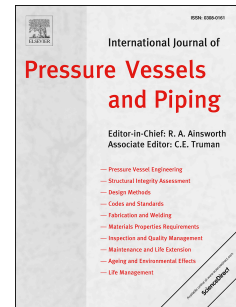


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# Characterising Electron Beam Welded Dissimilar Metal Joints to Study Residual Stress Relaxation from Specimen Extraction

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## Abstract

Nuclear power plants require dissimilar metal weld joints to connect the primary steam generator made from ferritic steel to the intermediate heat exchanger made from austenitic steel. Such joints are complex because of the mismatch in the thermal and the mechanical properties of the materials used in the joint. Electron Beam (EB) welding is emerging as a promising technique to manufacture dissimilar joints providing a great many advantages over conventional welding techniques, in terms of low heat input, high heat intensity, narrow fusion and heat affected zones, deeper penetration and increased welding speeds. However before this method can be considered for implementation in an actual plant, it is essential for a careful and a comprehensive outlining of the joint characteristics and the apparent effects on performance during service. In the present study, an EB welded joint was manufactured using austenitic AISI 316LN stainless steel and a ferritic-martensitic P91 steel, without the addition of filler material. Neutron diffraction measurement was conducted on the welded plate to measure the residual stress distribution across the weld as well as through the thickness of the plate. A finite element analysis was conducted on a two-dimensional cross-sectional model using ABAQUS code to simulate the welding process and predict the residual stresses, implementing the effects of solid-state phase transformation experienced by P91 steel. The predicted residual stresses were transferred to a 3D finite element model of the plate to simulate the machining and extraction of a C(T) blank specimen from the welded plate and the extent of stress relaxation is studied.

**Keywords:** Residual stresses; Stress relaxation; neutron diffraction; finite element modelling; electron beam welding; dissimilar metal.

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## 1. Introduction

The Prototype Fast Breeder Reactor (PFBR) is a 500 MWe sodium-cooled fast breeder nuclear reactor presently being constructed in Kalpakkam, India [1]. The Indira Gandhi Centre for Atomic Research (IGCAR) is responsible for the design of this reactor. The cooling system of the reactor uses liquid sodium and requires additional safety measures to isolate the coolant from environment. The steam generator, made of modified 91steel, is connected to the intermediate heat exchanger, made of AISI 316LN stainless steel with a dissimilar metal weld. The schematic of the reactor system is shown in Fig 1(a) and the steam generator with the dissimilar metal weld in Fig 1(b). Currently the dissimilar metal weld is a tri-metallic transition joint and uses a multi-pass Tungsten Inert Gas (TIG) welding. The complex design of the joint was necessary to minimise thermal stresses. The arrangement of the welded joint is shown in Fig 2(a) [2]. ER16-8-2 is a filler material with 16% Cr 8% Ni and 2% Mo, used for high temperature austenitic stainless steels. Alloy 800 is an Inconel alloy with very good creep rupture properties above 600 °C. Inconel 182 is an electrode used in dissimilar metal welds of stainless steels joined to carbon steels.

Experience with dissimilar metal weld joints has shown that a considerable number of failures occurred at a very early stage in service than expected, especially in power plants [3]. An extensive failure analysis was carried out at IGCAR on dissimilar metal welds between 2.25Cr-1Mo ferritic steel and AISI type 316 stainless steel with and without Inconel-82 buttering using the non-destructive X-ray diffraction (XRD) technique and to assess the effectiveness of the buttering on the extent of reduction in the residual stress [4]. Various earlier studies that characterise residual stresses in dissimilar metal welds using conventional welding process are available in the literature [3, 5–9].

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