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Example of Arresting Crack Growth in Welded Parts

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Abstract

The unstable growth of fatigue cracks brings a material or structure to catastrophic failure. It is better than any fatigue crack does not initiate in engineering applications. However, fatigue crack initiation cannot be prevented in some applications because maintaining their efficiency or performance is important factor for usage. When a crack is initiated in machine equipment, it should be repaired or the equipment replaced. Sometimes, the cracked material was repaired and many repair methods were proposed. In this report, a simple method of stopping crack growth is proposed to apply to a cracked plate with varying thickness. The stop-hole and crack arrester were applied in the present method.

Keywords: Fatigue; Crack growth; Stop-hole; Crack arrester; Plate with varying thickness; Welding part

Introduction

A simple method of stopping crack growth is drilling a stop-hole at the crack tip. This method has been studied and modified by many researchers [1-12]. Their methods are effective in arresting small-size cracks and cracks in small-size machine elements. On the other hand, when long crack is initiated in a big structure or a production facility, it is better to arrest crack growth by applying patches as reported by Baker [2], O'Donoghue and Zhuang [9]. Usually, after drilling stop-holes at the crack tips, the patches which cover the cracked site are fixed to the plate.

However, patches are difficult to attach in some situations; for example, the initiation of many cracks in a narrow section of the structure. Also, the welding method could not be used for repair in some cases, because of the occurrence of tensile residual stress. In such cases, a crack arrester in the cracked plate with stop-hole can be applied effectively. In this study, the effectiveness of applying a crack arrester in some cases is discussed.

It is effective for stopping crack growth that a crack arrester is applied with the drilling of a stop-hole. Makabe et al. [4,5] reported that many cracks initiated in a car production facility were stopped by using the crack arrester with bolted stop-hole. Figure 1 shows examples of stopping crack growth. They are discussed as follows; "In the case of Figure 1a: Stress concentration is reduced by drilling a stop-hole at the crack tip. In the case of Figure 1b: Inserting pins into drilled stop-holes is effective to arrest the crack growth. Because the hole was expanded, the material around the hole was elongated and compressive residual stress developed in the circumferential direction of the hole due to the elastic plastic deformation behavior in the vicinity of the hole. In the case of Figure 1c: A crack arrester was attached across the crack face. The crack opening displacement was reduced because a part of the stress concentrated at the ligament was re-distributed by the crack arrester". It is effective to apply a crack arrester with stop-hole. Also, the bolted stop-hole and pinned stop-hole are more effective to stop the crack growth when used with the crack arrester. For other examples besides Figure 1, the crack can be repaired by attaching a patch in the case of a structure, and the bolted stop-hole can also be applied in practical cases. In the case of a bolted stop-hole, deformation around the stop-hole is reduced by the friction with the contact area of cracked material and the bolt-nut (male and female screws). In the case of the previous study, female threading was ground drilled into the body of a plate-specimen corresponding to metric thread 'M10'. So, bolting was directly done into the threaded hole at the crack tip. In that case, the bolting work could be done from one side of the specimen face.

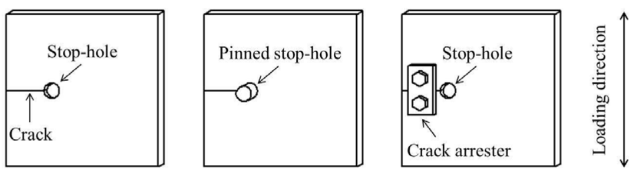

Figure 1: Examples of methods of stopping crack growth, (a) Original stop-hole, (b) Pinned stop-hole, (c) Stop-hole with cracker rester.

Figure 2 shows an example of a crack arrester being applied in a car production facility [4,5]. Due to the application of concentrated load on the welded parts, many cracks were initiated at the car production

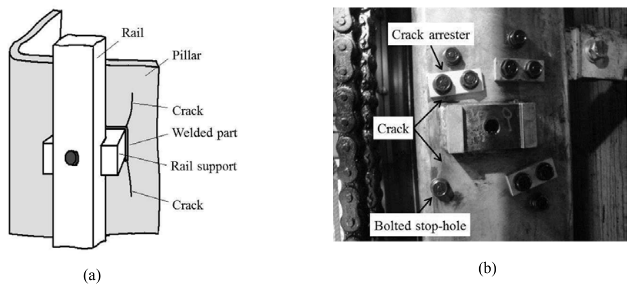

Figure 2: Crack initiation at a car production facility, (a) Schematic representation of crack initiation position, (b) Example of application of a stop-hole to prevent crack growth.

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facility. The cracks were initiated in some pillars which supported car lifting equipment. Figure 2 shows an example of the application of a crack arrester and a stop-hole. Figure 2a shows the schematic representation of the crack initiation situation. The cracks were initiated at the welded part of rail support. Because of the application of a lateral load to the rail axis, the cracks grew parallel in the direction of the rail axis. As shown in Figure 2b, the crack growth was stopped by attaching a crack arrester and bolting or pinning a stop-hole.

In the previous study [4,5] the crack arrester was bolted on a flat section. We applied the method of the previous study to a plate which had a section of different thickness in this study. The applicability of the previous method was confirmed by the difference in the case of the cracked structure or specimen from the previous study.

Material and Experimental Procedure

The material used was a carbon steel for welding structures. This is called SM490 according to Japanese Industrial Standard. The chemical composition and mechanical properties are shown in Tables 1 and 2, respectively. Usually, a fatigue crack is initiated in the heat-affected zone in the case of welded material under repeated axial stress. The heat-affected zone tends to develop in the vicinity of the boundary of the welded site. Therefore, we examined a method of arresting or stopping crack growth when the fatigue crack initiated in the vicinity of the welded site. To facilitate the fatigue test, a slit was cut in the vicinity of the welded site instead of making an initial crack.

Figure 3 shows the geometries of the specimen and the crack arrester. The crack arrester was attached by bolting. The female screws were cut in the case of types A and B. In the case of Type C, the bolt and nut were used to attach the crack arrester. We made three types

C	Si	Mn	P	S	Fe
0.16	0.39	1.44	0.15	0.04	Bal.

Table 1: Chemical composition (wt%).

Yield strength σS [MPa]	Tensile strength σB [MPa]	Elongation Ψ [%]
383	540	25

Table 2: Mechanical properties of the materials.

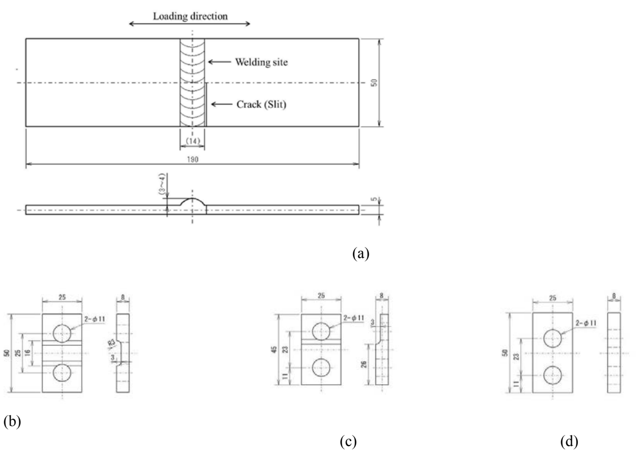

Figure 3: Examples of specimen and crackar rester (mm), (a) Welded specimen with crackon one side, (b) Crackarr ester, Type A, (c) Type B, (d) Type C.

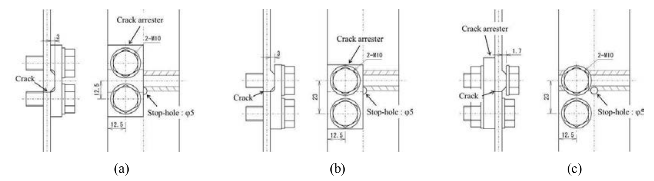

Figure 4: Application patterns of a stop-hole and crackarr ester (mm), (a) Type A, (b) Type B, (c) Type C.

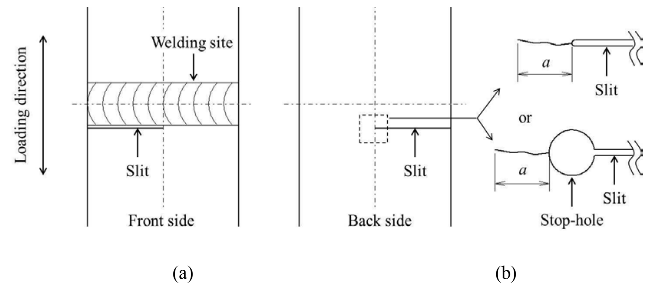

Figure 5: The definition of crack length *a*: (a) Situation of initial crackor slit, (b) Length *a* of new crack (or crack).

of crack arrester, depending on the fixed position and method of the attach working as shown in Figures 3b-3d.

Figure 4 shows the pattern of affixing the crack arrester to the specimen by bolting. A stop-hole was drilled at the initial crack tip (or bottom of the slit). The top part of the welded material was flattened by a milling machine to ease the attachment of a crack arrester in the cases of Types A and B. In the case of Type A, the crack arrester was affixed to a flat section of the specimen, and that was across the weld metal and crack. In the case of type B, one of the bolts was screwed into the weld material. In the case of type C, the crack arrester was affixed to the back side of the specimen. All part of this side was flat, because the weld work was done from the opposite side. In the case of types B and C, the crack arrester was across the slit or initial crack and affixed with 23 mm of distance between the centers of the bolts.

Fatigue tests were performed by using a hydraulic fatigue testing machine. Cyclic stress was applied with stress ratio (the ratio of minimum to maximum stress) R = 0. The maximum stress was determined by the stress conditions of the previous study [4-6] that consider of the applied load in a pillar with car elevator. The measurement of the length of a new crack initiated from the bottom of a slit or stop-hole was performed with an optical microscope.

Results and Discussion

The arrest of crack growth in the case of a welded specimen was performed by drilling a stop-hole and attaching a crack arrester. From the previous study [4-6], it was known that drilling a stop-hole at the crack tip had only a small effect on stopping crack growth. Therefore the stop-hole and crack arrester were simultaneously applied in the present study. In the present study, the effectiveness of a crack arrester on stopping crack growth was investigated from the crack growth behavior.

Figure 5 shows the definition of crack length in the present study. In the case where a stop-hole was not drilling, the new crack length a

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was measured from the slit bottom. In the case of drilling a stop-hole, the crack length a was measured from bottom of stop-hole.

Figure 6 shows the crack growth curves. When the stop-hole and crack arrester were not applied, the crack grew faster and the fatigue life Nf was lower than 1×10^5. This crack growth behavior could be improved by drilling a stop-hole, and it is ever more effective to arrest crack growth by using a crack arrester. However, the effect of the crack arrester on decreasing the crack growth rate was dependent on the geometry and the method of the attaching crack arrester. In the case of Types A and B, the fatigue lives were clearly longer than the base case. In the case of type B, the fatigue life is more than 10 times the base case. The longest fatigue life was obtained in the case of Type C. In this case, the crack initiation was confirmed at N = 2.4×10^6 and fatigue life Nf was about 3.7×10^6. Figure 7 shows the relationship between the crack length a and crack growth rate da/dN. It is clear that the crack growth rate in the cases of applying a crack arrester was lower than the base case. In particular, the crack growth rate da/dN was lowest in the case of Type C. Therefore, the crack initiation life and crack growth rate could be improved by applying a crack arrester with a stop-hole.

The effect of a crack arrester was examined by observation of the crack growth behavior and fracture features of the specimen. Figure 8 shows the comparison of cracking in the cases of specimens with a crack arrester. The scratch patterns made by an emery paper were observed, but they can be distinguished from the pattern of cracking.

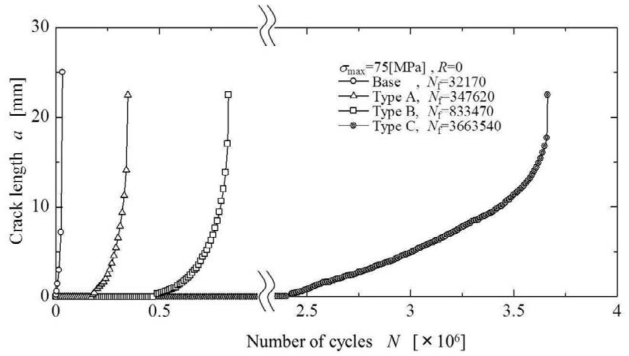

Figure 6: Crack growth curves (N_f is the fatigue life).

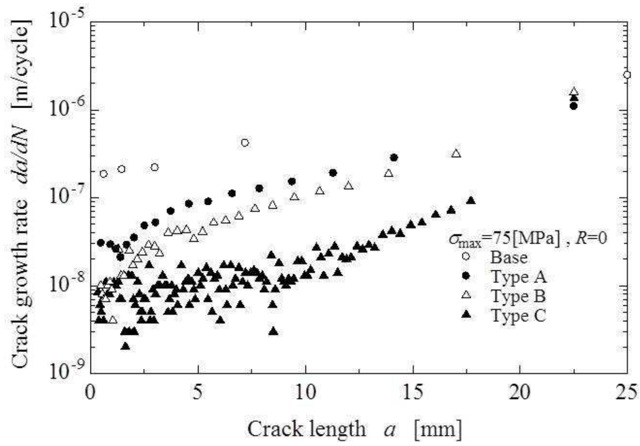

Figure 7: Crack growth rate *da/dN* vs.crack length *a*.

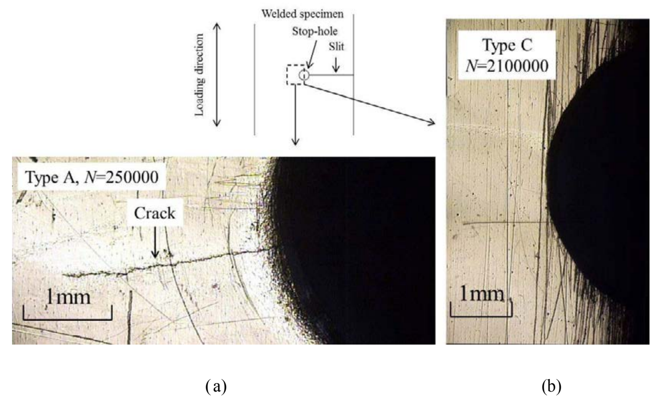

Figure 8: Observation of stop-hole vicinity to compare the effect of crackarresteron new crack initiation: (a) Type A, (b) Type C.

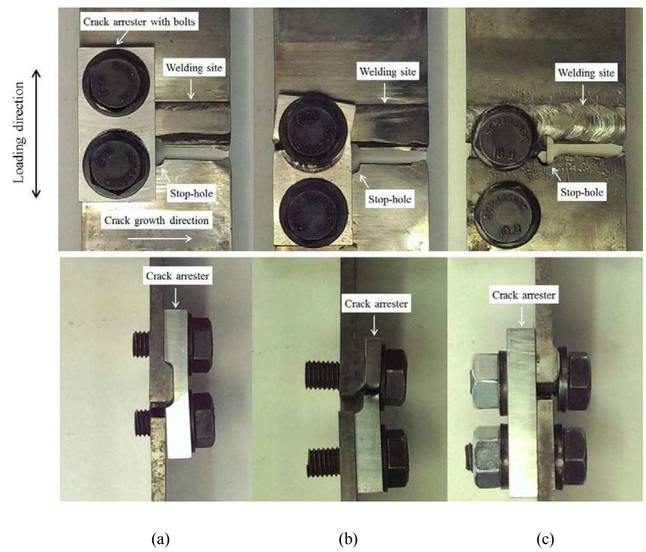

Figure 9: Features of broken specimens, (a) Type A, (b) Type B, (c) Type C.

In the case of Type A at N=2.5×10^5, the crack growth was clearly observed. However, in the case of Type C at N = 2.1×10^6, the crack was not observed. The straight line in the vicinity of the stop-hole is a scratching pattern.

Figure 9 shows the features of broken specimens. It is found that the top of a welded site was cut to make a flat area for attaching a crack arrester in the cases of Types A and B. In the case of type A, it is discussed that the friction between the crack arrester and the specimen surface was not enough to decrease crack opening displacement. Also, the brief bending and stress concentration at the site where the thickness changes happen at the crack arrester site. In the case of Type B, the friction between the crack arrester and specimen surface was larger than that in the case of Type A, and the deformation of the crack arrester was expected to be smaller. Therefore, the fatigue life in the case of Type B is longer than that of Type A. The longest fatigue life was obtained in the case of Type C. In this case, the crack arrester was applied at a flat site of the specimen. Therefore, the bending in the crack arrester was smaller and the area of contact between the crack arrester and specimen surface was wide enough. Consequently, the crack opening displacement was the smallest in the case of Type C. The reduction of crack opening is effective to arrest the crack growth by using a crack arrester. Therefore, it is important that we should choose the best method of attaching a crack arrester to reduce crack opening displacement.

Conclusion

Methods of arresting crack growth were investigated. A stop-hole was drilled at the crack tips and a crack arrester was attached across the initial crack. The crack arrester was applied to a welded specimen whose thickness varied. The main results obtained are as follows:

(1) The fatigue life of a welded specimen which has a crack in the vicinity of the weld site was improved by attaching a crack arrester and drilling a stop-hole.

(2) The extension of fatigue life was different, depending on the method of attaching the crack arrester.

(3) In the present study, the fatigue life was longest when the crack arrester was attached at a flat section on the opposite side of the weld site.

(4) When the contact area between the crack arrester and specimen surface was wider and the crack displacement was made smaller, the fatigue life become longer in the case of the specimen with a welded area.

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