# Impact of Welding Residual Stress on Fatigue Cracks and a Low-Cost Surrogate Method for Sample Preparation

Jialin Wang[1], Christopher Truman [1], Nicolas Larrosa[1], Clementine Jacquemoud[1]

[1]Solid Mechanics Research Group, Department of Mechanical Engineering, University of Bristol, United Kingdom

rh19106@bristol.ac.uk

## Abstract

Welding is an essential part of metal fabrication due to its efficiency and adaptability. However, residual stresses caused by welding can compromise weldment performance, particularly under cyclic loading. This study investigates residual stress and its implications of fatigue performance in electron-beam welded (EBW) 316L stainless steel pipe which is a critical concern for safety-driven industries like nuclear energy. This work collaborates with CEA, we employ a low-cost surrogate thermal-mechanical method to replicate EBW residual stress fields, combining numerical modelling, machine learning, and neutron diffraction validation. Subsequentially, four-point bending fatigue tests on pre-cracked pipe specimens will evaluate fatigue crack propagation under residual stress.

## Introduction

Welding has been widely used for fabricating metal parts in various industries according to its versatility, cost-effectiveness, high efficiency and ease of implementing automation [1]. However, the quality of welding cannot always be guaranteed. Sometimes, undesired residual stress can be observed at the welded joints since metal components usually undergo severe and uneven internal temperature changes as well as phase changes within the heat affected zone during welding process [2]. The complex residual stress distribution will affect the mechanical properties of the weldment, such as the fatigue crack will be accelerated with tensile residual stresses under the condition of cyclic loading [3]. Therefore, studying the residual stress and investigating its influence on the fatigue performance are crucial steps of understanding the mechanical behaviour of the weldment, it is especially important for industries which emphasis safety such as the nuclear industry.

For traditional welding methods, the use of filler material is usually unavoidable which adds considerable complication to study the residual stress. Currently, power-beam welding techniques are attractive since they are autogenous and the heat affected zone is generally narrower than traditional welding methods. The most typical power-beam welding techniques are laser-beam welding and electron-beam welding.

This work is in collaboration with CEA and currently focuses on the residual stress field and its effect on fatigue performance of the EBW 316L stainless steel pipe. There are two main parts, the first part is to generate the pipe specimens with desired residual stress distribution, and the second part is investigating the fatigue performance of the pipe under the influence of residual stress.

## Residual Stress Field Generation

The first part is to generate the pipe specimens with desired residual stress distribution. However, it is too expensive to generate a series of electron beam welded pipes. Therefore, a low-cost surrogate method has been introduced by the French Alternative Energies and Atomic Energy Commission (CEA) to reproduce the residual stress field of electron beam welding in the pipe specimens.

This method generates a residual stress field within the pipe by heating it with an induction coil at mid-height and then cooling it with flowing water on the inner side of the pipe as shown in Fig. 1. During the thermal treatment, a mechanical load is applied to the pipe in axial direction. Under the combined contribution of thermal and mechanical loads, different through-thickness residual stress profile could be generated at the centre of the heated zone to mimic that of an electron beam welded pipe. In this part, numerical simulation method and machine learning technique are used to optimise the parameter setting, ensuring the generated residual stress field closely approximates the one of ENW. Additionally, neutron diffraction is used for measuring the residual stress within the pipe specimen, and then used for validation.

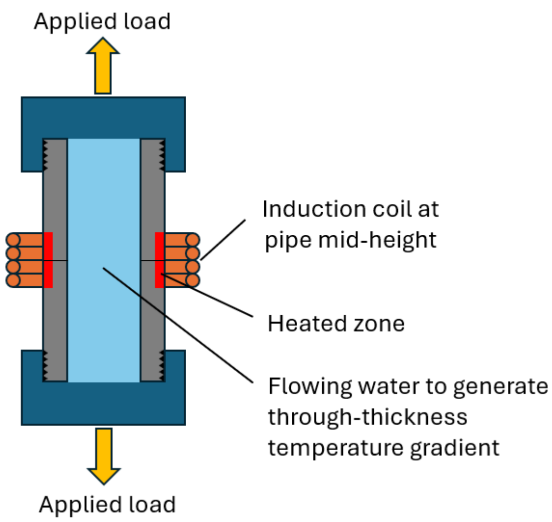


*Figure 1: CEA Induction Heating Experiment Setting*

### Fatigue Performance Evaluation

The second part is investigating the fatigue performance of the pipe under the influence of residual stress. This step is conducted by a four-point bending fatigue test. A customised bending rig has been designed by CEA for this test as shown in Fig. 2. The pipe specimen is fixed with threads onto the bending rig. For the rig, the base is fixed while the moving pins and their frame are assembled on the moving grip of the tensile machine, where cyclic loads are applied. A notch has been made on the pipe as indicated, to initiate and guide crack propagation. Numerical simulation method will be used to cross-validate experimental results, providing additional information for better understanding fatigue crack propagation under the influence of residual stress fields.

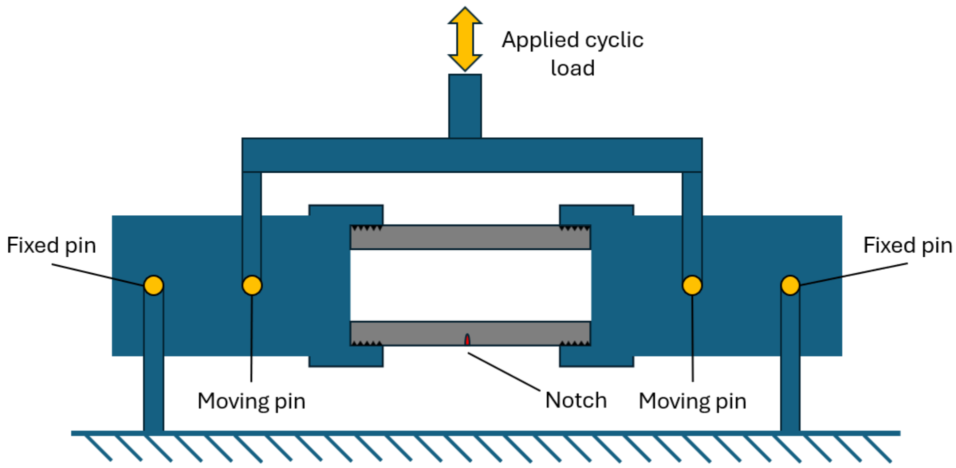


*Figure 2: CEA 4-Point Bending Fatigue Test Setting*

### Conclusion

This study investigates the influence of residual stress on fatigue crack propagation in EBW 316L stainless steel pipe through a combined experimental and numerical approach. By employing an induction heating-based surrogate method, sample production costs have been reduced. The research provides understanding of fatigue behaviour under residual stress, which is helpful for enhancing the durability and safety of weldment in critical applications.

### References

[1] Kah, P., & Martikainen, J. (2012). Current trends in welding processes and materials: improve in effectiveness. *Rev. adv. mater. Sci*, *30*(2), 189-200.

[2] Francis, J. A., Bhadeshia, H. K. D. H., & Withers, P. J. (2007). Welding residual stresses in ferritic power plant steels. *Materials Science and technology*, *23*(9), 1009-1020.

[3] Cheng, X., Fisher, J. W., Prask, H. J., Gnäupel-Herold, T., Yen, B. T., & Roy, S. (2003). Residual stress modification by post-weld treatment and its beneficial effect on fatigue strength of welded structures. *International Journal of fatigue*, *25*(9-11), 1259-1269.