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A Relationship between UT Reported Sizes and Actual Sizes of Defects in Rotor Forgings

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Abstact The relationship between the EFBH (Equivalent Flat-Bottom Hole) size measured by non-destructive method and the actual size by destructive method in many rotors manufactured at Doosan Heavy Industries & Construction Co. Ltd. was investigated. In this investigation, "the Master Curve" compensating the differences between UT reported sizes and actual sizes of defects in our rotor forgings were obtainable. The applicability of this "Master Curve" as a way of calculating the actual defect size was also investigated. For the evaluation of rotor forgings, it is expected that this "Master Curve" may be used to determine the accurate actual sizes of defects.

Keywords: rotor forging, rotor defect, ultrasonic testing

1. Introduction

In order to evaluate the reliability of rotor forgings, it is very important to know the actual sizes of defects in the rotor forgings. The determination of the defect size requires an accurate non-destructive measurement. However, there may be some differences between the reported sizes with an ultrasonic non-destructive testing method and the actual sizes of defects. These differences may cause a severe error in the evaluation of rotor forgings. Therefore, the calculated size with "the Master Curve" considering a safety factor, that usually results in a larger size than the reported size, has been used during the evaluation of rotor forgings (Ewald et. al., 1985, Doosan Heavy Co., 1991, Haigh, 1975, Chung, 1992). In this study, the relationship between the measured sizes and the actual sizes of defects in rotor forgings manufactured by Doosan Heavy Industries & Construction Co. Ltd. (hereafter DHIC) was investigated and the difference between the currently proposed relationship and the previously recorded relationship was also obtained.

2. Experiments

2.1 Non-Destructive Testing

In inspecting the rotor forgings by ultrasonic testing, we measured defects with the EFBH (Equivalent Flat-Bottom Hole) sizing method. In order to calculate the signal amplitude of ultrasonic beam reflected from a small circular reflector, Equations 1 and 2 can be used (Krautkramer, 1990).

$$\frac{\textit{echo from } \text{small } \textit{reflector}}{\textit{echo} \text{ from solid cylinder}} = \frac{2dA}{a^2\lambda} \tag{1}$$

$$\frac{\textit{echo from } \text{small } \textit{reflector}}{\textit{echo} \text{ from solid bore}} = \frac{2(d-b)A}{a^2\lambda}\sqrt{\frac{d}{b}} \tag{2}$$

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Where a is distance to reflector, b is bore diameter, d is diameter of forging cylinder, A is area of reflector and λ is wavelength.

During inspection of rotor forgings, the ultrasonic sensitivity in which the ultrasonic signal from a standard defect of 0.9 mm EFBH size at the center of rotor forging at 5% amplitude can be calibrated and the multiple factor can be shown as follows

$$Multi\ \text{Factor(solid rotor)} = 0.06\frac{d}{f} \tag{3}$$

$$Multi\ \text{Factor(bored rotor)} = 0.12\frac{d-b}{f}\sqrt{\frac{b}{d}} \tag{4}$$

Where f is frequency (MHz).

During inspection of rotor forgings at this multiple factor, the EFBH size can be calculated from Equations (5) and (6).

$$EFBH\text{(solid rotor)} = 0.8\frac{\sqrt{I}}{d}z \tag{5}$$

$$\text{EFBH(bored rotor)} = 0.8\frac{\sqrt{I}}{d-b}z \tag{6}$$

Where z is distance to reflector and I is ultrasonic amplitude.

By using above equations, the amplitude of ultrasonic signal can be converted to the EFBH size. In Solid and Bored Rotor, a distance ratio (R) can be also defined and it is as follows.

$$R\text{(solid rotor)} = \frac{\text{distance to indication}}{\text{distance to centerline}} \tag{3}$$

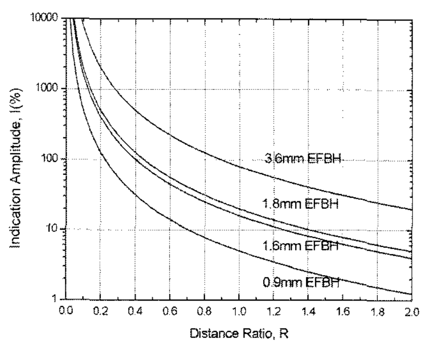

Fig. 1 Indication Amplitude vs. Distance Ratio

$$R\text{(bored rotor)} = \frac{\text{distance to indication}}{\text{distance to bore surface}} \tag{4}$$

Generally, the ultrasonic transducer with a diameter of 25 mm and frequency of 2.25 MHz is used to inspect the rotor forgings and the relationship between the distance ratio and the indication amplitude can be obtained during the inspection of defects having several EFBH sizes. Fig. 1 shows the relation.

2.2 Measurement of Actual Defect Size

To obtain the actual size of defects in many rotors manufactured by DHIC, the indication points based on an ultrasonic report were first marked and the specimens including the defects from the marked points were machined to a cylindrical shape. Then, to increase the probability of defects causing a given indication, the C-Scan focusing ultrasonic tests were conducted on the specimens to find the exact position of the defects in specimens. After cooling the specimens in the liquid nitrogen environment, the specimens were broken by a tensile test at the position of the defect and the actual sizes of defects were measured by a scanning electron microscope (SEM) or optical microscope. Fig. 2 shows the opened defects.

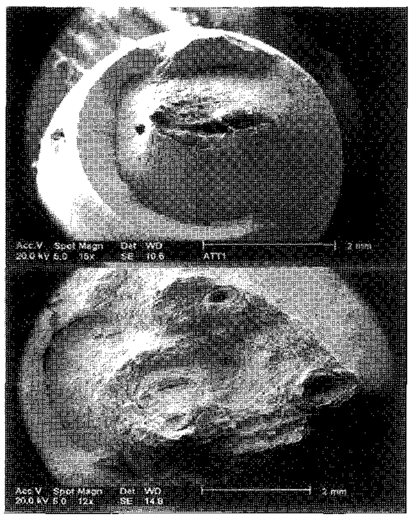

Fig. 2 Actual size of defects

Comparison of the actual determined sizes of defects with those calculated from ultrasonic data is strongly dependent upon the nature of defects, particularly when they are present in cluster. Some of the difficulties are encountered because the ultrasonic data used for calculation of the EFBH diameter, i.e., peak amplitude, is based on the integration of the reflections from all defects within a given volume defined by diameter of the ultrasonic window and a distance parallel to the sonic beam of 6 to 12 mm.

The metallographic determination on whether indications on radial plane are individual defects or parts of clusters is quite arbitrary and should be made based on how they would probably react under an applied stress instead of how they would affect an ultrasonic beam. This can be explained in more detail as follows. Drawn in Fig. 3 are two extremes of how metallographic defects might fall within a single ultrasonic window. The reflecting area is the same in both cases. However, the defects in the window on the left are apart enough so that none would be expected to agglomerate. On the right, the concentration of defects in one region leads to a metallographically defined cluster that is many times larger than the individual defects. This difference in defect distribution may not be distinguished through ultrasonic testing.

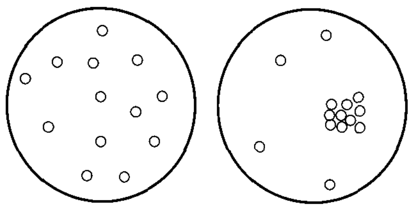

Fig. 3 Two metallographic types of defects

The upper picture of Fig. 2 shows the defect of a ultrasonic isolated indication and the lower shows the defects of a cluster indication. The defects that can be linked up to each other were defined as the same thing. In that case, the size of the defects was calculated by the sum of the each defect in the cluster

3. Results

To compare the defect size reported by non-destructive testing with the actual size, a graph was plotted on the dependence between them as shown in Fig. 4. In Fig. 4, the open circles were obtained by investigation of General Electric Co. (GE) and our results obtained in this study are plotted with the filled circles. The solid line called the "Master Curve" obtained by drawing the upper line of the opened circles in the graph has been used to calculate the defect size from ultrasonic signal amplitude (Kaplan, 1986, Kaplan, 1984). This graph indicates that the actual size can be about four times bigger than the one reported ultrasonically for small defects.

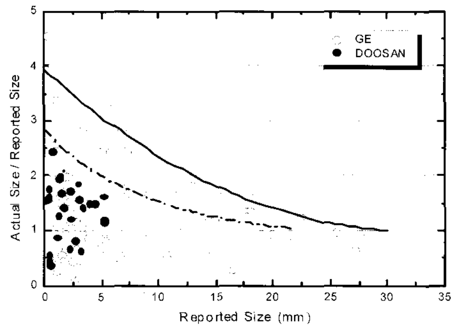

Fig. 4 Actual size vs. Reported size

But all of the filled circles have a gap from the solid line. This means that in case of using the master curve the safety factor of DHIC rotor evaluation may be too big. So a new curve with dotted a line can be suggested. Furthermore, if more data is obtained in future studies, the new master curve can be used instead of GE's master curve to evaluate the ultrasonic indications.

4. Conclusion

The relationship between the EFBH size measured by ultrasonic testing and the actual defect size by destructive testing was obtained for rotor forgings manufactured by DHIC. In this study, it is known that now the rotor evaluation of DHIC could have too big safety factor by using the relationship of GE. A new master curve is suggested to take care of this problem in the present study. With further study, this new master cureve which is more accurate in rotor forgings of DHIC, will be used to evaluate the ultrasonic indications.

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