Effect of combined loads in cracked rails using photoelasticity and finite elements

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Abstract: Modern rail networks have switched from jointed rails to welded rail systems due to better rider comfort. Welding restricts free contraction at low temperatures leading to tensile stress build-up in these rails. Defects like cracks present in rails under axial tension and vehicular contact loads can compromise its reliability during service and needs to be studied. Simple model studies are desirable for understanding the stress state in components in such scenarios of combined loading. Although numerical analysis helps simulate diverse load conditions, availability of experimental information for some combinations is necessary to interpret results in a meaningful way. Towards this, a photoelastic experiment is carried out on an epoxy beam with a small crack subjected to contact loading with and without axial tension and fracture parameters are evaluated. Similar configurations are numerically modelled using finite elements comparing well with experiments. The numerical model is then used to vary the crack orientation to qualitatively visualize the changes in the stress fields. This work helps in understanding the combined effect of axial tension and contact load on the fracture parameters which is useful for studying the fracture of welded rails at low temperatures.

Possible Sessions

8. Fatigue and fracture; 19. Optical and DIC techniques

Introduction

Rail fracture is a major problem encountered in welded rails in cold climatic conditions. Welded rails are subjected to axial tension at low temperature and high contact stresses from vehicular movement. Defects like squats, which are cracks that initiate on the running surface of the rails, are one of the major problems. These cracks are generally inclined to the surface initially, thereafter becoming transverse leading to fracture of the rails [1]. Understanding the behaviour of cracks under combined axial tension and contact loads is essential to mitigate failures. While there have been studies on surface cracks under contact loading using numerical frameworks [2, 3], the combined effects on the cracks have not been studied so far. The tension resulting from low temperature plays a role in the propagation of cracks in rails [4]. Hence, there is a need to study the effect of such a load combination on the cracks and this work is a step in this direction using simple model photoelastic experiments and numerical modelling. The fracture parameters are evaluated from the experimental results to quantify the influence and numerical models are used for visualizing the stress field by varying the crack orientation.

Methodology and Analysis

A planar epoxy beam of dimensions 200 mm × 30 mm × 5.3 mm with a small vertical through-thickness crack is subjected to contact loading using a circular indenter of 80 mm radius. The clear span of the beam is 100 mm with the contact load applied at 40 mm from the right support. Dark field circular polariscope arrangement is used to capture images of the isochromatic fringes which are subsequently processed using an in-house developed software to obtain whole field fringe order (N) data [5]. The stress intensity factors and T-stress are evaluated for this case using a multiparameter approach [6]. Numerical models are developed in Abaqus® by modelling the crack with a root radius and contact loading applied as a user-defined analytical field [7]. The field output is post-processed to obtain photoelastic fringes similar to experiments using an in-house developed method [5]. This provides a qualitative appreciation of the fringe features in different conditions which are subsequently discussed.

Results and Discussion

The dark field isochromatics from the experiments are presented in Fig. 1. Figure 1(a) shows the results for the case where only contact loading of 207 N is applied on the beam. For this case, the dark field fringes are used for data collection and the theoretical reconstruction of the fringe field is presented. Subsequently, the cases with only axial tension of 242 N (Fig. 1(b)) and combined load case of contact and axial tension (Fig. 1(c)) are processed using composite field fringes due to lesser number of fringes. The theoretical reconstructions with the experimental datapoints echoed back in red are presented for the regions of interest.

The evaluated fracture parameters using the multiparameter approach are presented in Table. 1. It is observed that the mode-I SIF (K_I) and T-stress show a significant reduction in the values from contact loading when axial tension is introduced which reduces the compression due to bending. However, it is observed that the mode-II response (K_{II}) remains unaffected in this case which is noteworthy.

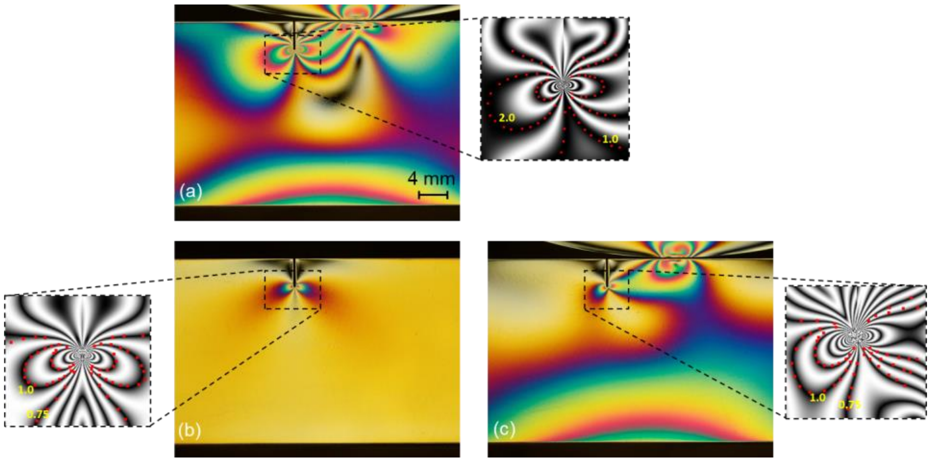

Fig. 1 Experimental dark field isochromatics and theoretical reconstruction for (a) only contact loading, (b) only axial tension and (c) combined axial and contact loading

Loading	K_I [MPa√m]	K_{II} [MPa√m]	*T*-Stress [MPa]
Only contact loading	0.537	0.041	1.947
Only axial tension	0.172	-	0.949
Contact loading + axial tension	0.193	0.042	1.169

Table 1 – Fracture parameters evaluated from the experimental results

Next, the numerically post-processed fringes are presented in Fig. 2. On respectively comparing Figs. 2(a and d) with Figs. 1(a and c), a good match is observed with experiments, thereby validating the numerical model. Further, on observing the isochromatics, the fringes appear similar even though the crack orientation changes with respect to the horizontal. This indicates an increase in mode-mixity.

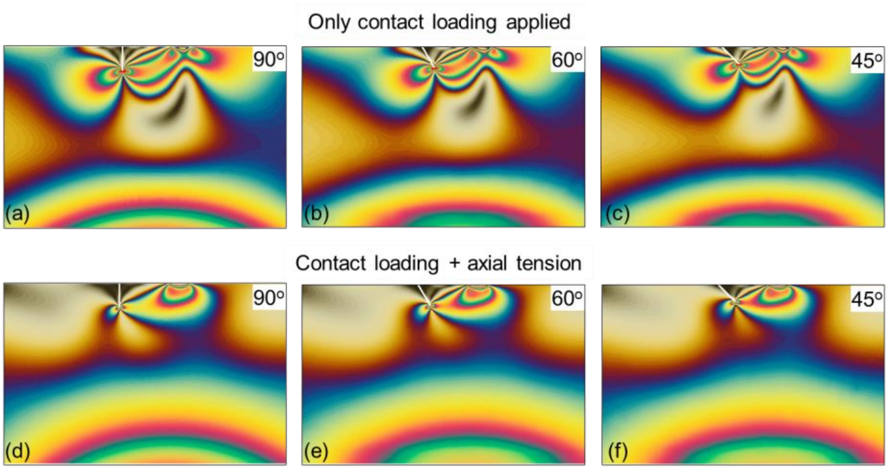

Fig. 2 Numerically post-processed isochromatics with varying crack orientations for (a-c) only contact loading and (d-f) combined contact and axial loading

Conclusion

The combined loading effects on cracks are studied using experiments by evaluating the fracture parameters. It is observed that while the mode-I SIF and *T*-stress show a reduction due to axial tension, mode-II remains unaffected. Additionally, numerically post-processed isochromatics qualitatively show that the fringe features are similar even with varying crack orientations indicating an increase in mode-mixity. This information is useful to further study the failure of rails subjected to contact loading in the presence of axial tension.

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