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Prediction of Fretting Fatigue Strength of Al7075 Alloys

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ABSTRACT

Fretting fatigue occurs when a component subjected to a contact pressure is subjected to fatigue loading also. The region upon which the contact pressure is applied will undergo fretting wear together with the applied fatigue loading. Due to the accompanied fretting wear, the fatigue life of the specimen will be reduced significantly. Usually components subjected to fatigue loading are subjected to contact pressure also, which leads to reduction of fatigue life due to accompanied fretting. So there is always great importance for the study of methods for predicting fretting fatigue life. The fretting fatigue strength can be predicted using several design curves. Recently a new design curve had been developed based on tangential stress range (TSR) and compressive stress range (CSR) acting on the components. This graph is unique for each material, could be used to quickly predict the safety of components subjected to fretting fatigue. Fretting fatigue phenomenon is found to occur in aluminium alloy Al7075 used for the construction of aircraft structures. In this work TSR-CSR diagram is going to be developed for aluminium alloys. Also a new design curve based on Von Mises Stress Range (VMSR) and TSR which is more accurate has also been developed for Al7075.

Keywords: Fretting Fatigue, Tangential Stress Range, Compressive Stress Range, Von Mises Stress Range, Abaqus, and Fe-safe.

INTRODUCTION

Fretting is the small-amplitude oscillatory movement which may occur between contacting surfaces under load, and may lead to surface damage, which was first reported about one century ago. Fretting is a form of wear due to relative movement of the contacting surfaces. Fretting can be divided in to fretting wear, fretting fatigue and fretting corrosion. Fretting corrosion refers to corrosion damage at the asperities of contact surfaces. This damage is induced under contact load and in the presence of repeated relative surface motion induced by vibration. Fretting fatigue occurs when the relative movement at the contacting interface required to cause fretting wear is caused by the applied cyclic load. Fretting fatigue is a combined phenomenon of fretting wear and fatigue loading, where the contact pressure causing fretting wear significantly reduces the fatigue life of the component. Fretting fatigue failure results from crack formation and propagation in a component under the combined action of two factors: (a) the total cyclic stress applied on the component and (b) the local stress arising from the relative slip of the surfaces of the two components and (c) the pressure.

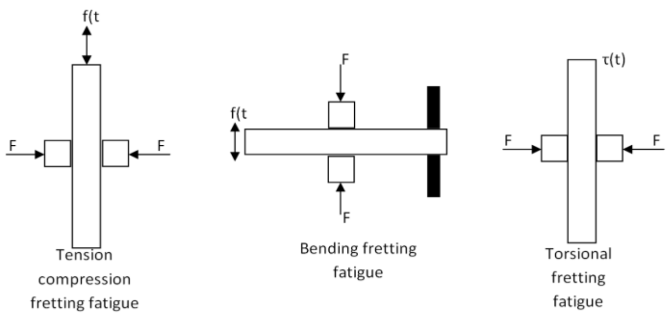

Figure1. *Classification of fretting fatigue*

According to the modes of body cyclic stress, the fretting fatigue can be divided into three types, i.e. tension–compression (or tension–tension) fretting fatigue, bending fretting fatigue and torsional fretting fatigue.

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In this work two design curves have been developed to predict the fretting fatigue strength of components made of Al7075 alloy. First graph is based on the tangential stress range (TSR) and compressive stress range (CSR). The second graph is based on Von Mises stress range (VMSR). TSR is the difference of tangential stresses (stress along the fatigue loading direction) when maximum and minimum fatigue loads are applied. Similarly CSR and VMSR is also obtained.

METHODOLOGY

The experimental procedure to develop TSR-CSR diagram will be explained first. The entire experiment was simulated in FEA using Abaqus and Fe-safe. Two components a rectangular beam and a rectangular plate called contact pad is modelled and made in to contact and pressure is applied at the contacting region. The rectangular beam is modelled with the material, whose TSR-CSR diagram is required to be developed. The FE model used for analysis of fatigue loading is shown in Fig 2.

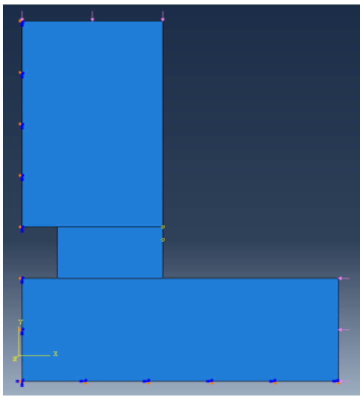

Figure2. *FE model for fretting fatigue loading*

Fretting fatigue tests are carried out by applying axial cyclic load on the beam. Thus as the contact pad and beam are kept under pressure fretting fatigue will occur at the contacting region. The schematic of the loading of fatigue specimen is shown below in Fig 3.

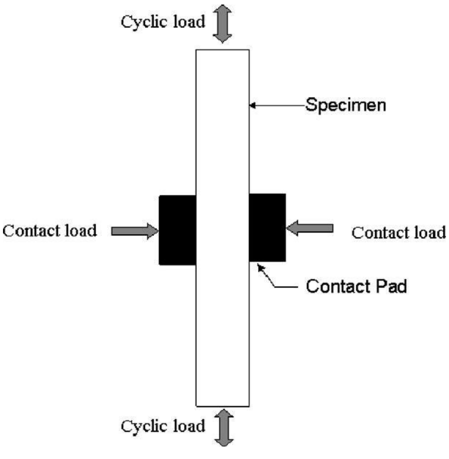

Figure3. *Schematic of fatigue loading*

The geometry of contact pad is shown in Fig 4 & the geometry of specimen is shown in Fig 5. The rigidity of contact pad can be varied by varying the height, h of the contact pad. Then fretting fatigue tests are conducted at different pad geometries up to the failure of the component to find the fretting fatigue limit. TSR and CSR at the contact edge are evaluated for each contact pad when the applied fatigue load is equal to fretting fatigue limit. The data points of TSR and CSR at fretting fatigue limit for different contact pad rigidity are plotted to obtain the diagram, which is a straight line graph.

First a unit contact and fatigue load is applied to the specimen in Abaqus. Because of symmetry of the model, only half of the model is to be analysed. To specify this symmetry roller support is given on both sides. After analysis is done the result file containing stress values at each nodes is exported to Fe-safe. In Fe-Safe the loading history is specified for fatigue loading. After performing the fatigue loading in Fe-safe, the number of cycles required for failure for the given loading is found. Then the loading history is changed and procedure is repeated until the number of cycles is obtained as one million. The load corresponding to one million cycles is the fretting fatigue limit. From loading history the maximum and minimum load is determined. The stress ratio of fatigue loading is kept as 0.1 for all tests. The maximum and minimum load is applied to the model in abaqus in separate steps along with contact pressure. TSR is found as the difference of tangential stress at maximum load and minimum load steps. Similarly the CSR is also found at the point where TSR is maximum. From literature, it has been found that crack originates at the point where TSR is maximum and thus only the maximum value of TSR needs to be considered. The maximum value of TSR in specimen was found near the external contact edge of contact pad, so in this work TSR and CSR were obtained from the point in the specimen near the external contact edge.

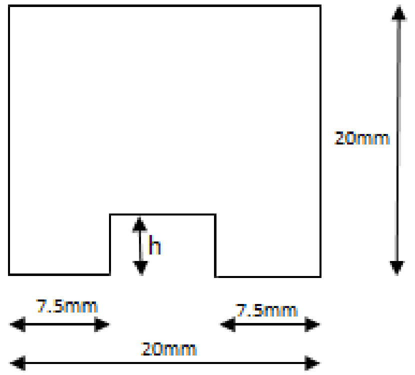

Figure4. *Geometry of contact pad*

VALIDATION

The validation of the work was performed by reproducing the TSR-CSR diagram of NiCrMoV steel available in the journal. The design curve for NiCrMoV steel was developed in the current work using Abaqus and Fe-safe. The error between the values of present work and that from the journal was found to be within 10%. The mesh size used for analysis in present work was 5µm, which was obtained from mesh convergence study.

TSR - CSR DIAGRAM OF AL7075

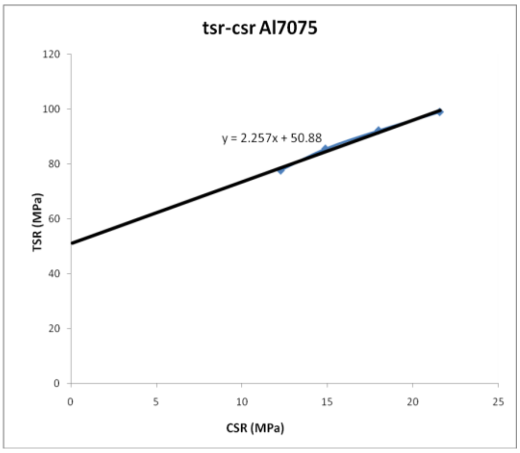

Figure5. *TSR - CSR diagram of Al 7075*

TSR - CSR DIAGRAM OF AL7075

TSR - CSR diagram of Al7075 is shown in Fig 5. The equation of the diagram was obtained as

TSR = (2.257*CSR) + 50.88

The constant in the equation 50.88 is called critical stress parameter (CSP), which is the intercept on y-axis when the graph was extrapolated.

TSR - VMSR DIAGRAM OF AL7075

An attempt was made to develop a new design curve similar to TSR - CSR diagram developed in previous section. To develop the design curve, two parameters are needed. Several combinations of stress ranges were tried such as

- shear stress range - compressive stress range
- Shear stress range - tangential stress range.
- tangential stress range - Von mises stress range

When the fretting fatigue strength of a bolted plate was attempted to solve using the above diagrams, the percentage error in the first two cases was more than 50%. But in the case of tangential stress range - Von mises stress range (TSR - VMSR), the error in the result was found to be less than 0.1%. Thus it is found that TSR - VMSR diagram is a promising design curve for predicting fretting fatigue strength.

The VMSR was found as the difference of Von mises stress when maximum and minimum fatigue loads are applied. Since it was found that crack originates at the point where TSR is maximum, VMSR was also obtained at the point where TSR is maximum. That is for each contact pad VMSR and TSR was obtained from external contact edge.

Table1. Variation of TSR & VMSR

Pad height	Von mises (MPa)	TSR (MPa)
1mm	73.76	77.63
2mm	80.27	85.4
3mm	85.52	92.21
4mm	91.21	98.92

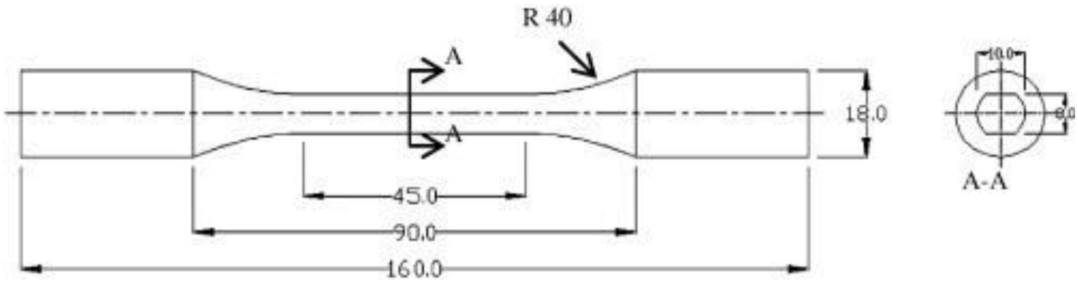

Figure6. *Fretting fatigue Specimen*

The variation of TSR & VMSR for different pads is shown in Table 1. A graph is drawn with VMSR on x-axis and TSR on y-axis as shown in Fig. 7 shows TSR - VMSR diagram developed for Al7075 alloy.

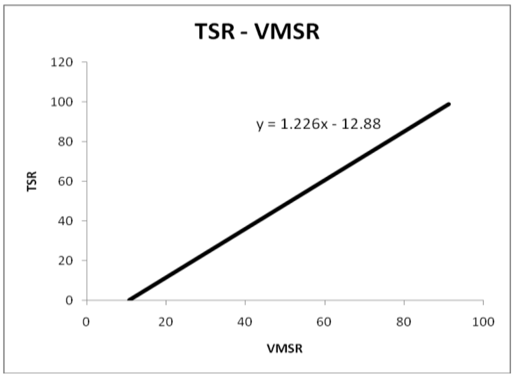

Figure7. *TSR - VMSR diagram of Al7075*

If the point obtained by plotting the TSR and VMSR of a component under contact and fatigue load falls above the graph, then the component is unsafe. If the point is obtained on the line, then the component is at fretting fatigue limit. If the point is below the curve, then the component is safe. If the fretting fatigue life is defined differently other than one million cycles, then the TSR and VMSR diagram has to be developed separately for respective lives. In this work the fretting fatigue life is conveniently chosen as one million cycle.

DETERMINATION OF FFL OF BOLTED PLATE USING TSR - VMSR DIAGRAM

To verify the validity of the TSR - VMSR design curve developed, the FFL of a bolted Al7075 plate was calculated using the diagram. The FFL was calculated by simulating fretting fatigue phenomenon in Fe-safe and both results were compared for validation. The dimensions of washer and plate is shown in Fig 8.

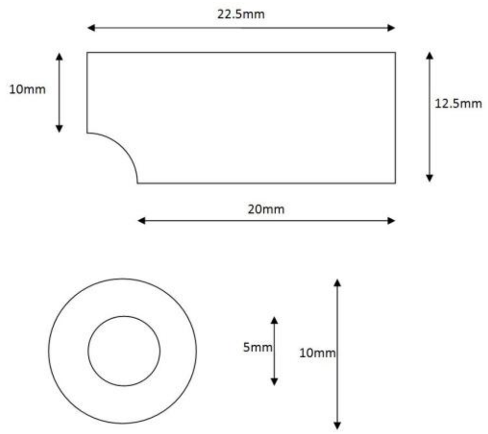

Figure8. *Dimensions of bolted plate*

Because of symmetry only one quarter of the plate is modelled. The washer and bolt are made of steel. The fatigue load is applied axially to the plate and fretting fatigue occurs at the contact between plate and washer which is also the contact between Al7075 and steel. Thus the stress values at the contact region of plate and washer is only required. Thus the bolt was removed from analysis to minimize the no. of elements. The bolt load was given as pressure to the area of washer where bolt comes in to contact. The assembled model of washer and plate is shown in Fig 9.

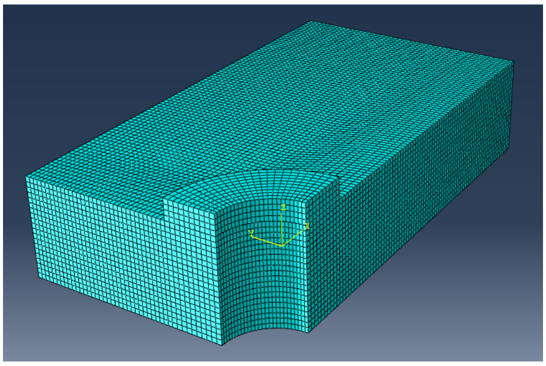

Figure9. *Plate and washer modelled in Abaqus*

The procedure for evaluating fretting fatigue strength of a specimen from TSR-VMSR diagram can be briefed as given below.

- For an applied cyclic load, TSR and VMSR at the contacting region of component are evaluated by the finite element analysis in Abaqus.
- Substitute the values of TSR and VMSR in the equation of the TSR-VMSR diagram of corresponding material to obtain the CSP value (the constant in the equation).
- The CSP values are obtained for various cyclic loads. The load which gives the CSP same as that in the equation of TSR-VMSR diagram is fretting fatigue limit.

The equation of TSR - VMSR diagram of Al7075 is obtained as shown below.

TSR = (1.226*VMSR) - 12.88 (1)

The CSP corresponding to fretting fatigue limit is 12.88. Using the results of analysis performed in Abaqus, a graph as shown in Fig 10. was plotted between CSP and load applied to interpolate the load corresponding to CSP of 12.88. The FFL or the load corresponding to CSP 0f 12.88 was interpolated as 279.3633MPa. The FFL obtained by simulating fatigue loading in Fe-safe was 279.5925MPa. The error between the two values was 0.08%.

The FFL was calculated using TSR-CSR diagram also following the above procedure. In this case the VMSR was replaced by CSR. The FFL obtained was 265.9503MPa. the error in the result when compared to the FFL obtained from Fe-safe was 4.8%.

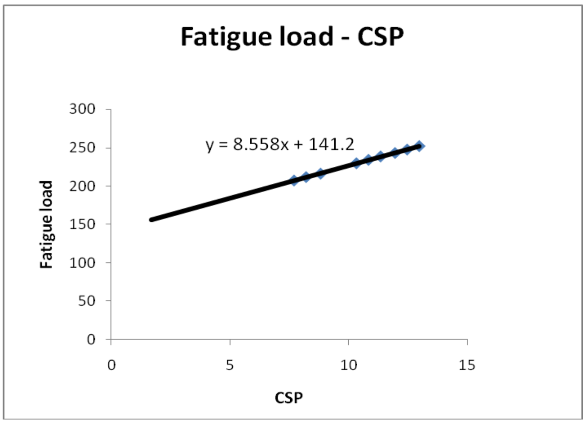

Figure10. *Fatigue load - CSP of bolted plate*

CONCLUSION

TSR - CSR diagram and TSR - VMSR diagram was developed for Al7075 alloy for predicting FFL. FFL of a bolted plate was predicted using both TSR - CSR diagram and TSR - VMSR diagram. From the results it was found that TSR - VMSR diagram is more accurate than TSR - CSR diagram. Also the FFL predicted using the design curves developed in this work lower than the FFL obtained using simulation in Fe-safe. Thus FFL predicted using the design curve can be safely applied for one million cycles. So the TSR -CSR diagram and TSR - VMSR diagram developed can be used for predicting FFL of components made of Al7075.

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