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Residual stress measurement in an extra thick multi-pass weld using initial stress integrated inherent strain method

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ABSTRACT

Residual stresses existing in a multi-pass butt joint with a thickness of 70 mm, using a flux-cored arc welding process, were measured by an inherent strain method (ISM). Since such a thick plate before welding contains a large amount of initial residual stresses (−300 to +100 MPa), the initial stresses were integrated with conventional ISM in order to determine the total residual stresses in a welded joint. Two methods named as initial stress integrated ISM and initial inherent strain integrated ISM were suggested for the consideration of the initial stress distributions through the thickness of base plates. The results show that there is a significant difference between the integrated ISM with initial stresses or initial inherent strain and the conventional ISM without initial stresses. The residual stresses measured by any of the initial stress integrated ISM and initial inherent strain integrated ISM agreed well with the neutron diffraction measurement. Thus, the proposed initial stress integrated ISM is a proper destructive measurement method in the case of thick weld joints.

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1. Introduction

With the increase of large-scale containership, a large amount of high-strength steels with extra thick plates is being extensively used. The welding stress existing in the extra thick welded plates has a significant effect on the integrity of the component in terms of brittle fracture and fatigue behavior. It has been reported that welding residual stress distribution in an extra thick plate can affect the propagation path of the crack [1]. Therefore, it is important to measure the distribution of welding residual stresses for the reliable design of the welded structures [2,3]. So far various researches have been carried out for the determination of residual stresses on the surface of steels. However, it has been recently recognized that the internal residual stress distributions in welded joints are an important factor affecting the fatigue and brittle fracture of the structures [4]. Thus, the measurement of the internal residual stresses is important for structure assessments.

It is possible to determine the internal residual stresses in welded joints with experimental measurement [5] as well as numerical simulation [6]. Because the experimental methods need special equipment and a long period to be executed, many simulation results were reported based on the thermal elastic-plastic analysis by using commercial finite element codes [7,8]. To verify the reliability of the simulation results, it is necessary to compare the results with experimental ones. The residual stress measurement was mainly carried out by Hole Drilling Method [9,10], Cutting Method [11], and X-ray Diffraction Method [12,13]. The Sachs Method [14] is a residual stress measurement method in which a specimen of cylinder or hollow cylinder is cut by a small portion and the changes in the cylinder diameter are measured. This method can be applicable only when the distribution of residual stresses is axisymmetric in cylinders. Using Deep Hole Drilling Method (DHD) [15–17], residual stresses through the thickness direction at a specified position can be measured from the changes of diameter of a drilled hole. It cannot provide the distribution of residual stresses in the entire structure. Meanwhile, Neutron Diffraction Method (NDM) [18,19] can measure residual stresses inside thick steel plates. Woo et al. [20] reported recently that neutron can penetrate a 70 mm-thick weld plate. They also determined the residual stress distributions through the thickness of the welded steel plate. Although NDM is time consuming and expensive, it is still employed in the measurement of residual stresses for the comparison in this study due to its reliability.

Inherent Strain Method (ISM) is one of the promising methods for the measurement of the three dimensional internal welding residual stresses in complicated welded joints [5,21–24]. In this ISM, the residual stresses are reproduced by inherent strains which can be inversely calculated from small numbers of the measured released strains by strain gauges when a specimen is cut into small pieces. Up to now, the researches for the inherent strain method mainly focused on the welding residual stress measurement without considering the initial stresses. However, since the initial stress, which has been generated during the manufacture of the high-strength steels, is high enough and cannot be ignored, a method which includes initial stresses into the conventional ISM was proposed and named as initial stress integrated ISM by authors.

In this paper, the total residual stresses in the 70 mm thick multipass FACW butt joint were measured using the initial stress integrated ISM. Concretely, two methods named as initial stress integrated ISM and initial inherent strain integrated ISM were employed to determine the total residual stresses. Furthermore, the distributions of residual stresses were compared with the results of the Neutron Diffraction Method.

2. Initial stress integrated inherent strain method

2.1. Conventional inherent strain method

Generally, inherent strain produced by welding is distributed near the welded zone. Inherent strain is classified into two types; i.e., i) ineffective inherent strain, which causes deformation but does not generate the residual stress, and ii) effective inherent strain (hereinafter referred as “inherent strain”) which induces both residual stress and deformation.