



Guidelines for High-Temperature Weld Repairs - Review of Worldwide Plant and R&D Experience

- Covering 2.25CrMo, 0.5CrMoV, 1CrMoV, P91 and Type 316 Steels

(Acronym: Weld Repair Guidelines)

Final Report

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Executive Summary

Due to privatisation and competition in the electricity and petrochemical industry there is now a great deal of emphasis on extending plant life by better plant maintenance and conducting weld repairs wherever and whenever necessary and appropriate. With the improvement of welding techniques and procedures, the application of weld repair has become even more common in high temperature plant. The use of cold weld repair techniques, which avoid post-weld heat treatment (PWHT), has also become more widespread. The cold welding method was initially considered to be a temporary measure until the next outage, but the technique has been developed such that cold weld repairs can be considered more permanent, depending on the circumstances.

The objectives of this project were to review the plant experience and R&D findings in the field of weld repairs to high temperature components, with particular emphasis on 2½Cr-1Mo, ½CrMoV, 1CrMoV, P91 and Type 316 steel welds. Information has been collated on weld repair practices adopted by plant operators and service providers in Europe, North America and worldwide. The service experience together with the recent work carried out by researchers has been reviewed and compiled to provide guidelines and an information resource on weld repair procedures and integrity/life assessment for use by high temperature plant owners, operators and service providers.

This study has been conducted by accessing published (journals, conference proceedings, etc) and unpublished (through ETD contacts) information from a number of European, Japanese, North American and other sources. Surveys of plant operator experience have also been carried out, and available information from R&D work funded by individual organisations, national bodies, European Commission, etc, has been reviewed, thus building up a dossier of information and experience. ETD was one of the main partners in the European project 'Integrity' (2000 to 2004) and the results of this investigation, which included full-scale component testing and integrity assessment of repair welds in P22, P91 and Type 316 steels, are included in this report.

This report is comprised of 13 sections as summarized below. Each section of the report includes a comprehensive list of references.

- Section 1 sets the scene with an introduction to the operation of power plant, the typical features of welds, the typical damage that may affect welds in service and the consequent need for weld repair.

- Section 2 provides an introduction to the main aspects of weld repairs, from the excavation design and geometry of weld repair (full repair or partial repair) to the welding processes, and welding and PWHT requirements of the construction codes that relate to repair by welding.
- Section 3 describes conventional weld repair techniques, summarizing typical weld repair procedures for 2¼Cr-1Mo, P91 and 316L(N) steels, and discusses the methods for performance assessment of repair welds: (i) examination of procedural welds, simple room temperature properties and assessment of the inspection records; (ii) laboratory-based uniaxial and cross-weld testing of repair welds; (iii) case histories based on stress analysis methods; (iv) evaluation of repair welds through the use of full-size repair-welded component tests; and (v) examination of plant damage, failures and repair performance in practice. (These assessment methods are further discussed and elaborated upon in subsequent sections of the report.)
- Section 4 addresses the controlled deposition welding processes, discussing the principles of microstructural control within weldments, the reheating and refinement of structures by subsequent welding passes, and describing controlled deposition welding processes using matching filler metals (for example, two-layer refinement and temperbead processes).
- Section 5, following on from the previous section, reviews the cold weld repair techniques and the experience with using nickel-based filler metals. Cold weld repair using matching (ferritic) consumable is compared with the use of nickel-based filler metal.
- Section 6 considers the qualification and validation of repair welds, starting from a consideration of the structures developed within a weldment and the properties of the different zones and then discussing the assessment of the creep performance of repair welds by cross-weld testing, large-scale model or full-size component tests. Results from testing programmes are presented and discussed.
- Section 7, following on from the previous section, provides a detailed review of laboratory testing of weld-repaired components and evaluation of the creep life using cross-weld testing and data extrapolation. Results from major R&D programmes involving weld repairs that have been conducted in Europe, USA and elsewhere are presented and discussed.
- Section 8 concerns the prediction of weld repair life using stress analysis methods. The findings of case histories based on stress analysis methods are summarised, and the results of a number of specific cases studied by workers in the UK and Europe are reviewed in detail. Attention is also given to residual stresses in repair welds.

- Section 9 discusses the weld repair of low alloy ferritic steels, including typical piping grades 2¼Cr-1Mo (P22) and ½CrMoV. Firstly, typical forms of damage/cracking experienced in service by components/welds are described and examples of cracking in plant are discussed, including cracking in headers and seam-welded pipes and transverse weld metal cracking. Guidelines are provided for conventional weld repair of 2¼Cr-1Mo, 1Cr-½Mo / 1¼Cr-½Mo and ½CrMoV steel welds. Cold weld repair methods are also covered. Major research programmes on weld repairs to low alloy ferritic steels are summarised (elaborating on the details given in Section 7). Research investigations have included component tests to study the influence of weld repair on performance and to evaluate the effects of omission of PWHT, additional (end) loadings and use of matching or under-matching filler metals. A review of published case histories of weld repair performance evaluation using uniaxial creep testing is provided. The results of 2½Cr-1Mo component tests carried out in the European ‘Integrity’ project are presented and discussed, including data from cross-weld creep tests and crack growth tests as well as full-size component testing and damage modelling. Finally, this section of the report addresses the new 2Cr steels, T23 and T24, and also considers weld repairs to 1CrMoV turbine rotors.
- Section 10 provides a detailed review of the weld repair procedures and practices applied to 1CrMoV steam turbine casings. Details of welding procedures, welding consumables and weld heat treatment are given. The service experience with repair welds in turbine casings and associated cast 1CrMoV turbine components (steam chests and valve bodies) is reviewed based on published and unpublished cases and also an ETD survey of plant operator experience with stress-relieved weld repairs and cold weld repairs.
- Section 11 considers the weld repair of martensitic steels by focussing on modified 9Cr-1Mo steel, i.e. P91. Firstly, the plant experience with damage and cracking in P91 steel weldments is reviewed, including the early UK industry experience and also providing examples of cracking in P91 dissimilar metal welds. Guidelines are provided for conventional weld repair of P91 welded components. Cold weld repair of P91 is also discussed and the potential problems that may arise when PWHT is omitted are highlighted. The results of full-size P91 component tests carried out in the European ‘Integrity’ project are reviewed in detail, and data are presented from cross-weld creep tests and crack growth tests as well as full-size component testing and damage modelling. This study included creep testing and life assessment of a weld-repaired P91 T-piece. Finally, this section of the report considers two aspects of particular significance to users of P91 steel: (i) the number of repairs by welding that may be possible for P91 material, and (ii) the repair of P91 welds with abnormal hardness levels.
- Section 12 provides a review of weld repairs in austenitic steels, with particular reference to Type 316 stainless steel. The types of damage and cracking experienced by austenitic welded components in service are described. Guidelines are provided for weld repairs of Type 316. The results of 316L component tests carried out in the European ‘Integrity’ project, including cross-weld creep tests and crack growth tests

as well as component testing (cracked plates) and damage modelling, are presented and discussed.

- Section 13 is the concluding section of the report and it considers the current state and future development of weld repair techniques and guidelines, including alternative welding processes and development of filler metals that provide a better match to the properties of service-exposed material.

In summary, this review of worldwide industry and R&D experience in weld repairs of high-temperature plant components, covering low alloy ferritic, martensitic and austenitic steels, provides a wealth of information on weld repair procedures and the performance, integrity and life assessment of weld repairs.

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