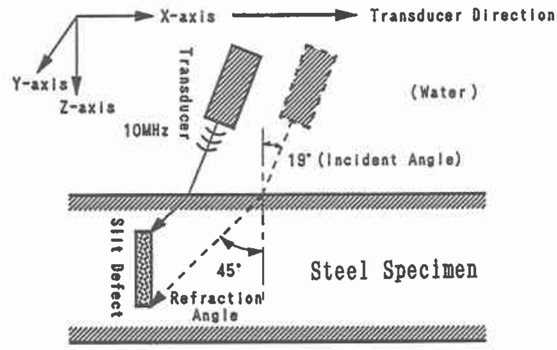
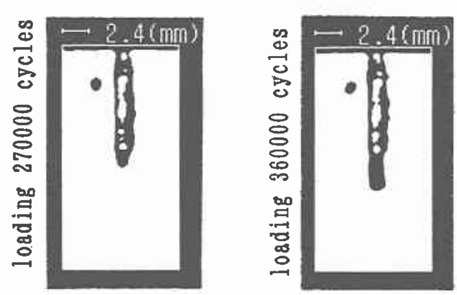


Fig.4. Angle Beam Scanning

4. EXPERIMENTAL RESULT

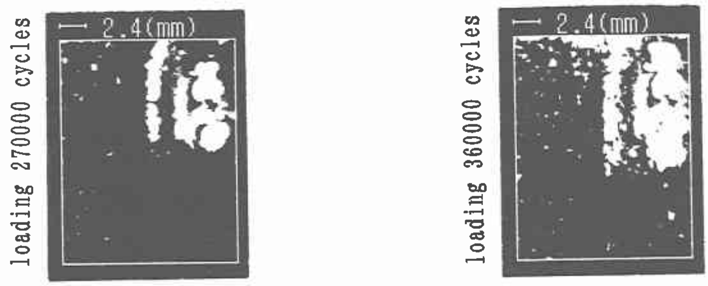
Image Display

White bright portion where echo amplitude is high and black portion where echo amplitude is low. Scale for the image is shown upper left side of the image. In Fig.5(a) C-scan images of specimen No.1 for fatigue loading finished of 270000 cycles and 360000 cycles by normal beam scanning are shown. The black portion in center is the shadow of the slit. The bright portion in the middle of the shadow represents echo from inside of crack. For reflection echo from bottom of the crack plane shadow image size is larger than the original slit size. In Fig.5(b) image for angle beam scanning of same loading cycles is shown. The centrally bright elongated portion is upper tip echo and in right hand side lower tip echoes are seen. From images slow rate of progress of crack propagation is observed. Because the distance between lower tip and bottom surface is small, lower tip echo is scattered. But we can identify the lower tip echo from the received waveform. After loading 360000 cycles comparing image during crack propagation, it is observed that at normal and angle beam scanning crack length measured from slit corner to crack tip is 3.4 mm. Crack extension in depth direction measured from tip echo is measured as 5.3 mm.



(a) Normal beam scanning

Fig.5. C-scan Image for Specimen No.1



(b) Angle beam scanning

Fig.5. C-scan Image for Specimen No.1

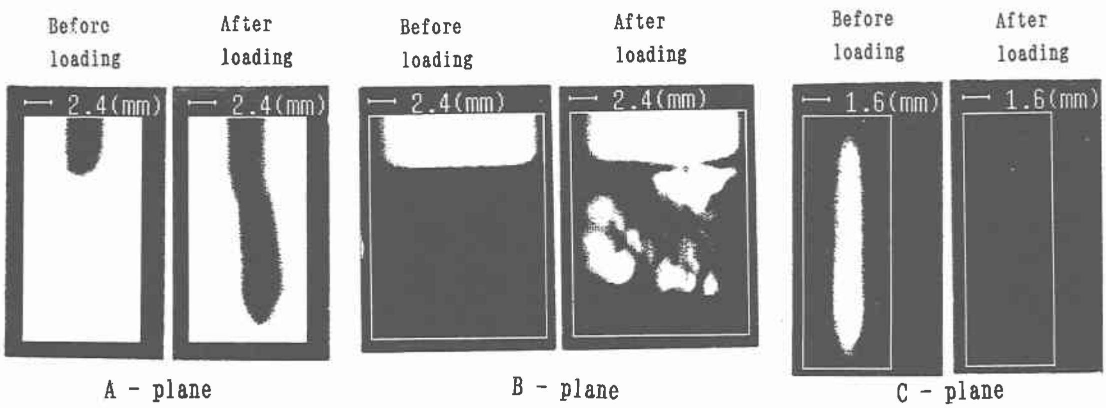


Fig.6. C-scan Image for Specimen No.2 Before and After Loading 160000 cycles

For angle beam scanning where refraction angle 45° is constant. Fig.6 shows C-scan image for specimen no.2(Fig.3) before and after finished of 160000 cycles loading. Image for scanning on plane A(Fig.3) and reflection echo from bottom plane where crack length elongated and becomes sharp which can measure by eye estimation. Scanning on B plane observed image from scanning parallel to crack plane and reflection wave recorded directly from the cracked area. Rough and undulated surface of fatigue crack is effecting on the scattered image at the crack tip in Fig.6 (a) and (b). In Fig.6(c) wave direction is parallel to the crack. If we have the propagation of crack tip, wave is scattered and weak reflection echo is observed as shown in Fig.6(c).

5.REFLECTION WAVE ANALYSIS AND DISCUSSION

For scattering wave at defect boundary it is difficult to get clear defect image. The scattering may be occurred due to variation of wave length, size and shape of defect. For specimen No.1 focus of the 10 MHz resonance frequency transducer adjusted 1 mm inner side of slit corner as the center of the cracked area then scans over the area of 10mm*5mm. Then reflection waves received by 0.02 mm pitch. Received original waves are shown in Fig.7. Wave recorded from corner of the slit to the crack propagating direction at pitch 0.02 mm for 36 points as wave No.1 ~ 36. Here horizontal axis is for time and vertical axis for echo amplitude which are reflected from the cracked area in the specimen. As the reflection wave has both the boundary echo and bottom echo, it is observed that when the transducer comes close to the crack tip, and then the amplitude of boundary echo becomes greater than bottom echo. After loading 360000 cycles surface echo appears 1.2μs later than incident echo. It is observed from wave No.9 ~ 14 that crack tip echo is 0.76μs later than surface echo. From wave No. 28 ~ 36 it is observed that the bottom echo appears around at 3.6 ~ 5.3μs later than surface echo. We calculated the delay time from surface echo to bottom echo corrected with amplification factor. So we can measure the length of crack as thickness and location of crack tip shown in Fig.9. Again original waveform and its spectrum of specimen No.2 shown in Fig.8. Measured waveform received from 2mm inner side of the slit to downward direction with 0.02 mm pitch for 21 locations before loading and after loading by 160000 cycles with pitch 0.02 mm for 44 locations on B-plane. Wave No.1-10 is from slit and the rest is from crack propagated area. Here firm line is for wave before loading and dotted line indicates wave after loading. Comparing original waves from slit and crack area wave shape is same for before and after loading, so the frequency of reflection wave does not changes. Feeble echo reflects from crack area and scattered due to rough surface and undulations. For spectrum of these waves from crack area more weaker echo of reduced amplitude is observed. These weak continuous waves indicate the presence of crack.

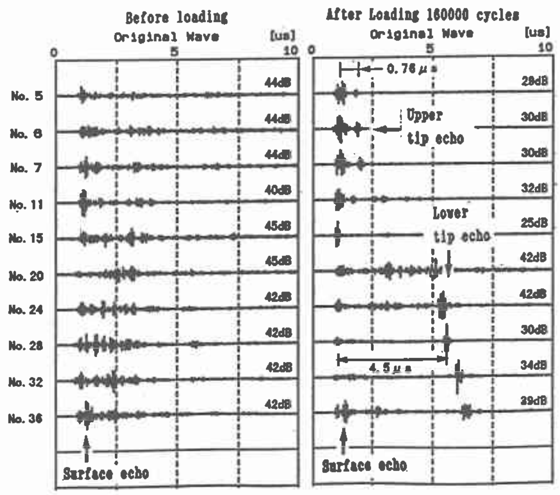


Fig.7. Original Wave from Specimen No.1

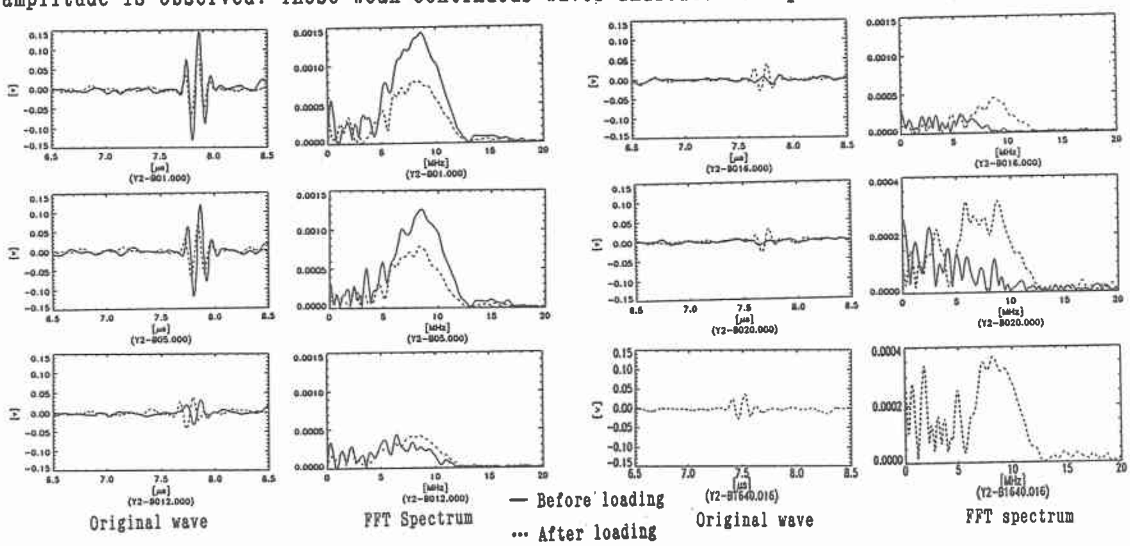
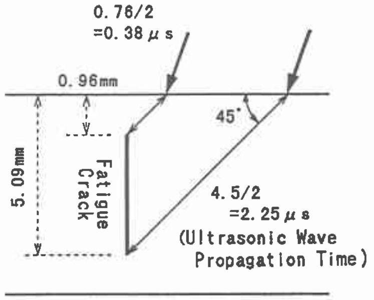


Fig.8. Original and FFT Spectrum for Specimen No.2 (B-plane)

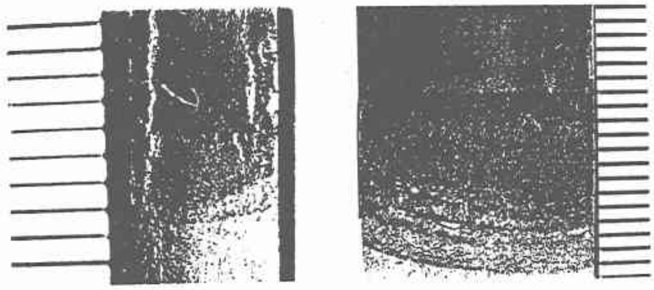
5.1 Image of Breaking Plane

Fig.10 (a) and (b) show the photograph of breaking plane. From these pictures boundary of crack propagation are observed. Crack is propagated only in horizontal direction there is no vertical crack propagation is noticed.



Crack length = 5.09 - 0.96
= 4.13 mm

Fig.9. Calculation of Crack Length



(a) Specimen No.1 (b) Specimen No.2

Fig.10. Image of Breaking Plane

6.CONCLUSION

Observation by using ultrasonic method of fatigue crack before and after application of cyclic loading has led to following conclusions.

For specimen No.1 : From C-scan image propagated crack length is 3.4 mm. From fracture plane crack length is 3.5 ～ 3.8 mm. Crack length measured from depth direction scanning is 5.3 mm. From image we get different result due to changing focal points and scattering of reflection echoes. It is observed from picture of the broken plane there was no crack propagation in vertical direction. By calculation of crack length 4.13 mm from wave analysis is a good agreement. Crack propagated here at a very slow rate.

For specimen No.2 : For internal fatigue crack detection it is necessary to scanning and wave recording from different plane. Images from before and after loading indicate initiation and elongation of crack propagation. It is cryptic from the images whether crack occurs or not. Still it is very new research to characterize crack propagation nature and visualization.

7.REFERENCES

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