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Measurement of the residual stresses in a stainless steel pipe girth weld containing long and short repairs

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Abstract

A series of residual measurements were made to obtain the through-thickness residual stress profiles in an as-welded and repair welded stainless steel pipe. Long and short length repairs were manufactured after initial measurements in the original girth weld. Measurements were made using neutron diffraction, deep hole and surface hole techniques. The various measurement methods were found to complement each other well. All the measurements revealed a characteristic profile for the through-thickness distribution of the residual stresses in the heat-affected zone. The residual stresses at mid-length of the heat affected zone of the short repair were found to be higher than in the long repair.

Keywords: Deep hole drilling; Manual metal arc; Residual stress

1. Introduction

Repair welds are usually introduced into structures either to remedy initial fabrication defects found in castings or welds by routine inspection, or to rectify in-service degradation of components and thereby extend the life and economic operation of ageing engineering plant. The type of repair can range from filling a very localised shallow excavation using standard weld procedures, to welding deep excavations that can extend around a significant proportion of a structure. The latter kind of major repair may require the development of special welding procedures, for example as described by Hunter et al. [1] for nuclear power plant. Repairs can be further categorised into those centred on the original weld and those that are offset from the weld centre-line. The need to rectify lack of side-wall fusion defects, or degraded heat affected zone (HAZ) material, typically leads to offset repairs, or centred repairs encompassing material beyond the original fusion boundary.

A recent survey of weld repair technologies currently used by EPRI member utilities [2] has found that 40% of all repairs to steam chests, piping and headers resulted in subsequent cracking. It further reports that over 70% of the repairs were performed without implementing post-weld heat treatment. It is reasonable to infer that high residual stresses associated with the repair process probably played an important role in the many of these subsequent failures. The detrimental influence of residual stresses has been well documented for the case of a steam leak at a non-stress relieved pipe-work repair weld [3]. Here both the magnitude and multi-axial nature of the residual stress field was instrumental in driving creep damage leading to reheat cracking.

Accurate structural integrity assessments require a good description of the through-wall residual stress field in the component. However, reliable characterisation of residual stresses at non-stress-relieved welds is notoriously difficult. Some recommended upper bound residual stress profiles can be found in the R6 Revision 4 defect

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assessment procedure [4], as well as alternative structural integrity codes. Development of more realistic residual stress profiles for structural assessment requires high quality experimental measurements coupled with an understanding of component structural behaviour and non-linear analytical modelling of the welding processes responsible. Publications detailing measurements of through-wall residual stress distributions at repair welds are sparse. Leggatt [5] used block sectioning to measure transverse residual stresses associated with an extended, offset, 28 mm deep multi-pass repair weld in a 75 mm thick C–Mn steel panel, containing an original double-V weld which had been stress relieved. The same technique was applied to quantify residual stresses at extended, 50% and 67% depth, axial repairs in ferritic pressure vessels [4, 6]. Through-wall residual stresses at an extended, 35 mm deep, multi-pass repair in a 60 mm restrained ferritic thick plate containing an original double-V weld have been measured employing the deep hole (DH) technique [7], and the results compared with finite element simulations [8]. The DH method has also been applied to measure residual stresses associated with short-length, centrally embedded repairs to a 37 mm thick stainless steel girth weld [9,10]. Neutron diffraction (ND) has been used to characterise the residual stress field at a short-length, 50% depth, centrally embedded repair in a 20 mm thick, 170 mm OD stainless steel pipe [11].

2. Materials and geometry

2.1. Manufacture of test component

Residual stress measurements were carried out on a test component manufactured from two ex-service forged AISI Type 316H stainless steel steam headers provided by British Energy. The 432 mm outside diameter by 63.5 mm thick headers were bore-machined to an average thickness of 19.6 mm and then solution heat treated (for 1 h at 1050 °C followed by air cooling) to remove any residual stresses remaining from original fabrication of the headers.

One end of each header was further machined to form a J-groove girth weld preparation. The matching sections were mounted on a mandrel and joined using a ‘down-hand’ welding technique by slowly rotating the component about its horizontal axis. This minimised circumferential variations in heat input associated with the welding position. The root pass was made using the tungsten inert gas (TIG) method. Subsequent passes were made by the manual metal arc (MMA) method using Babcock ‘Type S’ electrodes of varying size conforming to BS 2926 19.12.3LBR. The final arrangement of the bored and welded headers, creating a Type 316H stainless steel pipe component is shown in Fig. 1. Further geometric parameters, material properties and weld characteristics are provided in Table 1.

After welding, one end of the test pipe was shortened by 190 mm to ensure that the large fabricated component would fit into the neutron diffractometers for strain measurements. A rectangular slot, 90 mm long around the circumference and 50 mm wide, was machined on the weld line at 345° from top dead centre (TDC). This enabled measurements in the hoop direction to be made with the neutron beam only passing once through the thickness of the pipe. No significant strain relaxation ($\pm 10\ \mu\varepsilon$) was measured using strain gauges in vicinity of the repair weld locations during this machining.

2.2. Introduction of repair welds

Following residual stress measurements on the plain girth weld, described later, two repair welds were introduced into the test component using typical manufacturing practice. A $\approx 20°$ arc-length short repair, WR1, was introduced circumferentially centred at 70° from TDC and a $\approx 62°$ arc-length long repair, WR2, centred at 240° from TDC. The locations of the repairs are shown schematically in Fig. 2. The circumferential positions of the repairs were

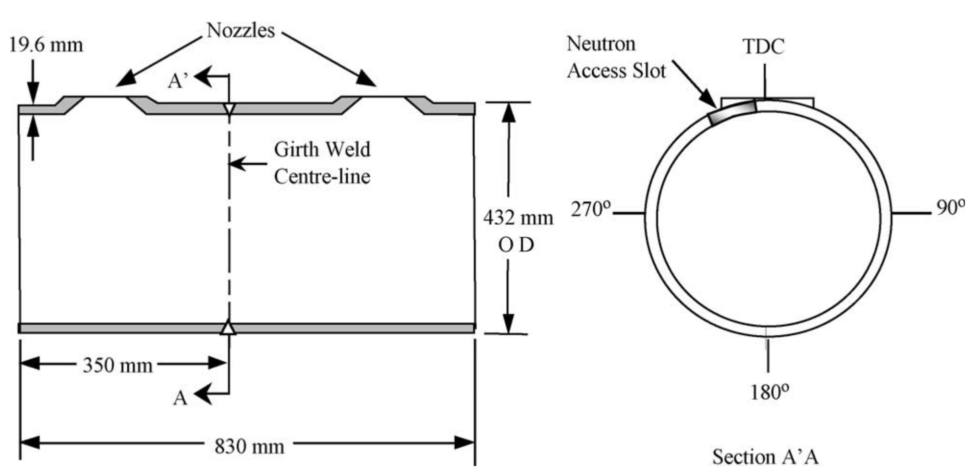

Fig. 1. Arrangement of test component.