

OBJECTIVES

- To generate and assess cross-weld creep rupture data on welded joints failing by the Type IV Heat-Affected Zone (HAZ) cracking mechanism in steels for high temperature application in advanced PF plant.
- To assess the long term risks of welded plant component failure.
- To optimise steel selection for thick section high alloy ferritic steel components in advanced coal-fired power plant.
- To provide a sound basis for determining appropriate limiting plant design temperature and stress conditions.

SUMMARY

Type IV cracking in the weld Heat-Affected Zone (HAZ) is likely to be the critical problem which will limit design conditions for satisfactory operation of advanced PF plant. The FOURCRACK project carried out high temperature creep testing of welds in advanced high alloy steels with a range of specifications, supplemented by specialised testing, optical and electron metallography, weld simulation and data assessment. Further work outside FOURCRACK will extend testing to longer durations.

E.ON UK led the project and undertook metallurgical investigation and assessment. Mitsui Babcock carried out weld manufacture and creep rupture testing. RWE npower investigated and characterised a special weak material. In parallel work, Loughborough University carried out electron metallography and weld simulation. Five external organisations also provided test materials and/or weldments.

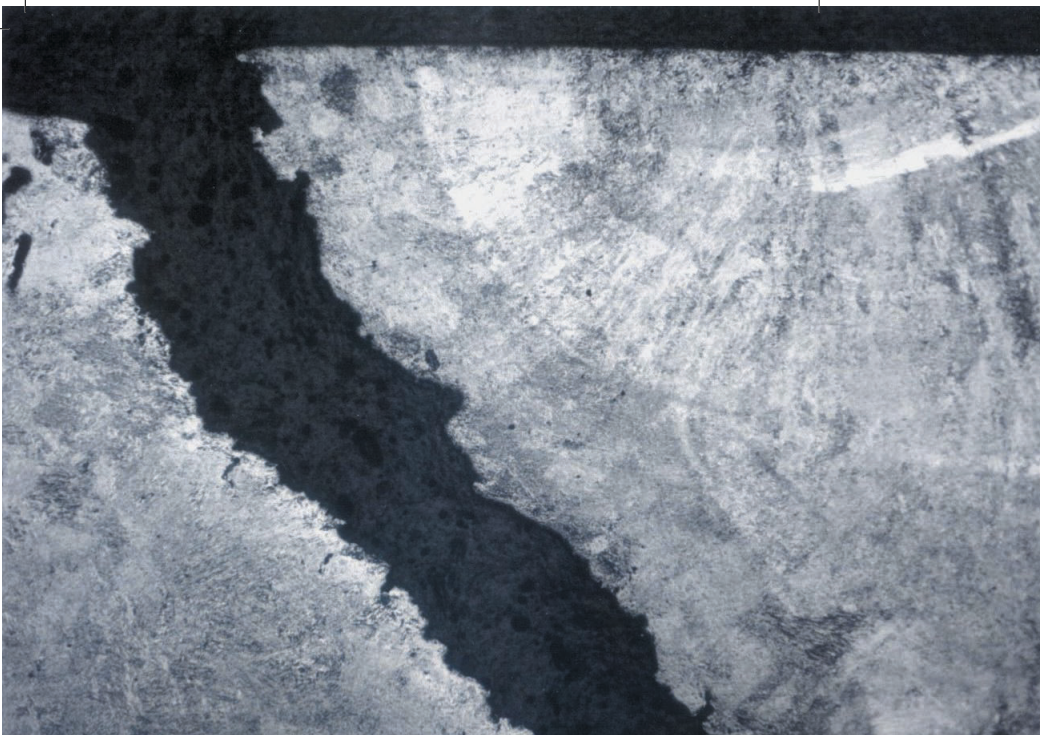


Figure 1. Type IV weld HAZ cracking in a FOURCRACK P122 weld creep test specimen. (Courtesy of E.ON UK)

The results showed that stronger parent materials often have stronger HAZs, but there is no direct correlation. Future development should therefore focus on optimising weld HAZ as well as parent material properties. The results confirmed the conclusions of the earlier DTI Clean Coal PIPPE project, and showed that they apply to Japanese and US as well as European steels. Long term weld HAZ creep strength typically falls to no more than about 60% of that of parent material. Conservative design will therefore be required for welded components if recurrent plant maintenance and repair problems in service are to be avoided.

BACKGROUND

Advanced coal-fired power plant, operating at higher temperatures and pressures, can achieve substantial improvements in thermal efficiency and hence reductions in carbon dioxide emissions. However, these opportunities may be lost if plant reliability, availability, maintainability and operation cannot be guaranteed. Because of the perceived technical risks and uncertainties with advanced plant, established subcritical power plant designs are still frequently successful on the international market, despite their relatively poor efficiencies. Lack of confidence in the long term performance of welds in advanced ferritic steels is one of the main concerns. It is becoming increasingly clear that Type IV cracking in the weld heat-affected zone may be the life-limiting failure mechanism in advanced high temperature components such as superheater and reheater headers and steam pipework, chests and valves.

However, most of the long term creep test data currently available applies only to the parent steels.

If we choose which steel to use on the basis of parent data alone, we may not make the best choice for satisfactory long term weld performance. If we design components without taking account of weld properties, we risk incurring major weld inspection, repair and replacement costs during the lifetime of the plant. If we instead design conservatively on the basis of inadequate information, we run the opposite risk of an over-conservative and hence uncompetitive plant design. Project FOURCRACK aimed to overcome these uncertainties, establish the effective limits on power plant design conditions and operating temperature, and thereby improve the market prospects for cleaner coal technology in the UK and worldwide.

The earlier DTI supported PIPPE project, undertaken by Mitsui Babcock Energy Limited (MBEL), British Steel (now Corus) and Powergen (now E.ON UK), established the new European E911 steel as a viable high temperature plant material in competition with Japanese developments. PIPPE showed that E911 has good creep properties and

oxidation resistance and does not suffer undue long term degradation in service. However, the relatively short term creep tests carried out on welded joints were less encouraging. Extrapolation of the data suggested that long term weld strength might, because of Type IV cracking, fall to as little as 50% of the parent material rupture strength. This would put all welds - not just those under substantial system loading - at risk of early failure. However, the severe extrapolation was subject to uncertainty. Also, little comparative data assessment had been carried out, and it was not clear to what extent alternative high alloy steels would be at comparable risk.

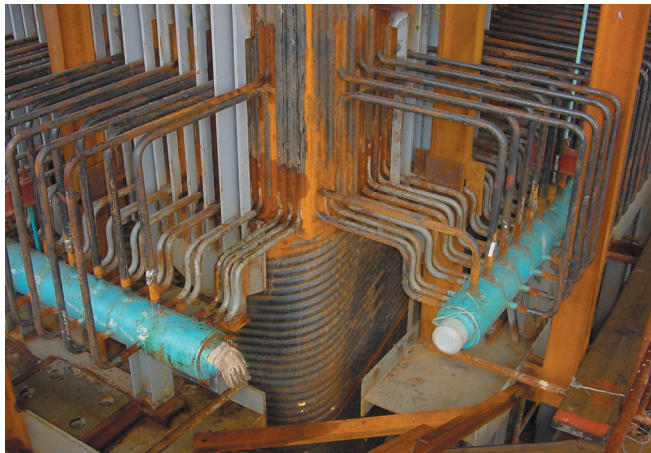


Figure 2. Newly installed P91 steel headers in 660MW Changshu spiral wound supercritical coal-fired power plant.
(Courtesy of Mitsui Babcock Energy Ltd.)

THE FOURCRACK PROJECT

Outline

The project was designed to produce cross-weld creep data on a wide range of alternative advanced high alloy ferritic steels, manufactured with different processing routes, heat treatment conditions, and chemical compositions. The European E911 steel was compared with the leading Japanese alternatives P92 and P122 and with the older established steel P91. The welded materials tested included forging, casting, plate, and pipe components. A special cast of Grade 91 steel with known

poor properties due to its adverse aluminium / nitrogen ratio was also investigated. Separate test series were carried out after welding onto this material in the as-manufactured, renormalised and tempered (strengthened), and preaged (weakened) conditions.

A novel test matrix was devised to investigate variations in both stress and temperature with four tests per weldment. This made it possible to test as many as ten weldments and obtain sufficient data to rank their relative performance over a range of test conditions. The programme was supplemented by additional testing with a special waisted specimen geometry, comprehensive metadata compilation, weld thermal simulation, a creep data assessment project on E911 data supplied by the European Creep Collaborative Committee (ECCC), and optical and electron metallographic investigation.

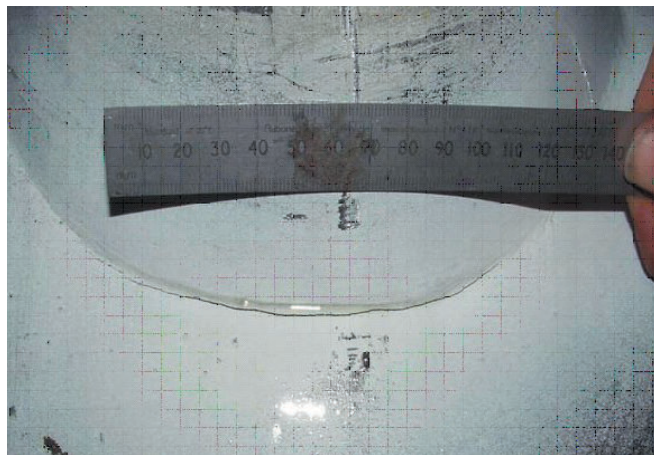


Figure 3. Type IV crack on the header side toe of a large P91 branch weld on a coal-fired power plant.
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Results and Discussion

The assessment of the ECCC E911 database was carried out at an early stage, in collaboration with Dr C. Servetto of the Italian Welding Institute. A larger data set than that of PIPPE and an improved PD6605 based assessment procedure indicated that weld creep rupture strength falls toward a floor value of about 60% of the parent strength in the longer term. Whilst this is

slightly less pessimistic than the PIPPE prediction, it confirms the general trends and the scale of the problem. The assessment also provided reference life predictions for mean E911 weld performance as a function of test conditions. These provided a baseline for comparison of the alternative welded materials investigated in FOURCRACK.

The test results on the stronger P92 and P122 parent materials included many short term failures in the weld metal. Hence, there is some concern that for these stronger alloys, the creep properties of matching weld metals cannot keep pace with those of the parent materials. However, there were clear trends toward HAZ as opposed to weld metal failure as the test temperature, and/or test stress, was reduced to a lower value, closer to the conditions which would apply to real components. As both temperature and stress acceleration promote weld metal failure, it can be difficult to find test conditions which produce Type IV failure in a short term test. However, it can be concluded that it is HAZ Type IV failure which remains the greater long term risk under advanced plant operating conditions.

Those weldments which did fail in the HAZ showed significant differences in relative creep rupture strength, and these proved to be largely independent of the test conditions. The HAZ failure data could therefore be used to determine a broadly consistent ranking order of the relative creep rupture strengths of the different weldments. Hence, in those cases where weld metal failure did not intervene, short term accelerated test HAZ failure data appeared to be a reasonable guide to relative creep rupture strength in the longer term.

An overall assessment of the data showed a broad correlation between parent material and cross-weld HAZ creep performance. Stronger parent materials tend to have

stronger HAZs. However, the correlation is far from perfect. Hence, future alloy development should address the optimisation of cross-weld, as well as parent, material creep properties. The main reason why parent and HAZ properties are not always perfectly correlated was identified as the effect of variations in prior heat treatment. These can substantially affect parent material properties, but may have only a minor influence on the properties of a subsequent weld HAZ. Hence, thick section components, with relatively poor parent creep properties associated with long heat treatment times, may tend to have relatively good HAZ properties. The work on Grade 91 material provided the most striking demonstration of the complex influence of heat treatment. Renormalising and tempering, while greatly strengthening the weak parent material employed, actually had a marginally adverse effect on the performance of the subsequently manufactured weldment.

In most cases, it was apparent that changes in alloy chemistry which strengthen the parent material also tend to strengthen the HAZ. Thus, P92 and P122 generally outperformed E911 both as parent materials and as weldments, although the weaker casts of these Japanese materials when tested in FOURCRACK were not greatly superior to the mean E911 weld data. Conversely, the older Grade 91 (P91) material is generally weaker than E911, both in tests on the parent material and on the weldment. However, the special high aluminium weak Grade 91 material tested, which substantially underperforms mean P91 parent creep data, showed a lesser shortfall in its cross-weld performance. It could therefore be that high aluminium, which is known to combine with nitrogen and suppress the formation of key creep strengthening carbonitride precipitates, has a more substantially harmful effect on parent steel properties than on those of the weld HAZ.

In summary, the results confirmed the broad conclusions of PIPPE, and showed that they apply generally to Japanese and US steels as well as to European steel E911. The cross-weld creep strength falls to a level at which weld HAZ cracking must generally be expected to occur far in advance of parent material life exhaustion. Conservative plant design may therefore be essential to avoid expensive long term maintenance and repair costs.

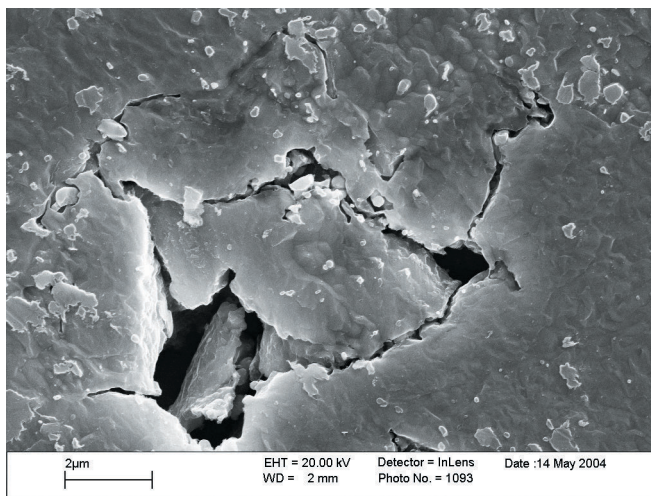


Figure 4. FEGSEM electron micrograph showing grain boundary microcracking close to the Type IV zone fracture face in a FOURCRACK P92 weld test specimen.

(Courtesy of Loughborough University)

CONCLUSIONS

- Type IV cracking in the weld heat-affected zone is likely to be the life-limiting failure mechanism in advanced high temperature plant components.
- Weld HAZ creep performance shows a broad, but far from perfect, correlation with parent material performance.
- Generally, weldments in the established steel P91 are weakest, with E911 intermediate, and advanced materials P92 and P122 strongest. However, there is substantial cast-to-cast variation.
- The weaker of two parent material casts can thus, in some cases, have the stronger HAZ. The main reason for this is

the effect of prior heat treatment on parent material strength.

- Typically, weldment creep rupture strength appears to fall toward a floor value of the order of 60% of the parent strength in the longer term.
- However, different material casts show significant differences in their weldment/parent material creep strength ratios. Hence, future alloy development should focus on optimisation of cross-weld, as well as parent, material creep properties.
- Conservative design of advanced supercritical PF plant may be essential to avoid the risks of costly long term maintenance and weld repair problems, and to gain the confidence of new plant buyers and operators.

POTENTIAL FOR FUTURE DEVELOPMENT

At present, the prospects of developing new high alloy ferritic steels or welding processes which would eliminate the Type IV cracking problem appear fairly slim. However, it is much more likely that materials selection to optimise weld performance will achieve useful improvements in achievable plant design limits and operational reliability. New alloys, for example those now being developed for improved oxidation resistance under the new COST 536 programme supported by DTI, thus need to be critically evaluated against established competitors both in terms of cross-weld and parent material creep performance.

FOURCRACK successfully obtained weld creep rupture data to durations beyond 10,000 hours. However, truly long term creep data, out to over 30,000 hours and beyond, are normally required for design purposes. Commonly, only parent material data to these durations are available, and plant is designed using simplified safety

factors to allow for weld performance. For advanced high alloy ferritic steels, therefore, there is a need for genuinely long term cross-weld data. This will enable the development of improved design philosophies which recognise the critical importance of welds, and thereby improve confidence in the future reliability and hence market prospects for advanced coal-fired power plant.

The UK High Temperature Power Plant Forum (HTPPF) has recognised these critical needs. A HTPPF test programme which will use specimens from the FOURCRACK Grade 91 weldments to extend the test data out to 50,000 hours has just commenced, while a second test programme on the FOURCRACK advanced steel weldments is in preparation.

COST

The total cost of this project is £304,000, with the Department of Trade and Industry (DTI) contributing £152,000, and E.ON UK, Mitsui Babcock, and RWE npower contributing the balance.

DURATION

48 months – January 2001 to December 2004.

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