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INVESTIGATION OF THE COMBINED EFFECT OF NOTCH AND FRETTING ON BENDING FATIGUE

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Abstract. Being a common phenomenon in failure mechanism, fretting fatigue has emerged as one of the major concerns in recent years both in research and industrial applications. In the present study, the effect of notch and fretting on bending fatigue has been examined by FEM analysis. Based on the available and validated FEM model, analyses have been carried out on single point fretting with a double notch and double point fretting with a single notch respectively. Along the predefined paths through the edge, thickness and notch, fatigue behavior and stress-strain distribution have been studied. It has been found that stress and strain distribution is uniformly spaced for constant fretting loads with a variable concentric load whereas variable fretting loads yield almost two times results. Stress and strain singularity is found for transverse loading when highly stressed. Peak stress was found on the stress distribution path for fretting action for the combined fretting and notch presence. Fatigue life was influenced more drastically by variable fretting loads than variable concentric loadings only in case of tension. Dual action of fretting with notches was found more detrimental than the single action of double fretting/notching.

1. Introduction

Fret can be defined as the gradual elimination of something by rubbing or friction. It is the wear that occurs in the contact area of two bodies under force [1]. This causes surface damage as well as deterioration [2–5]. More research is being conducted on bending [6–13] than on fretting [14–19]. However, a few papers on bending fretting fatigue have been published [6, 20]. D. Nowell showed the effect of rapidly varying contact stress fields on fretting fatigue [21]. A model combining both phases, notch and fretting, was proposed in the paper. With a stress gradient, that model was applied to uniaxial and multiaxial fatigue in samples: a section of test samples with spherical and cylindrical fretting contact and another section of

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test samples with a notch [22]. An investigation was conducted to observe the fatigue behavior of Al 7075-T6 under stress raisers (notch, fretting, and a combination of notch and fretting), which revealed the effect of stress concentrators generated by geometrical discontinuities such as the tested notch compared to the fretting wear setup. However, negligible differences were noticed between the fatigue lives of the notched samples and the combined notch and fretting condition [23]. Using a simplified equivalent 2D plane strain FEM model with an equivalent normal load resulting from the 3DFEM model, the bending fretting fatigue analysis of 316L stainless steel was simulated [24]. Other works by the present authors can be found in [25–28].

In the present study, a Finite Element Model has been developed for bending fretting fatigue. Its validity was justified on the basis of previous research works. Two conditions were observed: a single fretting point with a notch and a double fretting point with a notch. Paths were created for the investigation of the contact edge, center line and notch length. Simulation was run by ANSYS 14.5 to create geometry, model constraints and, finally, to get the result.

2. Analytical model

A specimen of 80×12×9 mm with 5 mm radius pads, which acts like a cantilever beam, has been used. Figure 1 presents the schematic drawing.

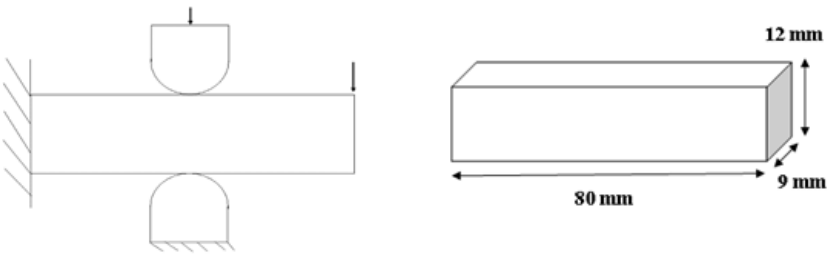

FIGURE 1. (Left) Schematic diagram of bending; (right) dimension of the specimen.

Material Properties			
Material	Poisson's ratio	Young's Modulus	UTS
SUS 316L	0.33	193 GPa	555 MPa
52100 bearing steel	0.33	210 GPa	2000 MPa

The formula for bending stress which has been used in this analysis is as follows:

$$\sigma_{\max} = \frac{6WL}{bh^2}$$

$\sigma_{\max}$ = maximum bending stress, W = cyclical bending load, L = distance between the bending load and fretting pads, b = thickness of the sample, h = height of the sample.

According to Hertzian Contact theory, contact pressure distribution along the contact line is

$$p(x) = \frac{2p_0}{\pi a^2}\sqrt{(a^2 - x^2)}$$

where p_0 is the peak contact pressure,

$$p_0 = \sqrt{\frac{PE}{\pi R}}$$

and a is the half-contact width, which could be calculated by

$$a^2 = \frac{4PR}{\pi}$$

3. Finite element modeling

Here, ANSYS 14.5 was used for FEM modeling.

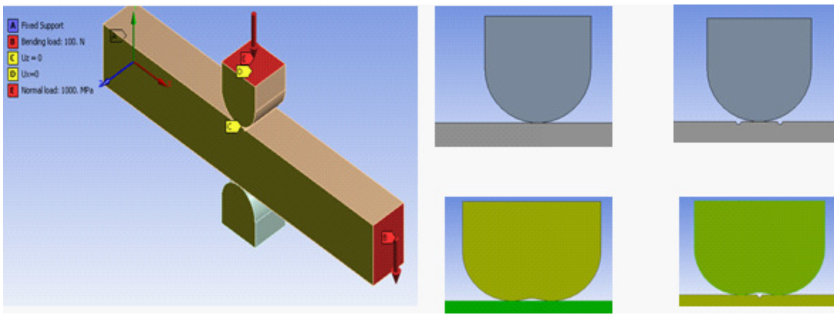

FIGURE 2. FEM model of fretting bending fatigue: a. Single point fretting, b. Single point fretting with two notches, c. Double point fretting, d. Double point fretting with a central notch.

The FEM model was developed based on previous validated work [24]. Figure 2 shows the FEM model for the purposes of this research. A symmetrical boundary condition, $U_z = 0$, is applied on the symmetrical plane surface for both pads and specimen. A fixed constraint is applied on the base plane of the lower pad and $U_x = 0$ is applied on the upper pad to control displacement. The left end of the specimen is fixed while the right end is subjected to bending loading. A normal force is applied on the upper pad to establish a contact. Paths have been created as shown in Figure 3 (left) through the edge of contact surface (10 mm), thickness through contact and length of notch (0.9 mm). The frictional co-efficient between contacts is taken as 0.2. A validation stress-strain curve is shown in Figure 3 (right).

4. Results

As expected, fretting and notching effects were found detrimental to the strength as well as fatigue life. However, in order to calculate the individual effects of each, conditional studies were done, i.e. single fretting, single fretting with a

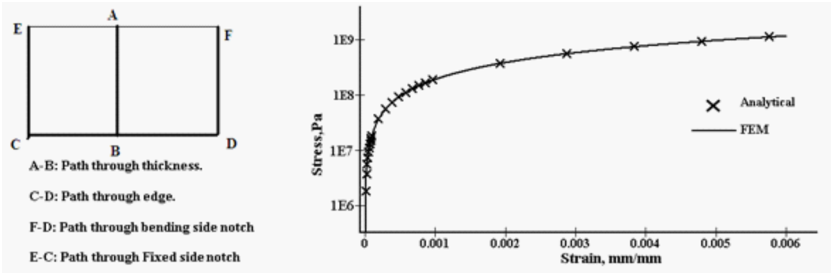

FIGURE 3. (Left) Defined paths and (right) stress-strain curves on plotted values.

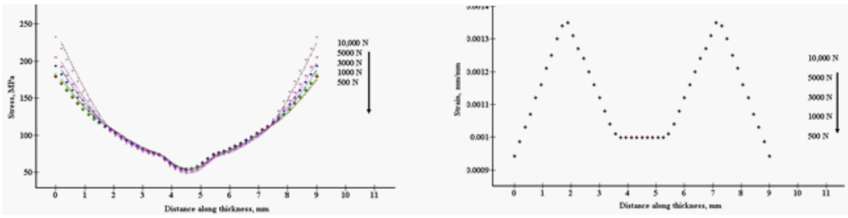

FIGURE 4. Stress and strain distribution through contact surface along thickness (constant fret).

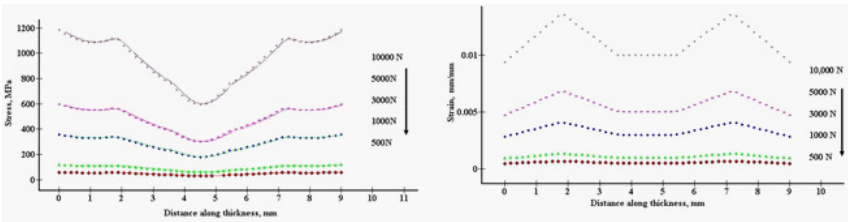

FIGURE 5. Stress and strain distribution through contact surface along thickness (variable fret).

double notch, double fretting with a single notch etc. Stress and strain distribution through the defined paths were observed for the justification of actual effect. Fatigue lives were compared later, which indicated the ultimate consequence of the combined action of fretting and notching.

4.1. Effect of fretting on bending fatigue. Figures 4 and 5 present stress-strain distribution through the contact path for constant and variable fretting loads, respectively. For constant fretting loading, stress and strain distribution along the central thickness remains almost the same as for variable bending loadings i.e., 500 N to 1000 N where the stick regime is significant and lies in the same region. On the other hand, for variable fretting loads as in bending in the previous case, a comparatively horizontal line is found for low order loading while an incremental stress and strain distribution curve with a notable crest and slip-stick zone is seen for higher order loading. It seems that variable fretting loading has a greater effect on the stressed body than the variable bending one.

4.2. Effect of single point fretting with a double notch.

4.2.1. *Stress-strain behaviour at the edge.* For the combined application of fretting and notching, the equivalent Von Mises stress along the free edge through notches and contact has been plotted as in Figure 6 (left). The red curve shows three crests where the highest position is for fretting action which slides a little to the left, the intermediate one is between the bending side notch and fretting pad due to the resultant effect of those concentrators on the bending side and the third one is in the position of the notch behind the pad. On the other hand, the lowest point i.e. minimum stress is found for the position of the notch on the free bending side. For no notching condition, peak stress is found for the fretting applicable zone by gradual increment from left to decrement on the right side of the pad position. Following the red curve, except the highest middle peak position, no fretting condition obeys the same rule as peak stress on the left notch and minimum stress on the right notch. The black inclined straight line is for pure bending without any fretting or notching. Shear strain behavior also takes almost the same character as in the case of equivalent stress as shown in Figure 6 (right).

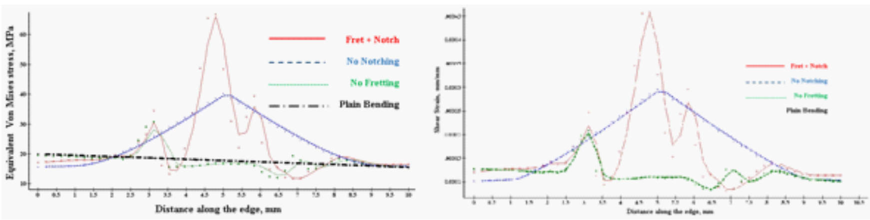

FIGURE 6. (Left) Equivalent stress and (right) shear strain distribution along the edge

4.2.2. *Stress-strain behaviour at the contact through thickness.* Since no fretting action is found at the center, hereby no fretting line almost coincides with the plain bending line on the stress-distance plot. From zero distance to the edge of thickness, stress declines as a slope before half the thickness in total and decreases slightly up to the final point. Single fretting dominates over the application of both fretting and notching, However, differences become negligible after the sloped declination. Stress-strain distribution along the notch is shown in Figure 7, which shows almost the same character of increasing from start to end of the edge.

4.3. Effect of double fretting point with a single notch.

4.3.1. *Stress-strain behaviour at the edge.* Two prominent apex points of shear stress are found for fretting loads on both sides of the central notch for the case of dual application of fretting load with a notch (Figure 8). A relatively lower crest is found for the only notch at the center which presumes the lower effect of notching than the fretting action. It may be noted that the single fretting action takes almost the wave shape while notching alone rises at the center of the position of the notch. Almost the same character is found in the case of shear stress distribution along the edge.

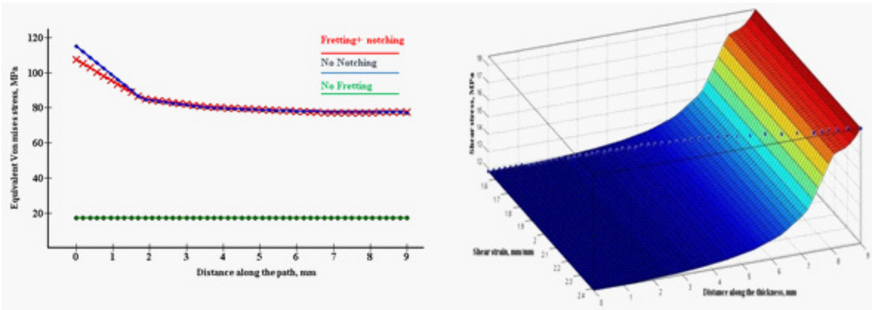

FIGURE 7. (Left) Stress distribution along the thickness, (right) stress-strain distribution at notch after fretting point

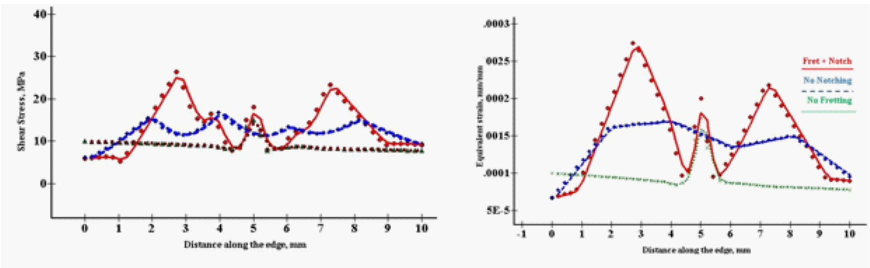

FIGURE 8. (Left) Equivalent stress and (right) shear strain distribution along the edge

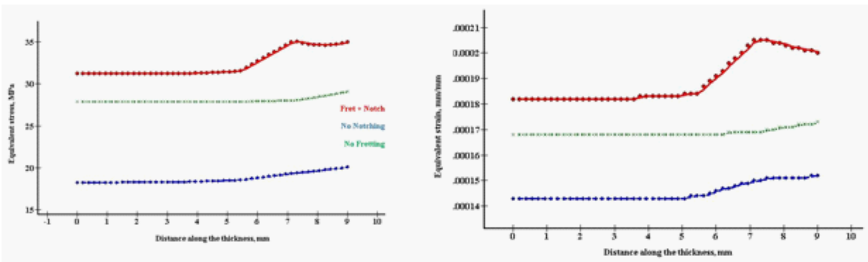

FIGURE 9. (Left) Equivalent stress distribution and (right) strain along the thickness

4.3.2. *Stress-strain behaviour at the contact through thickness.* Through the path along thickness, up to more than half a distance, both equivalent stress and strain remain horizontal (Figure 9). Since notching raises no effect at the center, the blue marked curve obtains the lowest value for both stress and strain. It shows the reciprocal character of curves for a central single fretting action.

4.3.3. *Fatigue life.* Figure 10 shows that fatigue life decreases abruptly for alternating bulk stress (left). Two identical loads of 500 N and 1000 N were considered alternatingly under constant and variable fretting pressure. For the same loading range, fatigue life was found to go down considerably more for constant fretting than variable fretting. Stress controlled fatigue life scheme was the criterion used here. On the other hand, notches have a more adverse effect on fatigue life than the quantity of fretting points.

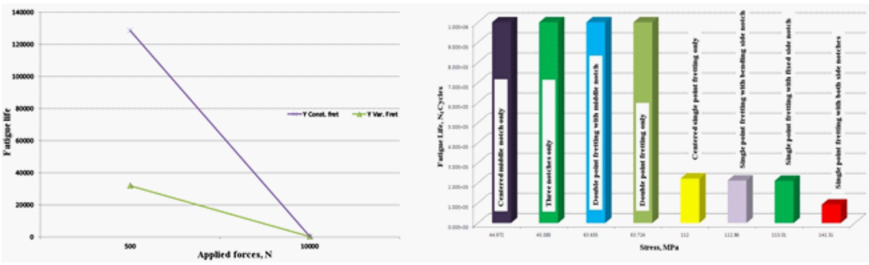

FIGURE 10. Fatigue life comparison: (left) fretting-bending load alternation as constant, (right) single/double point fretting with/ without a notch(es).

5. Conclusions

Bending through Y-axis has been done by alternating values for fretting and end loading for single fretting, single point fretting with a double notch and double point fretting with a single notch. Stress and strain distribution through contact surfaces between the pad and body was demonstrated. Stress-strain singularity shows definable characteristics while fatigue life decrements show less reduction due to fretting parameter alternation. The following observations are notable as outcomes.

– Stresses lower and strains were almost linear near the contact center. In other words, the edge or corner fiber is greatly stressed.

– Fatigue life reduces more drastically under variable bending loads than normal fretting loads along with notches. Moreover, a variable fretting load has a more adverse effect than constant fretting load in case of tensile loading.

– Fretting pressure causes peak stresses on the contact surface. However, in conclusion, double notches with a central fretting point have a higher impact on fatigue life than all other conditions.

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ИСТРАЖИВАЊЕ КОМБИНОВАНОГ УТИЦАЈА ЗАРЕЗА И ГЊЕЧЕЊА НА ЗАМОР ПРИ САВИЈАЊУ

Резиме. Будући да је уобичајена појава у механизму лома, ублажавање замора је један од главних проблема последњих година, како у истраживању, тако и у индустријским применама. У овој студији, ефекат зареза и гњечења на замор при савијању испитан је FEM анализом. На основу доступног и потврђеног FEM модела, спроведене су анализе гњечења са једном тачком и двоструким зарезом и на двострукој тачки гњечења са једним зарезом. Дуж унапред дефинисаних путања кроз ивицу, проучаване су задебљања и зарези, као и понашање замора и расподела напона и напрезања. Утврђено је да су расподеле напона и напрезања равномерно распоређене за константна оптерећења гњечења са променљивим концентричним оптерећењем, док променљива оптерећења гњечења дају готово два пута веће резултате. Нађена је сингуларност напона и напрезања за попречно оптерећење када је под великим напоном. Пронађен је максимум напрезања на расподели при гњечењу за комбиновано присуство гњечења и зареза. На дуговечност замора драстичније су утицала променљива оптерећења гнечења од променљивих концентричних оптерећења само у случају затезања. Показано је да је дуално дејство гнечења са зарезима штетније од појединачног дејства двоструког гњечења/зареза.

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