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Crack Prediction on Aircraft Wing Spar

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Abstract **- This paper presents the results of Crack propagation rate of an aircraft wing spar. For this I- section spar is considered. Computational analysis and analytical calculations are calculated from the I-section spar. Crack surface is considered on the root of the wing spar. Spar section is modelled in Catia V5 R21 software. Crack propagation rate is calculated from the crack surface of I-section spar using Ansys 14.5 workbench software. For the crack surface area analytical calculations are calculated. Stress intensity factor and crack propagation rate is calculated analytically and graph is plotted with the results. Number of cycles to failure is calculated using the analytical method. S-N curve is plotted for the fatigue lifecycles. Crack propagation rate vs. stress intensity factor graph is plotted from the analytical and computational results. Comparison of results is done by plotting the graph and hence the graph has been validated.**

Keywords ***- (Crack propagation rate, Fatigue, S-N curve, stress intensity factor.)***

INTRODUCTION

Determination of the crack-growth rate**:** The Fatigue crack growth rate has been dictated by estimating the separation between the progressive exhaustion split development groups from the split inception to the most remote weariness split development band. The stress intensity factor K. The fracture toughness, Kc. The applicable fatigue crack growth rate expression. The initial crack size. The final or critical crack size, .Material Fracture Toughness**:** Material fracture toughness might be characterized as the capacity to convey stacks or disfigure plastically within the sight of a score. Crack Size: Crack size starts from discontinuities that can change from to a great degree little splits to significantly bigger weld or weakness splits.

THE THREE MODES OF FRACTURE:

1.) Mode I - Opening mode 2).Mode II - Sliding mode3). Mode III - Tearing mode.

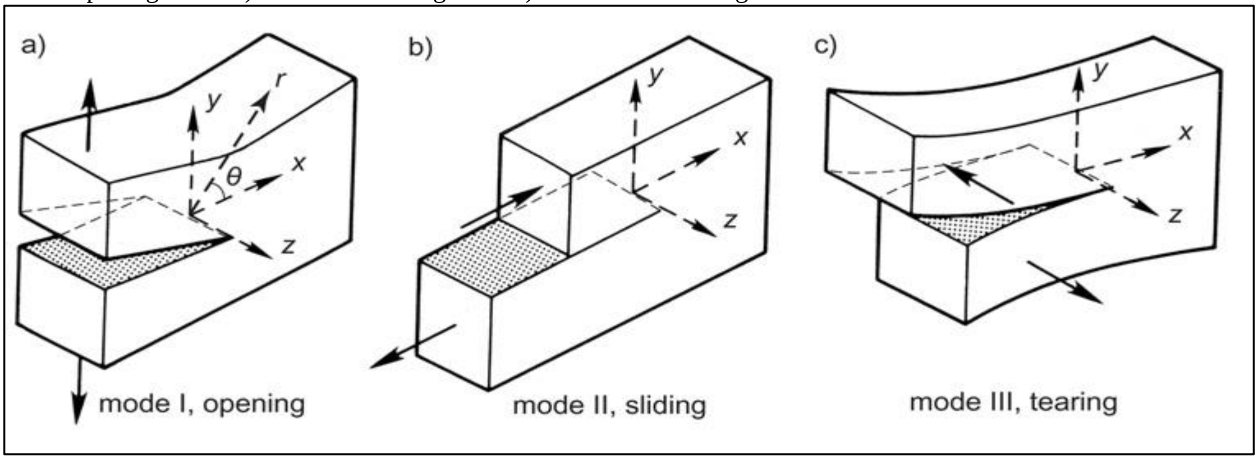

Fig 1: Three Modes Of Fracture

Fatigue Life Calculation: Count of fatigue life is completed by utilizing Miners Rule. For the fatigue calculation, the variable range stacking is disentangled as piece stacking. Each piece comprises of load cycles relating to 100 flights. Damage count is done for the entire administration life of the aircraft. The load factor "g" is characterized as the proportion of the lift of an aircraft to its weight and speaks to a worldwide measure of the load to which the structure of the aircraft is subjected to Rule.

ANALYTICAL CALCULATION

1. Stress Intensity Factor: The Stress intensity factor is utilized as a part of break mechanics to foresee the pressure state close to the crack tip of a crack caused by a remote load or leftover burdens.

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A).Center Crack Stress Intensity Factor Calculation

$$K_I = \frac{P}{B}\sqrt{\frac{3.14}{w}}\left[16.7(\tfrac{a}{w})^{\frac{1}{2}} - 104.7(\tfrac{a}{w})^{\frac{3}{2}} + 369.9(\tfrac{a}{w})^{\frac{5}{2}} - 573.8(\tfrac{a}{w})^{\frac{7}{2}} + 360.5(\tfrac{a}{w})^{\frac{9}{2}}\right]$$

P=applied load, B=thickness, a=crack length, w=width.

P=13459 N, B=.164M, a=0.1mm, w=5M

$$K_I = \frac{13459}{.164}\sqrt{\frac{3.14}{5}}\left[16.7(\tfrac{.1}{5})^{\frac{1}{2}} - 104.7(\tfrac{.1}{5})^{\frac{3}{2}} + 369.9(\tfrac{.1}{5})^{\frac{5}{2}} - 573.8(\tfrac{.1}{5})^{\frac{7}{2}} + 360.5(\tfrac{.1}{5})^{\frac{9}{2}}\right]$$

$$K_{I(0.1)} = 135650;\ K_I(0.2) = 169976;\ K_I(0.3) = 185272;\ K_I(0.4) = 197532$$

B).Edge Crack Stress Intensity Factor Calculation

$$K_I\text{=S}\sqrt{a}\left|1.99 - 0.41\left(\frac{a}{w}\right) + 18.7\left(\frac{a}{w}\right)^2 - 38.48(\tfrac{a}{w})^3 + 53.85(\tfrac{a}{w})^4\right|$$

$$\text{S=}\frac{\text{P}}{\text{BW}}$$

$$K_I(0.1)\text{=16413}\sqrt{0.1}\left|1.99 - 0.41\left(\frac{.1}{5}\right) + 18.7\left(\frac{.1}{5}\right)^2 - 38.48(\tfrac{.1}{5})^3 + 53.85(\tfrac{.1}{5})^4\right|$$

$$K_I(0.1) = 10365; K_I(0.2)\text{=14524}; K_I(0.3)\text{=17813}; K_I(0.4)\text{=21280}$$

2. CRACK PROPAGATION RATE:

A).Center Crack Propagation Rate Calculation

$$\frac{da}{dN}\text{=c}\Delta K^m \text{ cm=material constants}$$

$$\Delta K = k_{max}\text{-}k_{min}\ ,\ \frac{da}{dN}\text{=crack growth rate per cycle.}$$

$$\frac{da}{dN}\text{=c}\Delta K^m, \frac{da}{dN}\text{=1}\times 10^{-12}(135650)^3$$

$$\frac{da}{dN}(0.1)\text{=2.4, }\frac{da}{dN}(0.2)\text{ =4.9; }\frac{da}{dN}(0.3)\text{ =6.3, }\frac{da}{dN}(0.4)\text{ =7.0}$$

B).Edge Crack Propagation Rate Calculation

$$\frac{da}{dN}\text{=c}\Delta K^m, \frac{da}{dN}\text{=1}\times 10^{-12}(10365)^3$$

$$\frac{da}{dN}(0.1)\text{=1.11, }\frac{da}{dN}(0.2)\text{ =3.06; }\frac{da}{dN}(0.3)\text{ =5.65, }\frac{da}{dN}(0.4)\text{ =9.36}$$

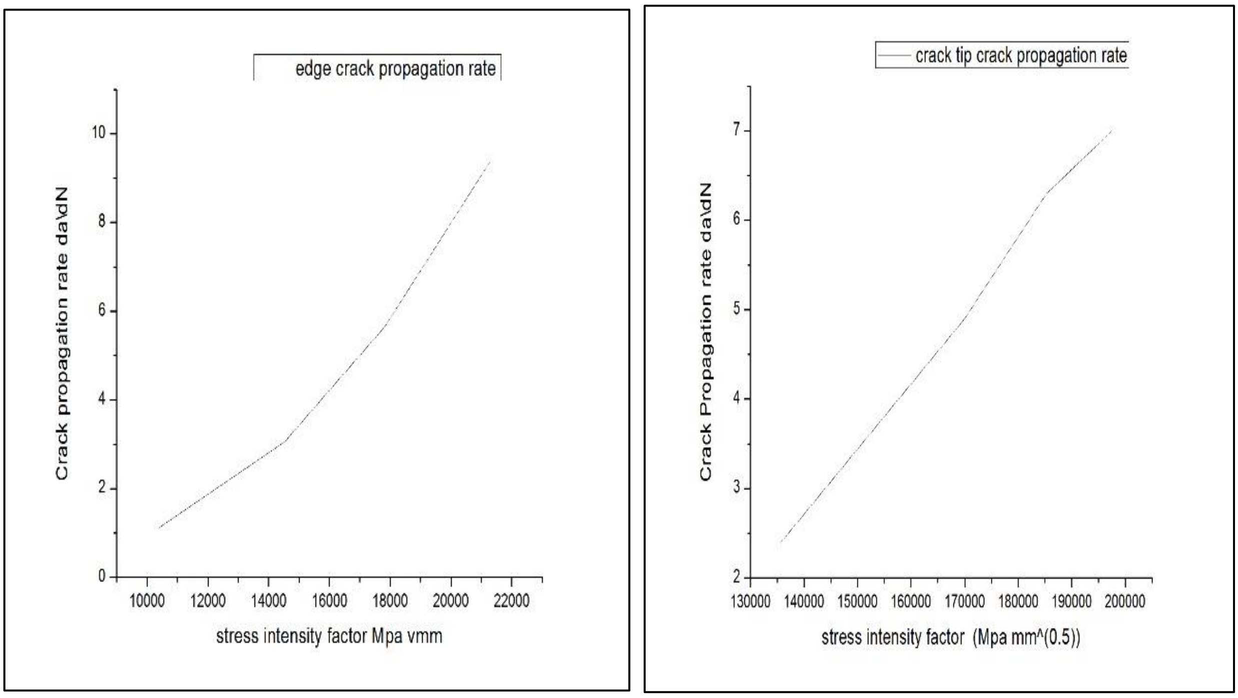

Fig 2: Analytical Center Crack Tip & Edge Crack Graph

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COMPUTATIONAL ANALYSIS

1.) Centre Crack Analysis

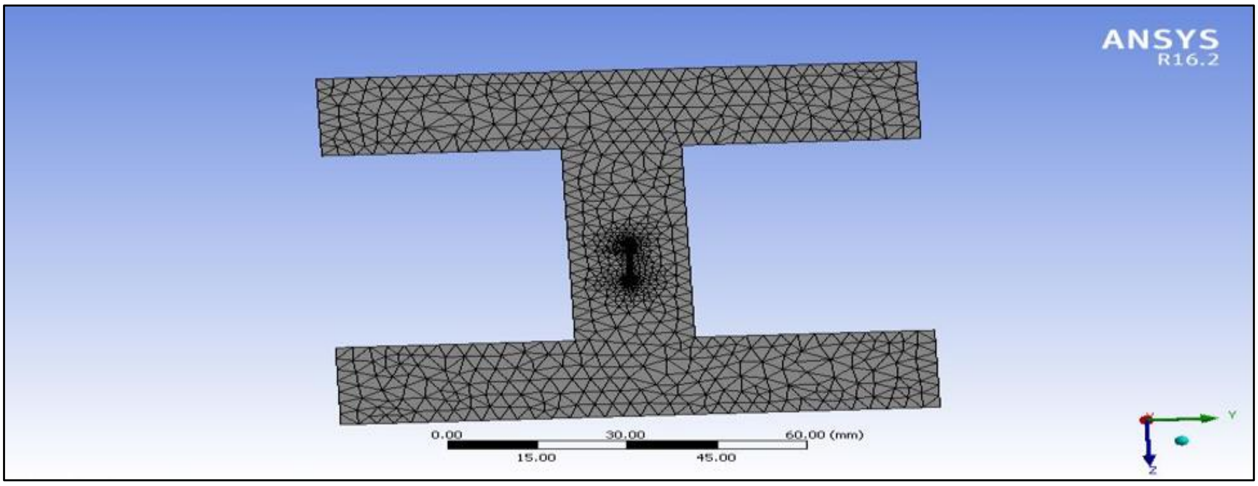

Fig 3: Mesh Model of Centre Crack Surface

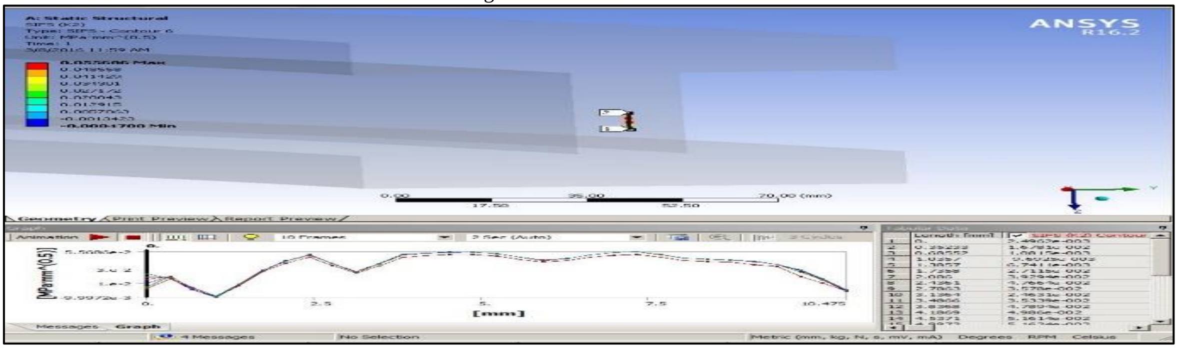

Fig 4: Crack Propagation Rate Length

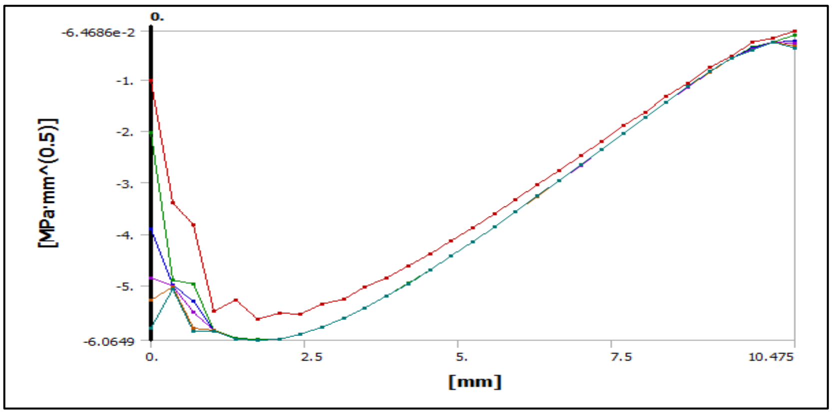

Fig 5: Crack Propagation Rate length graph

Table 1. Computational Analysis of Edge Crack Propagation Rate

Length [mm]	SIFS (K1) Contour 1 [MPa·mm^ (0.5)]	SIFS (K1) Contour 2 [MPa·mm^ (0.5)]	SIFS (K1) Contour 3 [MPa·mm^ (0.5)]	SIFS (K1) Contour 4 [MPa·mm^ (0.5)]	SIFS (K1) Contour 5 [MPa·mm^ (0.5)]	SIFS (K1) Contour 6 [MPa·mm^ (0.5)]
0.	-1.0234	-2.0394	-3.9013	-4.8664	-5.2812	-5.8222
0.35233	-3.3881	-4.8915	-4.9931	-5.0038	-5.0294	-5.0756
0.68552	-3.8161	-4.9794	-5.307	-5.514	-5.8226	-5.8807
1.0357	-5.5066	-5.8605	-5.8627	-5.8666	-5.8722	-5.8804
1.3857	-5.2843	-6.0308	-6.038	-6.0403	-6.0435	-6.0472
1.7358	-5.656	-6.0525	-6.0567	-6.0589	-6.0617	-6.0649
2.086	-5.5407	-6.0367	-6.0398	-6.0415	-6.0437	-6.0462
2.4361	-5.5524	-5.9438	-5.9468	-5.9481	-5.9496	-5.9505
2.7863	-5.3567	-5.8075	-5.8104	-5.8117	-5.8134	-5.8155
3.1364	-5.2565	-5.6294	-5.6322	-5.6333	-5.6345	-5.6347
3.4866	-5.0346	-5.4326	-5.435	-5.4357	-5.4366	-5.4373
3.8368	-4.8636	-5.2088	-5.2112	-5.2118	-5.2126	-5.2123
4.1869	-4.6259	-4.9638	-4.9656	-4.9656	-4.9654	-4.9647
4.5371	-4.3891	-4.7009	-4.7023	-4.7019	-4.7014	-4.6999

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4.8873	-4.1431	-4.435	-4.4365	-4.4364	-4.4361	-4.4353
5.2374	-3.8809	-4.1565	-4.1581	-4.1581	-4.1582	-4.1574
5.5876	-3.6144	-3.8688	-3.8698	-3.8692	-3.8682	-3.8663
5.9378	-3.3344	-3.5711	-3.5717	-3.5708	-3.5693	-3.5669
6.2879	-3.0508	-3.2726	-3.2732	-3.2724	-3.2711	-3.2691
6.6381	-2.7701	-2.9669	-2.9673	-2.9663	-2.9648	-2.9624
6.9883	-2.4734	-2.6674	-2.6675	-2.6663	-2.6645	-2.6617
7.3384	-2.2072	-2.3637	-2.3636	-2.3622	-2.3601	-2.3572
7.6886	-1.9018	-2.0602	-2.0599	-2.0582	-2.0557	-2.052
8.0387	-1.6339	-1.7495	-1.7488	-1.7467	-1.7437	-1.7399
8.3889	-1.333	-1.4506	-1.4496	-1.4472	-1.4438	-1.4389
8.739	-1.0766	-1.1523	-1.151	-1.1484	-1.1446	-1.1399
9.0892	-0.7677	-0.87275	-0.87077	-0.86697	-0.86126	-0.85289
9.4392	-0.55707	-0.59639	-0.59496	-0.59251	-0.58811	-0.58195
9.7893	-0.27507	-0.37062	-0.40502	-0.41917	-0.43348	-0.43639
10.123	-0.19881	-0.27701	-0.27934	-0.27612	-0.27152	-0.27137
10.475	-6.4686e-002	-0.13822	-0.25639	-0.30719	-0.34865	-0.39218

2.) EDGE CRACK ANALYSIS

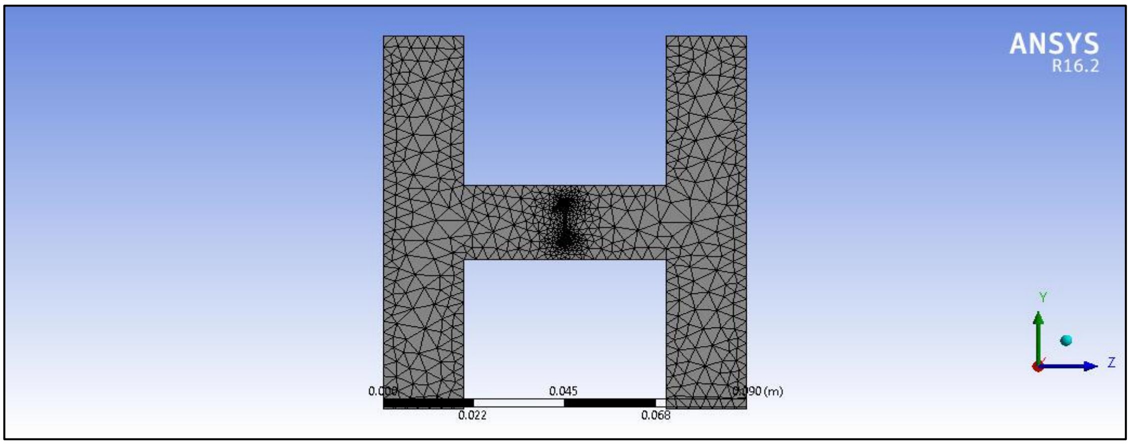

Fig 5: Mesh Model of Edge Crack Surface

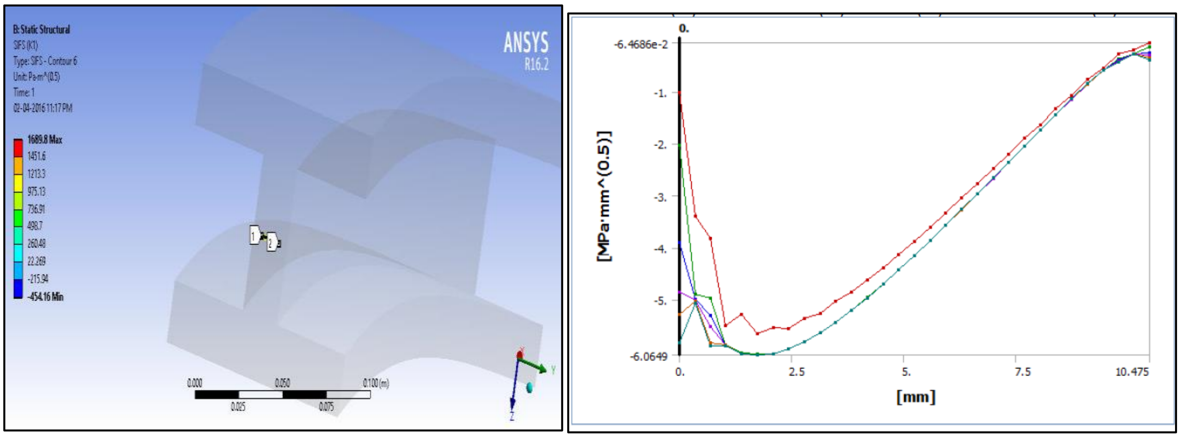

Fig 6: Stress Intensity Factor K vs. Crack Propagation Rate Data for Edge Crack

Table 2. Stress Intensity Factor K vs. Crack Propagation Rate Data

Length [mm]	SIFS (K1) Contour 1 [MPa·mm^ (0.5)]	SIFS (K1) Contour 2 [MPa·mm^ (0.5)]	SIFS (K1) Contour 3 [MPa·mm^ (0.5)]	SIFS (K1) Contour 4 [MPa·mm^ (0.5)]	SIFS (K1) Contour 5 [MPa·mm^ (0.5)]	SIFS (K1) Contour 6 [MPa·mm^ (0.5)]
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0.35233	-3.3881	-4.8915	-4.9931	-5.0038	-5.0294	-5.0756
0.68552	-3.8161	-4.9794	-5.307	-5.514	-5.8226	-5.8807
1.0357	-5.5066	-5.8605	-5.8627	-5.8666	-5.8722	-5.8804
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4.5371	-4.3891	-4.7009	-4.7023	-4.7019	-4.7014	-4.6999
4.8873	-4.1431	-4.435	-4.4365	-4.4364	-4.4361	-4.4353
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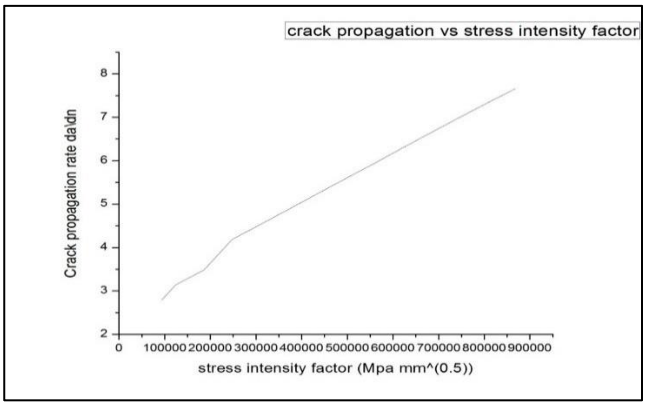
10.475	-6.4686e-002	-0.13822	-0.25639	-0.30719	-0.34865	-0.39218

COMPARISION OF COMPUTATIONAL Vs ANALYTICAL CRACK PROPAGATION RATE GRAPH



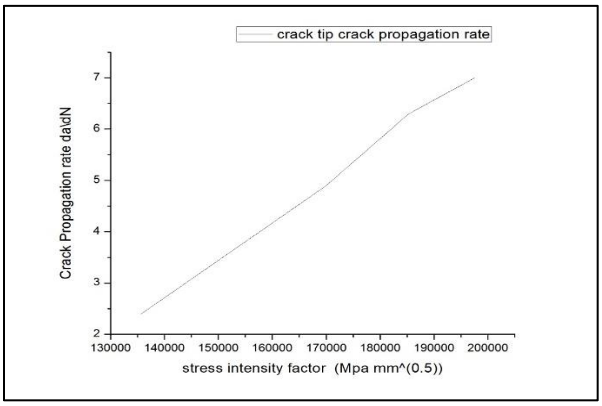


Fig 7: Computational Center Crack Propagation Rate Graph vs. Analytical Center Crack Propagation Rate Graph

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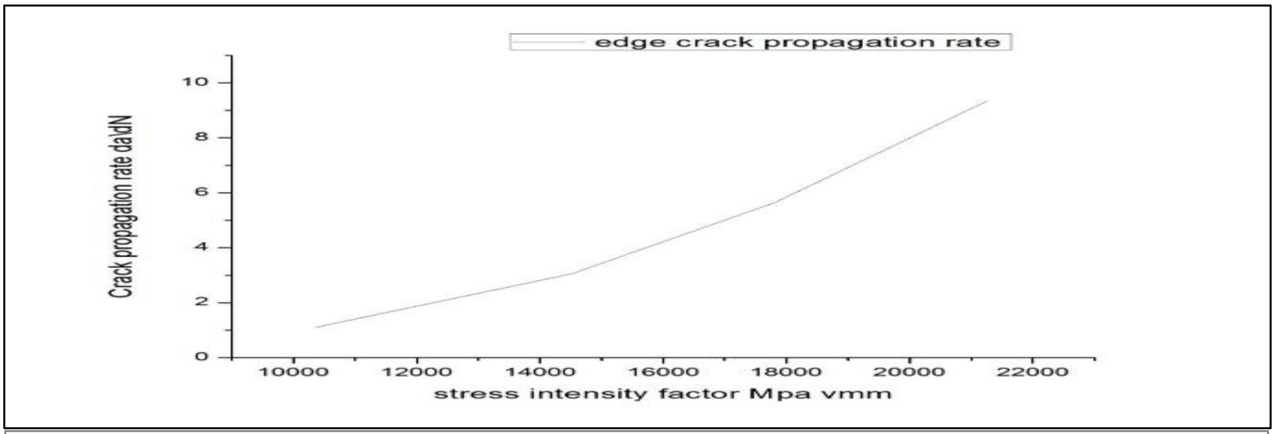

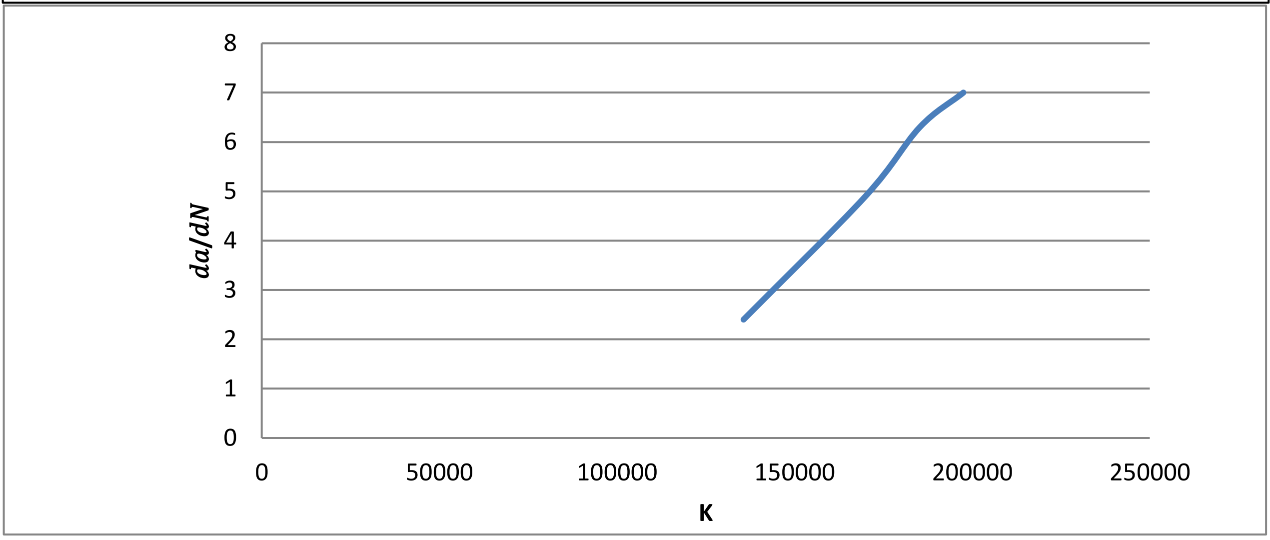

Fig 8: Computational Edge Crack Propagation Rate Graph vs. Analytical Edge Crack Propagation Rate Graph

FATIGUE S-N CURVE

Table 4. S-N CURVE DATA

	A	B	C	D	E	F
1	loads (pa)	maximum stress (pa)	minimum stress(pa)	Maximum directional deformation (m)	Minimum directional deformation (m)	fatigue life cycles
2	5000	1.14E+07	157.54	2.31E-06	-2.32E-06	1.00E+08
3	10000	2.28E+07	315.09	4.63E-06	-4.64E-06	1.00E+08
4	15000	3.42E+07	472.63	6.94E-06	-6.96E-06	1.00E+08
5	20000	4.56E+07	630.17	9.26E-06	-9.28E-06	1.00E+08
6	25000	5.70E+07	787.7	1.15E-05	-1.16E-05	1.00E+08
7	30000	6.80E+07	945.26	1.38E-05	-1.14E-05	1.00E+08
8	35000	7.98E+07	1102.8	1.62E-05	-1.62E-05	1.00E+08
9	40000	9.12E+07	1260.3	1.85E-05	-1.85E-05	1.00E+08
10	45000	1.02E+08	1417.9	2.08E-05	-2.08E-05	1.25E+07
11	50000	1.14E+08	1575.4	2.31E-05	-2.32E-05	3.42E+06
12	60000	1.36E+08	1890	2.77E-05	-2.79E-05	8.44E+05
13	70000	1.59E+08	2205.6	3.24E-05	-3.25E-05	2.65E+05
14	80000	1.82E+08	2520.7	3.70E-05	-3.71E-05	9.23E+04
15	90000	2.05E+08	2835.8	4.16E-05	-4.17E-05	3.61E+04
16	100000	2.28E+08	3150	4.63E-05	-4.64E-05	1.04E+04
17	110000	2.56E+08	3465	5.09E-05	-5.10E-05	3.70E+03
18	120000	2.73E+08	3781	5.55E-05	-5.57E-05	1.81E+03
19	130000	2.96E+08	4096.1	6.02E-05	-6.03E-05	0.00E+00

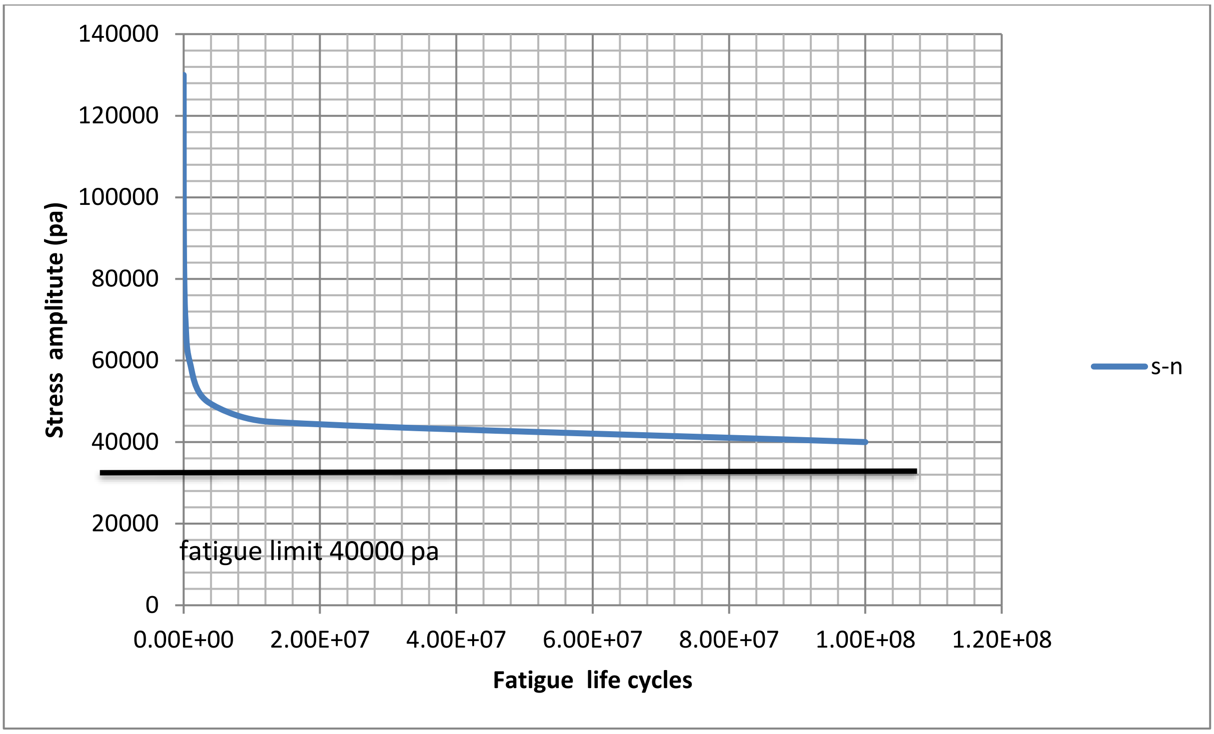

Fig 9: S-N Curve

CONCLUSION:

Crack propagation rate vs. stress intensity factor graph is plotted from the computational and analytical results. Crack propagation rate vs. stress intensity factor graph is compared between the computational and analytical graph. S-N is plotted and found fatigue or endurance limit of 40000 pa.

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