International Journal of Offshore and Polar Engineering
Vol. 12, No. 3, September 2002 (ISSN 1053-5381)

Fatigue Life Extension of a Through-Thickness Crack Using Local Heating

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ABSTRACT

Based on the well-established effect of compressive residual stresses on crack growth retardation, compressive residual stress fields were artificially induced at a through-thickness crack by local heating near the crack tip. To demonstrate the beneficial effect of the proposed approach, crack growth tests and some numerical analyses were carried out on 3 types of CT specimens in accordance with the ASTM standard. Based on the results of tests and analyses, crack growth retardation of a fatigue crack is demonstrated, and results are discussed quantitatively.

INTRODUCTION

In shipbuilding and ocean engineering, all welded structures suffer cracking by various types of in-service loadings, such as impact, fatigue and corrosion. Recently, a large portion of cracking has been ascribed to fatigue cracking initiating at weld toes. These fatigue cracks can be divided into 2 types: surface cracks and through-thickness cracks (Haagensen, 1994).

Most of the past research on extending the fatigue life of an existing crack has been limited to repair and strengthening methods. Especially for through-thickness cracks, a wide variety of repair methods (Haagensen, 1994) has been developed, such as repair welding, hole drilling, clamping, grouting, TIG dressing and peening. As is widely known, most techniques for extending fatigue life are time-consuming, and considerable costs are involved.

This study proposes a relatively inexpensive technique for the extension of a through-thickness crack's fatigue life. The approach consists of artificially introducing compressive residual stresses to an existing through-thickness crack by local heating near the crack tip.

A local heating method is a popular technique for extending fatigue life in welded structures. For example, spot heating (Masubuchi, 1980) and Linde's method (Kim, 1989) have been used. In spot heating, the structure is heated locally, usually with a gas torch, so as to produce local yielding resulting in compressive thermal stresses. As the locally heated metal cools, it shrinks, causing residual stresses. Linde's method is a low-temperature stress relaxation method. Welded joints are locally heated, with a gas torch, about 100 mm away from the welding line up to the temperature of 200°, and compressive residual stresses are created after water cooling can be superposed on welding tensile residual stresses. But the applications of these 2 methods are basically restricted to the extension of fatigue crack initiation life in welded structures, because the purposes of these methods are to reduce the effective mean stress by superposing the compressive residual stress induced by local heating on the high magnitude of tensile welding residual stress near the weld toe.

The authors would like to emphasize that the approach described in this study is somewhat different from the spot heating and Linde's methods, because the study focuses on the extension of fatigue crack growth life, and not on crack initiation life. Of course, the basic principle of local heating is identical with past works. But the application of local heating to an existing crack has additional advantages for the following reasons:

- Local heating near an existing crack can produce excessive compressive residual stresses on the crack surface, resulting in crack closure. This reduces effective crack tip driving force.
- The proposed approach can be applied to almost all steel structures, including welded joints.

To examine the effectiveness of the proposed technique, both the experiments and numerical analyses were used.

The crack growth tests were carried out on 3 types of CT (Compact Tension) specimens. The first type is the specimen without residual stresses; the other two types are specimens with residual stresses imposed by local heating, and they have different levels of compressive residual stresses by controlling the heat flux during local line heating. In the same heating conditions, the imposed heat flux corresponds to the heating speed.

To verify the effect of residual stresses on crack growth retardation, the effective stress intensity factor ranges of the specimens were evaluated by numerical analysis, as follows:

- The levels of residual stresses imposed by local heating were evaluated by transient thermal elastic-plastic analysis, which considered the nonlinear properties of material. Initial distributions of residual stresses were measured by the hole-drilling strain-gage method to verify the accuracy of numerical analysis.
- A finite element modeling technique was developed to simulate the redistribution of residual stresses due to fatigue crack growth.
- Based on the results of tests and analyses, the retardation of fatigue-crack propagation is discussed quantitatively by introducing the concept of the effective stress intensity factor range evaluated by considering the redistribution of residual stress fields.

Received June 29, 2002; revised manuscript received by the editors August 3, 2002. The original version (prior to the final revised manuscript) was presented at the 12th International Offshore and Polar Engineering Conference (ISOPE-2002), Kitakyushu, Japan, May 26–31, 2002.
KEY WORDS: Fatigue life extension, compressive residual stress, through-thickness crack, local heating, fatigue crack growth test, effective stress intensity factor.