Characterisation and fatigue life assessment of handling surface damage

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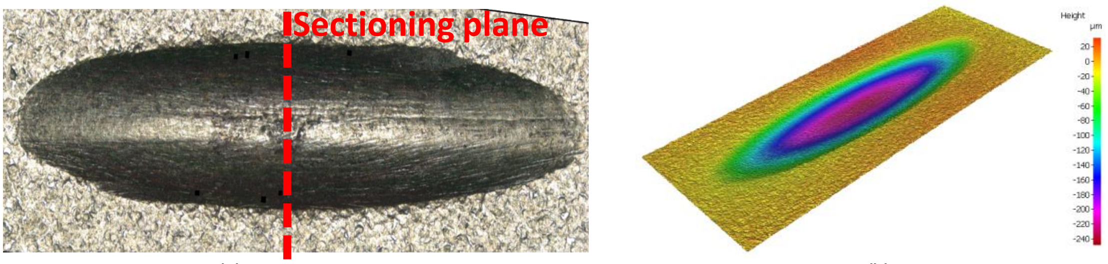
Abstract. The objective of this work is to predict the fatigue life of components in the presence of handling surface damage. In order to accurately predict the change in fatigue life of components due to the dents at the surface, the geometry of the dent and the residual stresses due to the impact need to be assessed. In previous work, we have created an FE model to predict the geometry of the dent. Here, we validate the predicted residual stress under the dent with experimentally measured stresses through a Focused Ion Beam hole-drilling technique combined with Digital Image Correlation (FIB-DIC). The residual stresses and 'notch' geometry are included in a short crack propagation model for fatigue life estimation for different dent depths.

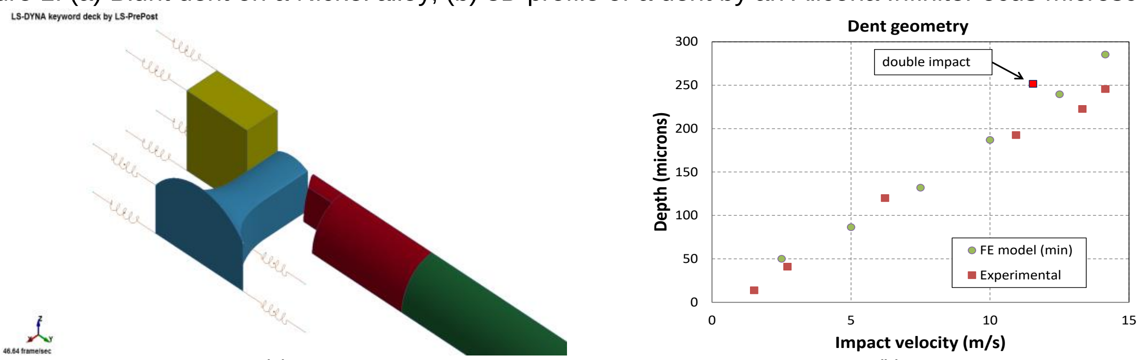
Introduction

The effect of handling surface damage which may occur during manufacturing and maintenance of engines has long been overlooked by manufacturers, but new regulations by aviation authorities have increased the interest in accurate prediction of their effect on the fatigue life of engine components. These occur due to low velocity impacts (i.e. 1-15m/s) of hard heavy objects causing scratches and dents on the surface of components (Fig. 1). In order to accurately predict the effect of handling damage on the fatigue life, one needs to consider the geometry of the damage and the residual stress under it. Previously, we have developed an explicit FE model capable of predicting the geometry of dents as a function of the impact velocity, Fig. 2, and the residual stresses over a volume around the dent were validated using laboratory X-ray diffraction [1]. In order to use the residual stresses predicted with the FE model, we carried out a pointwise validation of the profile of stresses under the dent using a FIB-DIC technique [2]. This profile is then incorporated into the fatigue life calculation of damaged specimens.



(a) (b)

Figure 1: (a) Blunt dent on a Nickel alloy; (b) 3D profile of a dent by an Alicona InfiniteFocus microscope.

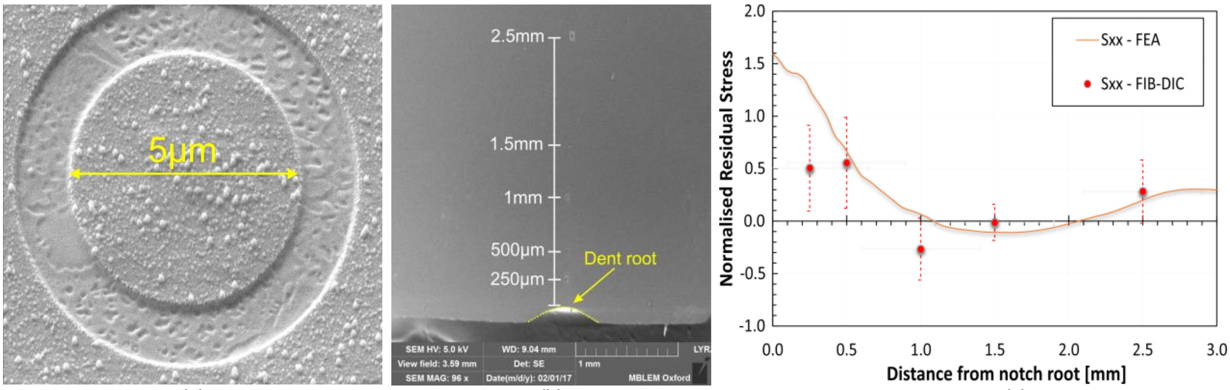


(a) (b)

Figure 2: (a) FE model used in LS-Dyna; (b) Experimental and FE dent depth as a function of impact speed.

Residual stress measurement and FE model validation

The residual stresses were also measured using a FIB-DIC technique. The FIB-DIC micro-ring core drilling [2] is a promising method for the quantification of the residual stresses at micron-scale. The version of the technique advanced in the MBLEM lab at Oxford is based on the use of FIB as the means of minimally invasive creation of a circular traction-free trench around the central micro-pillar. The deformation occurring at the pillar top surface is monitored during milling using SEM. DIC is used to measure the strain relief of the pillar, which is directly correlated with the residual stresses field.The stress distribution can be obtained from the measured strain relief of the ring core at each depth [3]. The elastic residual strain prior to the drilling is then obtained by fitting the curve of the stress relief as a function of the normalised trench depth h/D (Fig. 3a). Measurements were taken at 5 points under the dent root (Fig.3b). At each point the trench was drilled up to a final depth of h/D=1. The stress distribution measured by FIB-DIC and predicted by the FE method is given in Fig. 3c.



(a) (b) (c)

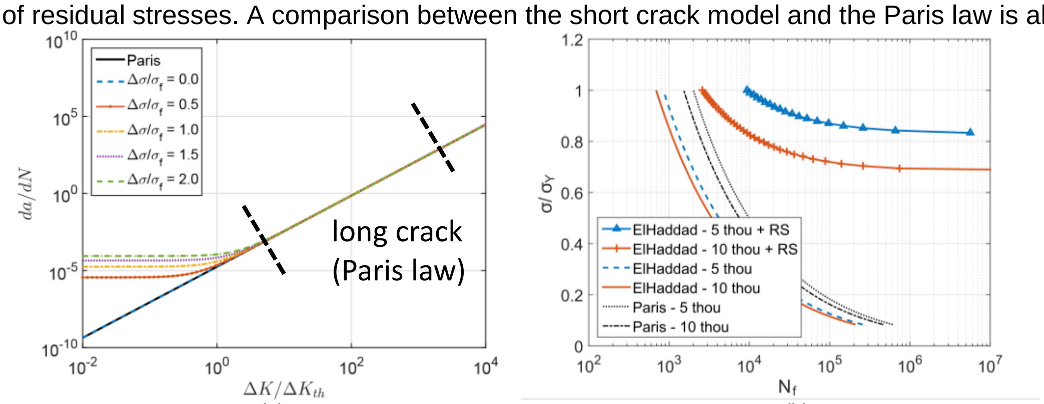
Figure 3: (a) Diameter D of the ring core; (b) and drilling points distance from dent root; and (c) Comparison between residual stress σ_{xx} predicted by the FE model and measured by FIB-DIC.

Fatigue life prediction

A short crack growth model given in [4,5] was used in the fatigue life calculations. In this model, the stress intensity factor in the Paris law is modified to include a minimum crack length, defined here by El Haddad's characteristic length, a_0. The effective stress intensity factor, modified from Irving's definition, i.e. $\Delta K_{eff} = Y\Delta\sigma\sqrt{\pi(a+a_0)}$, is then included in Paris law we obtain,

$$\frac{da}{dN} = C\left(\Delta K\sqrt{1+\frac{a_0}{a}}\right)^m, \qquad \text{where} \qquad \frac{a_0}{a} = \left(\frac{\Delta K_0}{\Delta K}\frac{\Delta\sigma}{\sigma_f}\right). \tag{1}$$

The crack growth curve for different applied stresses are displayed in Fig. 4a. In order to obtain the fatigue life, Eq. (1) can be integrated for a crack length from 5µm to 2.5mm, the latter is the specimen half-width. The stress intensity factors for a crack propagating under a notch were obtained by a dislocation density approach [5]. The stress intensity range for an applied load, σ_0, and for the existing residual stress field were obtained. The predicted fatigue curves for two different dent depths are presented in Fig. 4b with and without the presence of residual stresses. A comparison between the short crack model and the Paris law is also given.



(a) (b)

Figure 4: (a) Crack growth law with El Haddad modification; (b) Predicted fatigue life for 5 and 10 thou dent depths with and without residual stresses.

Conclusion

The effect of handling surface damage dent geometry and residual stresses on the fatigue life of components were investigated here. The predicted stresses by the FE model show good agreement with FIB-DIC measurements. Only near the surface, the elasto-plastic model over predicts the stresses due to the lack of material damage in the model. A good prediction of the residual stresses are essential for a good prediction of the fatigue life (Fig. 4b) and stress relaxation mechanisms are necessary in order to compare the model with experimental fatigue tests of damaged samples.

References

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