

QUANTITATIVE DIGITAL IMAGE CORRELATION FOR FATIGUE DAMAGE ASSESSMENT IN DEGRADED 10CrMo9-10 STEEL

Adam BRODECKI¹, Mateusz KOPEĆ², Zbigniew L. KOWALEWSKI³

- ¹ 0000-0001-8303-1715, Institute of Fundamental Technological Research, Polish Academy of Sciences, 5b Pawinskiego Str., 02-106 Warsaw, Poland, E-mail: abrodec@ippt.pan.pl;
² 0000-0001-9565-3407, Institute of Fundamental Technological Research, Polish Academy of Sciences, 5b Pawinskiego Str., 02-106 Warsaw, Poland, E-mail: mkopec@ippt.pan.pl;
³ 0000-0002-8128-0846, Institute of Fundamental Technological Research, Polish Academy of Sciences, 5b Pawinskiego Str., 02-106 Warsaw, Poland, E-mail: zkowalew@ippt.pan.pl;

1. Introduction

Long-term operation of power engineering components leads to degradation of mechanical properties, particularly under cyclic loading conditions. A common approach to evaluate such degradation is a comparison between materials in the as-received state and after extended service. However, conventional measurement techniques such as extensometers provide only averaged strain values over a limited gauge length, which restricts the ability to detect localized fatigue damage initiation[1].

Full-field optical methods, especially Digital Image Correlation (DIC), enable detailed monitoring of strain localization and damage evolution. Previous studies have demonstrated that DIC can effectively identify crack initiation zones through strain accumulation and gradients. Nevertheless, most applications of DIC remain qualitative, relying primarily on strain maps[2].

The main objective of this study is to develop a quantitative DIC-based methodology for monitoring fatigue damage development (FDD) in 10CrMo9-10 steel, and to assess the influence of long-term service (280000h) on its mechanical response.

2. Materials and methodology

The investigated material was 10CrMo9-10 (10H2M) steel obtained from power plant pipes in two conditions: as-received and after prolonged service at 540°C under 2.9 MPa pressure. Specimens were extracted using wire cutting.

Initial uniaxial tensile tests were performed to determine mechanical properties, particularly yield strength. Subsequently, fatigue tests were conducted under stress-controlled conditions with stress ratio $R = 0$ and amplitudes of 330, 350, 400, and 430 MPa.

Strain measurements were performed using:

- a conventional extensometer (25 mm gauge length),
- a DIC system (ARAMIS 12M), enabling full-field strain acquisition.

A key aspect of the proposed methodology is the quantitative analysis of strain evolution at three selected reference points (located near extensometer grips and in the specimen center), as well as along defined cross-sections (strain profiles). The strain evolution was related to normalized fatigue life N/N_f , allowing consistent comparison between different tests.

3. Results

Microstructural analysis revealed significant degradation effects after long-term service. The initial ferritic-bainitic structure transformed into a bainite-ferrite structure with carbide precipitation at grain boundaries, leading to reduced mechanical performance. This degradation resulted in:

- a decrease in yield strength,
- a significant reduction in fatigue life (even up to ~50% compared to as-received state).

The DIC-based quantitative analysis showed distinct differences in fatigue damage evolution:

- High stress amplitudes (400–430 MPa):
 - Material after service exhibited continuous strain accumulation throughout the fatigue life.
 - Strain localization occurred mainly in the central region of the specimen.
 - Crack initiation was difficult to predict due to heterogeneous deformation behavior.
 - In contrast, the as-received material reached a stable strain level early and maintained it until failure.
- Low stress amplitudes (330–350 MPa):
 - Both material states showed relatively stable strain evolution.

- Strain localization occurred primarily near specimen edges.
- Crack initiation prediction was more feasible in the as-received material.

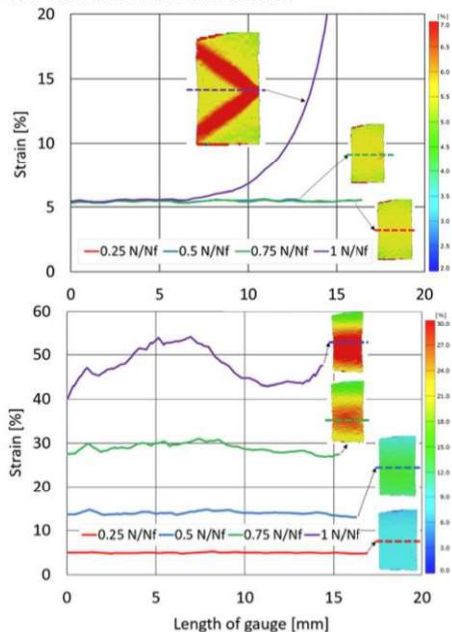


Fig. 1. Strain profiles registered by DIC during fatigue tests for the steel in as-received and after extended service.

Analysis of strain profiles (Fig.1) shows that:

- high stress amplitudes promote internal strain accumulation,
- low stress amplitudes lead to surface-localized deformation,
- strain gradients provide a reliable quantitative indicator of crack initiation zones.

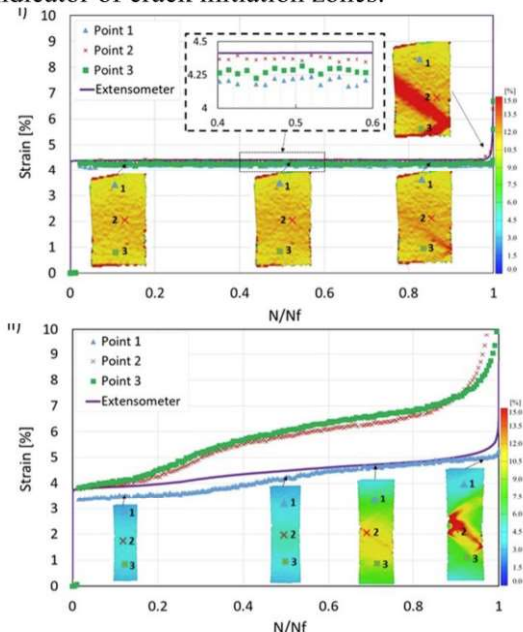


Fig. 2. Comparison of strain evolution in three independent points and extensometer for the steel in as-received state and after extended service.

Additionally, comparison of DIC data with extensometer measurements (Fig. 2) showed that local strain values strongly depend on measurement location, highlighting the limitations of traditional techniques.

4. Conclusions

The proposed quantitative DIC-based methodology enables effective monitoring of fatigue damage development in power engineering steels and provides deeper insight into degradation effects.

The main findings are:

- Long-term service significantly reduces fatigue life and alters deformation mechanisms due to microstructural degradation.
- Quantitative DIC analysis allows identification of strain accumulation patterns and damage evolution dynamics.
- High stress amplitudes lead to heterogeneous and unpredictable crack initiation in degraded material.
- Low stress amplitudes result in more stable damage evolution, with clearer localization of crack initiation zones.
- Strain profiles and point-based analysis provide more reliable indicators of fatigue damage than conventional strain measurements.

The developed approach represents a significant improvement over qualitative DIC analysis and can be applied for structural health assessment of critical components in power engineering systems.

5. Acknowledgments

This work was supported by the National Science Centre under Grant No. 2023/51/B/ST8/01751.

References

- [1] Brodecki, A., Kopeć, M., Kowalewski, Z.L., Monitoring of fatigue damage development in as-received and exploited 10CrMo9-10 power engineering steel supported by Digital Image Correlation, *International Journal of Pressure Vessels and Piping*, ISSN: 0308-0161, DOI: 10.1016/j.ijpvp.2023.104889, Vol.202, No.104889, 2023, pp.1-9.
- [2] Kopeć M., Brodecki A., Kowalcwski Z.L., Quantitative digital image correlation approach for the monitoring of fatigue damage development in 10CrMo9-10 steel in the as-received state and after extended service, *Measurement*, ISSN: 0263-2241, DOI: 10.1016/j.measurement.2024.114926, Vol.234, No. 114926, 2024, pp.1-9.