SUMMARY

The global energy markets are transitioning from fossil fuels to renewable sources. However, the demand for conventional energy persists, with coal continuing to play a role in energy security. Over the next 10–15 years, a "transitional renaissance" of coal is anticipated. As power plants adapt to increased start-ups and shutdowns, components of power plants degrade due to ageing particularly under creep conditions, owing to this their structural integrity becomes a critical concern for safe operation and reliability.

This thesis studies the fracture behavior of material used in components of electricity-generating power plants after exposure to industry and laboratory ageing under high-temperature creep conditions. Its starts with an overview of the fracture mechanics field and power plant steel grade, their operating conditions, and a description of the degradation mechanisms that damage power plant systems and components. Experimental and numerical assessments were conducted on steel elements with over 100,000 operational hours to evaluate fracture toughness. The stress intensity factor (K) was analyzed using the arc tension specimen geometry. Effect of multiaxial stresses and mixed-mode fracture due to crack angle orientation or multi-axial stress are investigated. To overcome the limitations of traditional clip gauge method non-contact measurements by digital image correlation were used to measure fracture toughness under mixed-mode loading using SENT specimens.

Comprehensive experimental isothermal ageing and high-temperature accelerated creep degradation were carried out to examine the impact of ageing and thermal degradation on the trends of fracture resistance in power plant steel. Results indicate that fracture toughness varies across structural components, with the valve chamber exhibiting greater toughness than pipeline sections. A comparative analysis of SENT and AT specimens provided further insights into fracture behavior under different conditions. The study emphasizes the need for additional structural integrity assessments, such as finite element analysis (FEA) combined with creep and high-temperature testing, to predict remaining service life and enhance safety measures.

This research offers critical insights into the effect of creep and isothermal ageing on the durability of components in electricity-generating boilers, aiding decision-makers in assessing load-carrying capacity, potential hazards, and maintenance strategies. Furthermore, the study employs advanced experimental and numerical methods to assess fracture toughness. The research compares as received and degraded samples. The artificial ageing was achieved through laboratory accelerated creep and isothermal ageing, simulating actual power plant operating conditions. Three stages of degradation and a minimum of three crack tilt angles were examined to provide a comprehensive understanding of fracture behavior.

In addition to fracture mechanics, supplementary material characterization techniques, including hardness testing, microstructural analysis, Charpy impact testing, and fractography, were utilized to get more insights into fracture behaviour after degradation. The combination of full-size AT, SENT, and SENB specimens, along with numerical simulations, provided valuable insights into the fracture properties of heat-resistant steel after prolonged operation. Although it is beyond the scope of this thesis, the hope is that this work will assist in making informed decisions regarding the extension or upgrading of power plant components. The thesis concludes with a summary of main findings and suggestions for future research.