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Residual stress-induced deformation and fatigue crack growth in weld-repaired high-strength low-alloy steel with soft buffer layer

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A B S T R A C T

Residual stresses (RS) in a bulk weld-repaired steel structure and thin samples sliced from the welded-section are different due to inevitable variations in the stiffness and boundary conditions. In this study, thin extended compact tension (E-CT) samples for fatigue crack growth measurements were sliced from three extensively weld-repaired high-strength low-alloy (HSLA) blocks with three different welding conditions, i.e. welding with a 4 or 10 mm thick soft buffer layer (BL) and welding without the soft BL. Deformation in the thin E-CT samples with notches due to the partial release of welding-induced RS) was measured, and then the samples were used to measure the fatigue crack growth. In this study, we reported detailed measurements of residual stress-induced (RS-induced) deformation in thin test samples and corresponding fatigue crack growth behavior of an extensively weld-repaired HSLA with or without a thin BL. Three groups of E-CT samples were prepared: weld-repaired HSLA without BL, and weld-repaired HSLA with a 10 mm or 4 mm BL. The RS-induced deformation and corresponding fatigue crack growth were measured, and studied together with the influence of BL. The results showed that the incorporation of a 4 mm BL had a profound influence on reduction of the RS-induced deformation, and the incorporation of a 10 mm BL had a significant influence on the fatigue crack growth behavior in the parent metal, heat-affected-zone and weld metal. Detailed SEM observations show that fatigue characteristics of the weld-repaired HSLA were also influenced by the buffer layer and welding-induced RS.

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1. Introduction

Residual stresses (RS) in an extensively weld-repaired structure can significantly influence the structural fatigue behavior at the welded section, just as RS due to overloading [1] or other processes. However, it is not an easy task to measure the RS due to the complexity in structure constraints and structural geometry. Sectioning of thin test samples from a bulk weld-repaired block (or structure) will partially release the RS due to the reduction in structure constraints or change in the boundary conditions, leading to deformation in the thin test samples due to the partial release of the welding-induced RS. As a result, the fatigue behavior is also altered due to the change in RS. Therefore, measurements of the RS-induced deformation are significant to the fatigue behavior, which may provide a useful indication on the suitability of a weld repair process and post-weld heat treatment.

To avoid any detrimental effect from the RS in welded structures, a number of studies have been carried out to assess the influence of weld size, heat input, phase transformation [2,3], heat treatment [4–6], and additional restraint [7]. Deng et al. reported that the magnitude of transverse shrinkage in a fillet-welded joint was increased with decreasing in the flange thickness under the welding condition studied. The flange thickness has little impact on the distribution of angular distortion along the welding line, but has a profound influence on the magnitude of welding deformation due to the temperature gradient variation [8].

Mechanical properties of welded structures are also influenced by post-weld heat treatment [9,10], strength mismatch [11], welding method [12,13], and the incorporation of a buffer layer between the parent metal and weld metal [14–16]. For a thermo-mechanical control process steel weldment without post weld heat treatment, the fatigue crack growth rate in the heat-affected zone is lower than that of the parent metal [17]. A bi-metal welded system with strength gradient [18] is also studied to investigate the fatigue crack growth characteristics through the soft parent steel and ultra strong weld of a maraging steel, and the result shows the high strength gradient across the weld interface greatly retards the fatigue crack growth rate.

To gain a better understanding of weld fatigue following those aforementioned studies on welded structures, the present study attempts a direct measurement of the residual stress influence on

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deformation of thin test samples sectioned from a bulk extensively weld-repaired structure or block, and its subsequent influence on fatigue crack growth. It is expected that the RS-induced deformation in those thin samples due to the partial release of RS will provide useful additional information on the corresponding fatigue crack growth behavior. Therefore, the primary objective of the present study is to measure detailed RS-induced deformation distributions for the welding conditions and sample geometry adopted in the present study so that the effects of a soft buffer layer (BL) between the weld metal (WM) and the parent metal (PM), and BL thickness on fatigue crack growth can be correlated to relevant RS-induced deformation distributions.

2. Experimental procedure

2.1. Material and sample

The PM used in this study was Bisplate80 steel, a HSLA steel, which is widely used for various engineering structures such as bridges, storage tanks, transport equipment, mining equipment, lifting equipment, and high-rise buildings. Two types of electrodes with different chemical compositions and mechanical properties, SmoothCor ™ 115 and SmoothCor ™ 70C6, were chosen as WM and soft BL respectively. Flux cored arc welding was used for welding repair to form three types of welded joints with different compositions and strength characteristics. The chemical compositions and mechanical properties of PM, WM and BL, and relevant welding parameters, used in this study, were reported in Ref. [15].

The extended-compact tension (E-CT) sample geometry was adopted in this study for all fatigue tests. The weld-repaired E-CT sample with a U-notch in the PM, as shown in Fig. 1(a), was machined using a wire electric discharge machine, and had three different weld conditions: weld-repaired HSLA without BL, and weld-repaired HSLA with 10 mm or 4 mm BL. Three E-CT samples for each group were prepared, two samples were used for fatigue test, and one sample was used for RS-induced deformation measurement after sectioning. The dimensions of the E-CT samples of weld-repaired HSLA with or without BL are shown in Fig. 1. The notch was within the PM, pointing to the weld-repaired section.

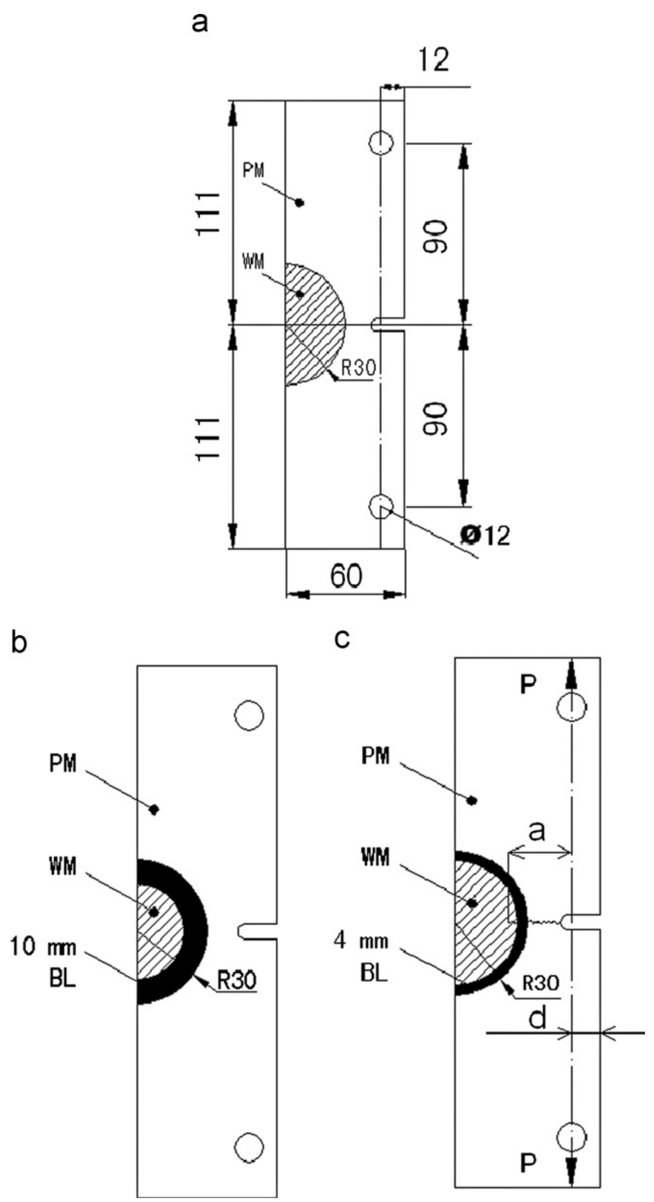

Fig. 1. Dimensions of the E-CT samples (all dimensions are in mm). (a) Weld-repaired HSLA without BL, (b) weld-repaired HSLA with a 10 mm BL and (c) Weld-repaired HSLA with a 4 mm BL.

2.2. Residual stress-induced (RS-induced) deformation measurement

To investigate the RS-induced deformation distribution in the weld-repaired HSLA with or without BL and clarify the effect of BL thickness variation on RS-induced deformation, three groups of weld-repaired blocks, (1) weld-repaired HSLA without BL, (2) weld-repaired HSLA with 10 mm BL, and (3) weld-repaired HSLA with 4 mm BL were fabricated.

The bulk weld-repaired block shown in Fig. 2(a) before sectioning and introduction of notch for fatigue measurement was much stiffer than that of a thin E-CT sample with a notch in the PM shown in Fig. 1(a). Therefore, zero RS-induced deformation was assumed for the bulk block as the base of reference (or zero deformation). The RS-induced deformation in thin E-CT samples after sectioning and introdution of the notch was then

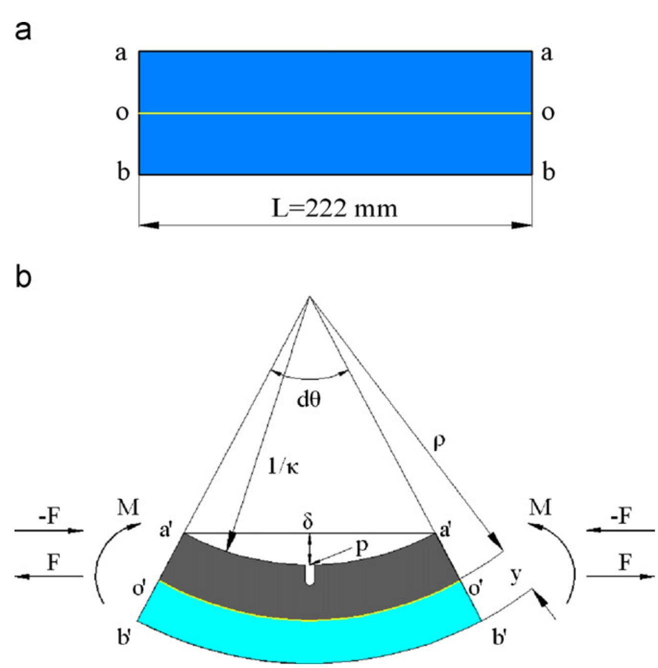

Fig. 2. Schematic RS-induced deformation in a weld-repaired HSLA E-CT sample due to partial release of RS. (a) Bulk weld-repaired HSLA block before sectioning and notching and (b) RS-induced deformation in E-CT sample after sectioning and notching.

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