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Linear Source Location of Acoustic Emission from Weld Cold Crack in Steel†

— Application of Acoustic Emission Technique for Weld Cracking (I) —

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Abstract

Accuracy of linear source location of acoustic emission (AE) from weld cold crack of high strength steel is investigated. TGRC test is used which is conceived by the authors to induce the cold crack at an optional position. Specimens of 350 and 2000mm in length are used and two transducers are placed at intervals of 300mm and 1900mm. Main conclusions obtained are as follows: (1) AE source locations are scattered within the crack location ± about 10% in the expression of a relative location which is defined to be 0% at one of two transducers and 100% at the other. (2) Arithmetical mean of AE source location well agrees with the crack location within ±5% of an error at the largest. The standard deviations are about 5%. (3) There is little difference in the accuracy of AE source location between short and long specimens.

1. Introduction

Acoustic emission (AE) is a phenomenon that stress wave is emitted in material during plastic deformation, metallurgical transformation, crack initiation and propagation etc. Thus AE monitoring, on the one hand, has become a new technique for materials study, and on the other hand, has become a useful nondestructive tool for detection of crack growth in structure during and after fabrication.

In welding field, hot cracks and cold cracks are very troublesome problems for the fabricator, and the practical use of AE monitoring has been desired as a nondestructive technique of real-time. Therefore various attempts to apply the AE monitoring to various welding processes have been reported[1-14] and the usefulness has been gradually recognized. However, there are many indistinct problems as regards the accuracy, reproducibility, quantitative analyses, treatment of noise, limits of application and so on.

While, weld cold cracks in steels have become more and more serious problems together with developments of high strength steels. However, it is said that AE from the cold cracks can be easily detected[13] without noises from slag, since they are hydrogen-induced delayed cracks occurring mainly after welding and high amplitude AE signals are given off during the crack growth[15,16]. Therefore a detailed investigation on source location of AE from the cold crack and estimation of the crack size etc. by the AE monitoring has been intended by the authors.

This first report discusses an accuracy of the AE source location for weld cold crack in steel.

2. Experimental Procedures

2.1 Weld Cracking Test

A weldable heat-treated high strength steel HT60 whose ultimate strength was 60 kg/mm^2 class was used for TGRC test, which was conceived and named by the authors to investigate the accuracy of AE source location for weld cold crack. The name of TGRC test is an abbreviation of Transversely Gapped Restraint Cracking test, and the specimen configuration is shown in **Fig. 1.** The principle of the TGRC test is as follows: A transverse gap of about 1 mm width is prepared by machining, and a bead-on-plate welding is carried out across the gap. Then, a transverse crack is induced in the weld metal at the gap due to contraction strain

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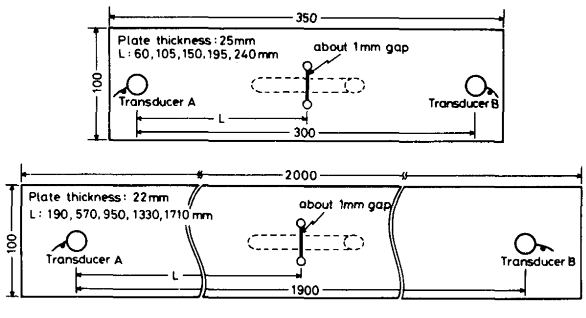


Fig. 1 Configuration of TGRC test specimen

after the welding. Since the crack location can be optionally selected by varing the gap position, the TGRC test is suitable to investigate the accuracy of AE source location for the weld cold crack by using two AE transducers placed near the both ends of the specimen.

Two types of specimen, which were 350 and 2000 mm in length, were used to observe effect of distance between the AE transducers on the accuracy of AE source location. The distances between the transducers were 300 and 1900mm, respectively. Then, the gap position, which is expressed as L in Fig. 1, was selected to 60, 105, 150, 195 or 240 mm in the short specimen, and 190, 570, 950, 1330 or 1710 mm in the long specimen. Expressing them by a relative location which is defined to be 0% at the left transducer and 100% at the right one in Fig. 1, they corresponded to 20, 35, 50, 65 and 80% in the short specimen, and 10, 30, 50, 70 and 90% in the long specimen. The bead-on-plate welding was carried out with TIG-arc process to remove any noise from slag. Any filler metal was not used and a mixing gas of argon and 1% hydrogen in the total amount of 20 l/min was supplied as the shielding gas to cause a hydrogen-induced cold crack. The welding conditions were 150 mm/min of welding speed, 20V of arc voltage, 300A of welding current and about 100 mm of weld length.

2.2. Acoustic Emission Technique

2.2.1 Acoustic Emission Monitoring System

AE monitoring system used is Dunegan/Endevco 3000 series which has dual channels and thus has a capability of linear source location. The block diagram is shown in **Fig. 2.** The transducers are differential type Dunegan/Endevco Model D9201, which has flat frequency response and has sensitivity of -84dB referred to 1V/μbar. The diameter of the transducer is 25.4 mm. Preamplifiers provide a fixed gain of 40dB and contain exchangeable filters. In this report 100 to 350 kHz bandpass filters were used. The filtered signals are further amplified by main amplifiers in a dual signal conditioner whose gain is variable in 1dB increments from 0 to 60dB. The amplified signals over a 1 volt fixed threshold are converted to digital pulses by the signal conditioner and are counted by a dual counter.

The digital pulses are fed to a Model 920 distribution analyzer to determine the AE events and to locate the AE source. There are several methods to determine AE events dependent on AE apparatus, which are related to the accuracy of AE source location in a case of frequent burst of AE. The method in the distribution analyzer is illustrated in **Fig. 3,** where outputs of the signal conditioner and the event determiner are shown in relation to time. An output of the event

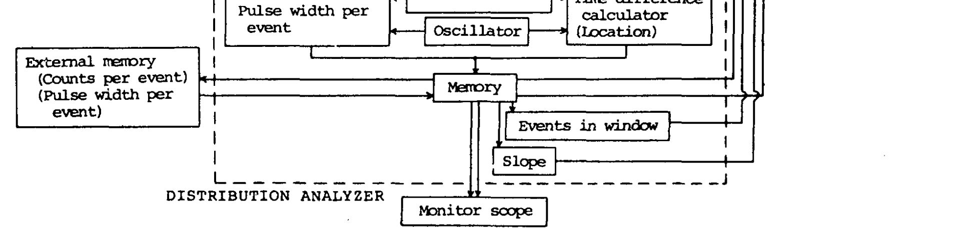


Fig. 2 Block diagram of AE monitoring system

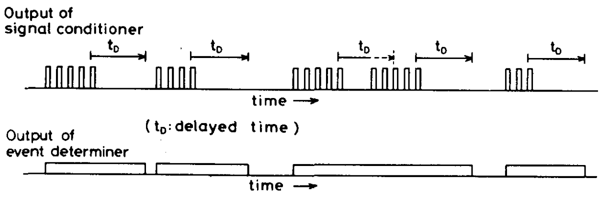


Fig. 3 Method of event determination

determiner is energized at the first pulse of a AE burst, remains energized during the burst, and stays energized for the period of a delayed time after the last pulse of the burst. The end of the energized time is defined as the end of an event. Four delayed times, that is 50μsec, 100μsec, 1 msec and 10 msec, can be chosen.

AE source location is carried out using the difference of arrival time between events of dual channels and the result is displayed on the distribution analyzer and a monitor scope.

2.2.2 Procedure of Acoustic Emission Monitoring

Since AE from hydrogen-induced crack is a burst type having a large amplitude, a large gain is not necessarily required. Moreover, considering an application of the AE technique to a welding performance in factories, a small gain is desirable from a viewpoint of removing various electromagnetic and mechanical noises. In addition a small gain is considered to be suitable to suppress an excessive increase in ringdown count from a viewpoint of determination of AE event. Therefore 70dB of a total gain was adopted.

As regards the delayed time, 10 msec was chosen, since one event may be misjudged as two or more events in 1 msec or less of the delayed time due to effects of wave dispersion, reflection and detouring. Conversely speaking, different events occurred at least within 10 msec of a time interval are misjudged to be belong to one event.

The transducers were fixed with magnet holders and machine oil was used as the couplant.

Previous to the AE monitoring, the distribution analyzer was adjusted so that an AE source location might indicate the correct result in the distribution analyzer or the correct position on the monitor scope, using a simulated AE source placed on a plate which had not a gap but the same configuration as that in the TGRC test. This adjustment corresponded to adopting 3140 m/sec of an acoustic velocity in the short specimen and 3230 m/sec in the long specimen. These velocities are considered to be group velocities of second symmetric mode in lamb waves.

The TGRC test was carried out after the above preparation had finished. The AE monitoring was started from about 30 sec after the welding. AE waves were observed at need by a Tektronix 7633 memoryscope.

3. Experimental Results

General appearance of weld metal near the gap in the TGRC test specimen is shown in **Photo. 1.** A slightly curved transverse crack was formed in the weld metal at the gap. None of the crack was observed in other parts.

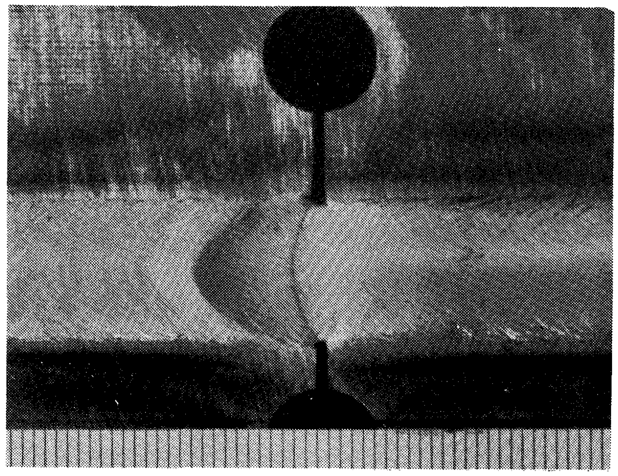


Photo. 1 General appearance of weld cold crack in TGRC test

An example of changes in AE total count and AE total event vs. time is shown in **Fig. 4**, which reveals intermittent occurrence of AE peculiar to hydrogen-induced delayed crack. The AE wave was typical burst-type as seen in **Photo. 2.** The AE wave seems to have a sharp rising and a smooth attenuation, but has

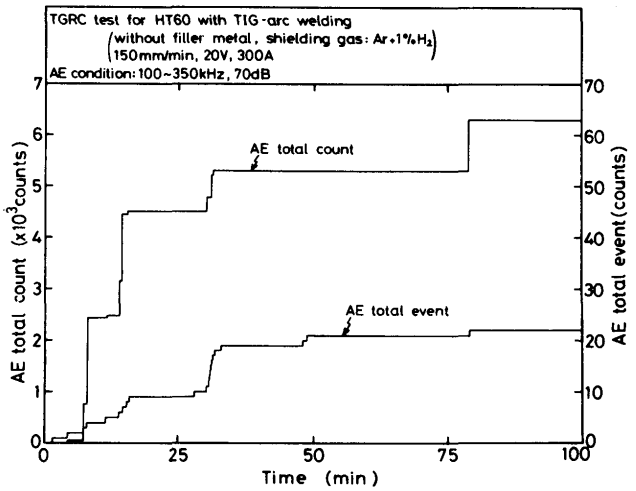


Fig. 4 Changes in AE total count and total event vs. time for weld cold crack in TGRC test

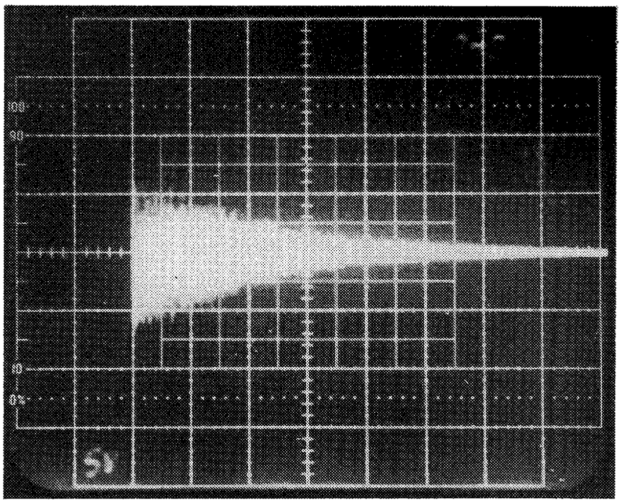


Photo. 2 AE wave from weld cold crack, abscissa; 2 msec/div, ordinate; 2 V/div.

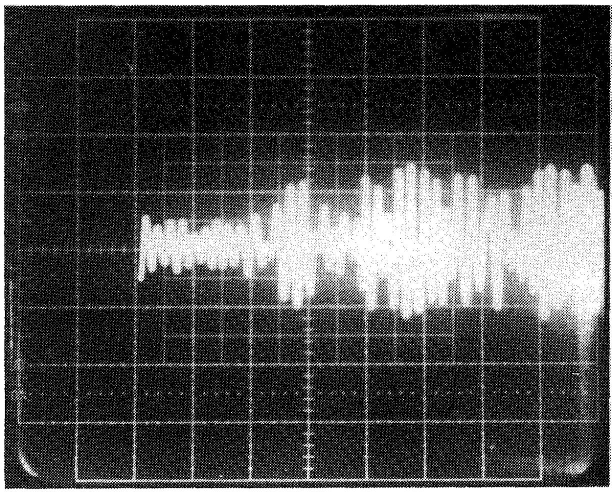
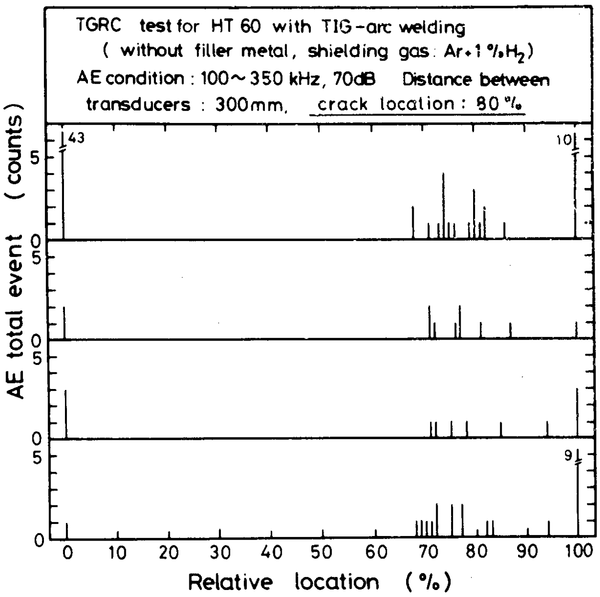
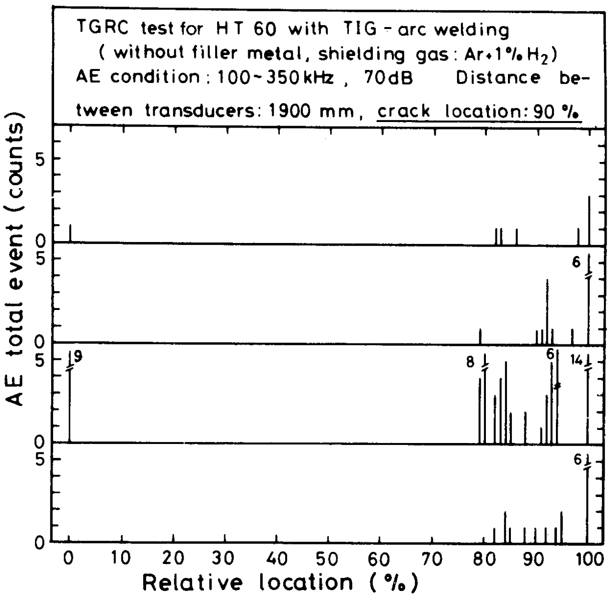


Photo. 3 Rising part of AE wave from weld cold crack, abscissa; 20 μsec/div, ordinate; 5 V/div.



(a) 80% of relative crack location in specimen of 350mm in length



(b) 90% of relative crack location in specimen of 2000mm in length

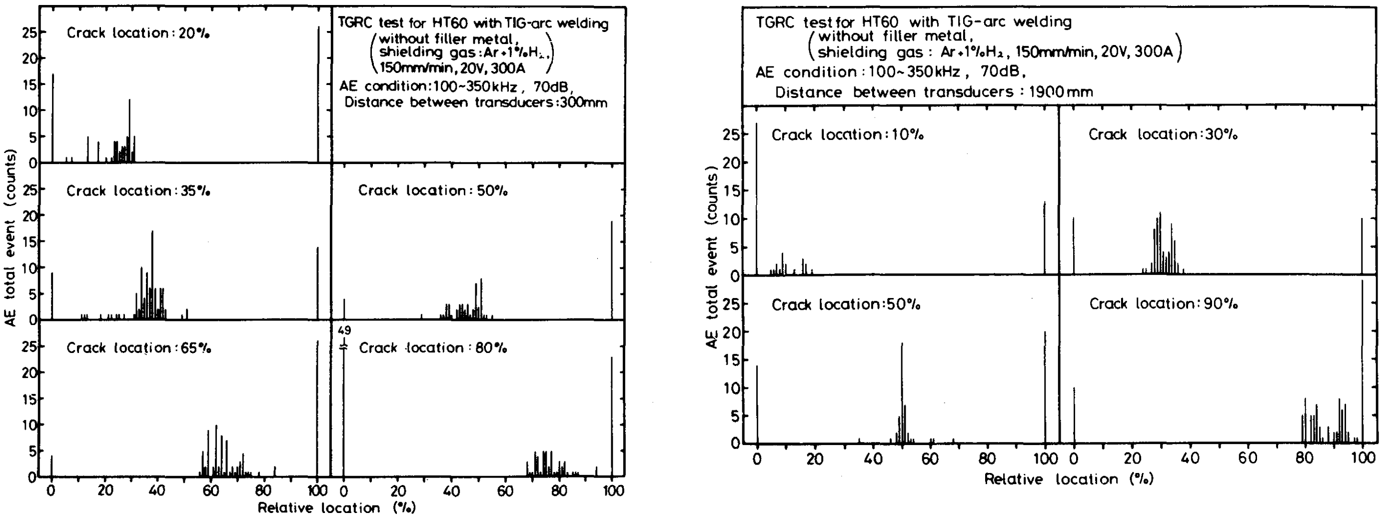
Fig. 5 Examples of AE source location for weld cold crack in TGRC test

not necessarily the sharp rising in a high magnified time scale. The example is shown in **Photo. 3.** This phenomenon appeared to be generally remarkable when the distance between the crack and the AE transducer was long*, and thus must have been one of the causes of scattering of AE source location as mentioned later. By the way, it is seen in Photo. 3 that the frequency of AE near the rising part is about 200 kHz.

Figures 5 (a) and (b) show examples of spatial distributions of AE events by AE source location in the case where the relative crack location is 80% in the short specimen and where that is 90% in the long specimen, in which the AE source location is carried out for four specimens of the same condition respectively. AE events in 0% or 100% of relative location are due to AE signals which crossed over the threshold level in only one of the dual channels. Therefore the ringdown counts of these events are very small. Other AE events are scattered within 80% ± about 10% in (a) and 90% ± about 10% in (b), that is within the relative crack location ± about 10%.

All results of AE source locations for various crack locations are summarized in **Fig. 6,** in which AE events of four specimens of the same condition are

* This tendency was clearly observed using simulated AE source.



(a) specimen of 350mm in length (b) specimen of 2000mm in length

Fig. 6 Summary of AE source locations in various crack locations in TGRC test

totalized. Figure 6 (a) shows the results in the short specimen and Fig. 6 (b) does those in the long specimen. It is observed that the scattering of AE events are similar to those in Fig. 5, independent of the crack location.

Figure 7 shows a relation between the crack location and the arithmetical mean of AE source location in Fig. 6, and further shows the mean location ± the standard deviation by I-shaped mark. The mean AE source location well agrees with every crack location within ± 5% of a relative error at the largest. The standard deviations are about 5%. Moreover there is

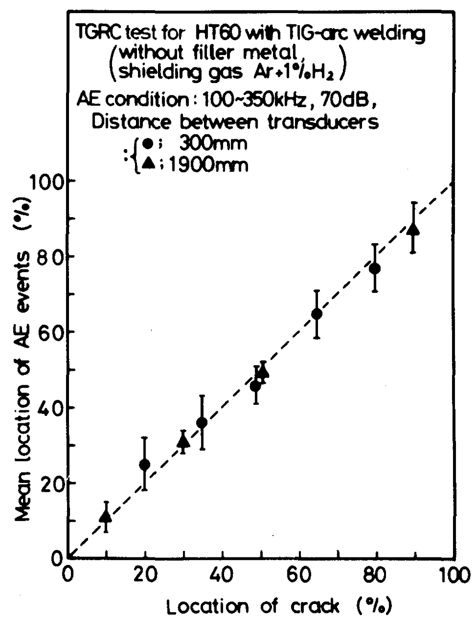


Fig. 7 Relation between crack location and mean AE source location

little difference in the accuracy of AE source location between the short and long specimens, though the accuracy of the long specimen seems to be slightly better. Essentially the diameter of the transducer makes the accuracy inferior in the short specimen. On the other hand, wave dispersion and slow rising of AE wave make the accuracy inferior in the long specimen. Perhaps a compensation of these effects brought about the similar accuracies. Besides, a tendency is observed that the mean AE source locations for 10 and 20% of the crack locations are estimated slightly larger and that the mean AE source locations for 80 and 90% of the crack locations are estimated slightly smaller. This tendency is considered to have resulted from a factor that the error of AE source location due to the error in selecting the acoustic velocity generally becomes larger as the crack is located near one of the AE transducers.

For reference, results of AE source locations for a simulated AE source are shown in **Fig. 8,** where there is little scattering and thus not mean values but data themselves are plotted. Comparing Figs. 7 and 8, there is little difference in accuracy between the mean values in Fig. 7 and the data themselves in Fig. 8. The reasons for the scattering of AE source location for the weld crack may be related to (a) the shape of AE wave of the crack, (b) the distribution of AE amplitude vs. the threshold level, (c) the frequency of occurence of AE events of the crack, (d) the change in the acoustic velocity due to the cracked temperature, and so on.

Above mentioned results in Figs. 5, 6 and 7 were obtained from the specimens in which the cold crack

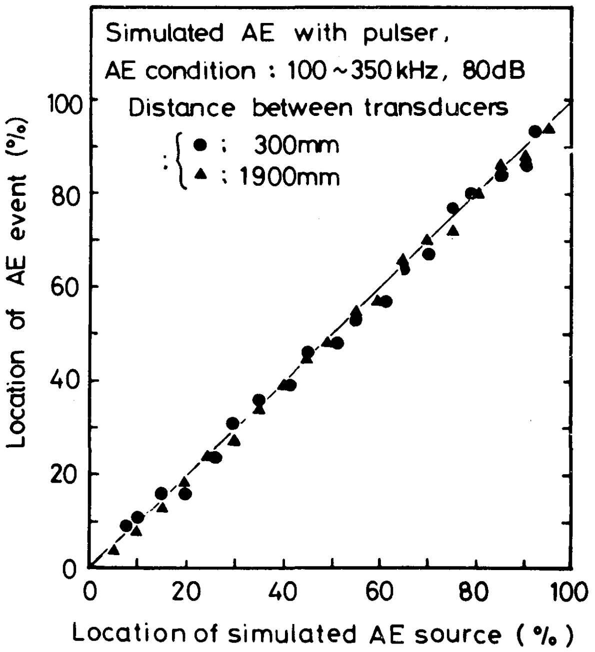


Fig. 8 Relation between position of simulated AE source and AE source location

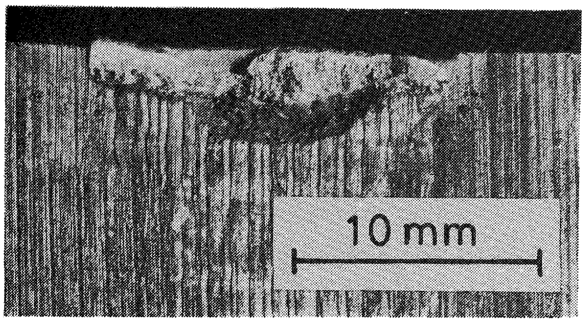


Photo. 4 Artificially fractured surface containing weld cold crack (black part) of specimen preheated to 100°C

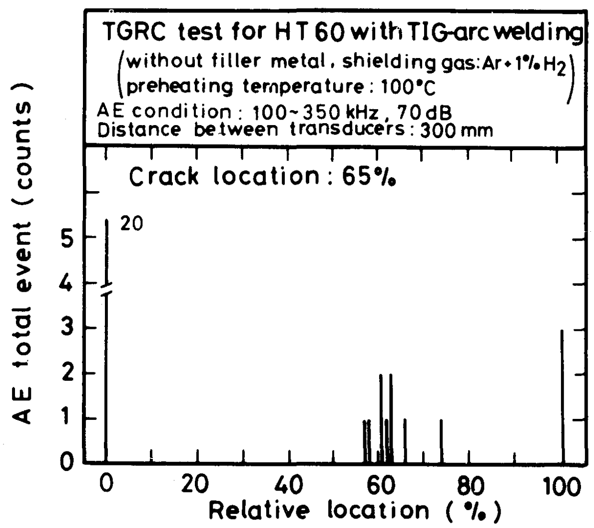


Fig. 9 AE source location for small crack in Photo. 4

completely or almost completely traversed the weld metal at the gap. Subsequently AE source location was carried out for a specimen in which a small weld crack was formed with preheating of 100°C. **Photograph 4** shows the artificially fractured surface containing the crack which were colored black by an oxidization in an elevated temperature. The crack is observed at the lower part of the weld metal and the area is about 8mm in width and about 1.5mm in height. The spatial distribution of the AE events is shown in **Fig. 9.** It is observed that AE source location is satisfactorily possible in the same accuracy as in Fig. 6.

4. Conclusions

Accuracy of AE linear source location for weld cold crack of high strength steel was investigated. Main conclusions obtained are as follows:

(1) AE source locations are scattered within the crack location ± about 10% in the expression of a relative location which is defined to be 0% at one of two transducers and 100% at the other.

(2) Arithmetical mean of AE source location well agrees with the crack location within ±5% of an error at the largest. The standard deviations are about 5%.

(3) There is little difference in the accuracy of AE source location between short and long specimens used.

(4) AE source location could be applied for a small crack, the area of which was about 8 x 1.5 mm at the lower part of the weld metal.

Acknowledgement

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