Comparative Fracture Study under Dynamic Conditions on a Flat Plate

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***Abstract*— Fracture gets produced in a structure by either during the manufacturing process or in the course of the normal service life of the Structure. So, this paper is about the study of fracture Behaviour, when the structure is subjected to a Static load and Dynamic load. The structure chosen for this paper is flat plate because it can be assumed as an Aircraft Wing Structure. So, when Aircraft Wing Structure having a certain crack when subjected to dynamic Load. How the fracture will behave, whether it will propagate or not, what will be the maximum safe load for the operation. The Analysis is done on ABAQUS by J-Integral Method. .So that, instead of undergoing an expensive change of structure, it can operate in that safe region. Thus saving money, time and materials.**

I. INTRODUCTION

The process of material manufacturing, processing, machining may introduce internal flaws in the finished structure/component. This type of flaws is common in most of the structures in the todays world. Not all this internal flaws are stable, some may lead to unstable condition in their service period, which can lead to catastrophic failure of the structure. So, for finding the behaviour of this type crack/fracture, we use fracture mechanics. Through Fracture mechanics it is possible to find, what crack length could be tolerated by the structure under certain loading, what is the life span of the structure and many more. So, this paper it deals with flat plate, which can be considered as an aircraft wing structure. This flat plate is being subjected dynamic loading, as we all know the Aircraft is being subject to dynamic condition. This analysis is carried out by ABAQUS, through J Integral method and thus finds the stress intensity factor at the crack tip. A comparative study is beendone with materials such as Aluminium and titanium, the reason for choosing this material is because this is one most commonly used material in aerospace industry. In this paper, finds the difference between the static and dynamic loading on an structure, how crack length depends on structural maximum loading. how different crack angles depends on the structure for two different materials Aluminium and Titanium.

II. LITERATURE REVIEW

Basically, crack length is an important parameter in the study of fracture mechanics for determining R Curve, crack propagation toughness, crack arrest toughness, crack propagation velocity for all this we require crack length. Crack length measurement in the dynamic loading conditions have its own set of problems such as crack tip opening displacement in a quasi-static loading test can be determined using commercially available gauges, similar gauges is not available for dynamic loading conditions. The crack length measured from compliance calibration method is an effective crack length rather than the physically measured crack length.

Stress intensity factor is very important in fracture analysis, which is been used in calculating stress and displacements at the crack tip. It can also predict crack propagation pattern for any structure. There are two approaches J and I integrals, theoretically they are same but numerically they are different by small fraction. For cracked structure, the stress and strain ahead of the crack tip control the mode of failure. For ductile material the plastic zone is formed around the crack tip. Smaller region around the crack tip, there is tensile fracture process zone where void nucleate and grows together. As the crack grows plastic region also grows. The compressive damage is greatest at the crack tip. The damage that occurs dictates the measure of the ductile tearing resistance. Such micro defects inevitably exist in the structures , the subsequent development of the crack during its service conditions should be assessed to guarantee the structure have enough residual strength and prevent the catastrophic failure. Numerical simulations of the crack growth prove that the method has the capacity to capture the arbitrary crack path, Non-linear simulation will be carried out by this strategy.

III. METHODOLOGY

3.1 Static Analysis

A flat plate of following specifications is being chosen for doing and understanding static Analysis.

Specification	
Dimension	0.7m*0.3m*0.01m
Young’s Modulus	70Gpa(Aluminium)
Poisson Ratio	0.3
Density	2700kg/m^3
Force(Concentrated)	100N (y-direction)

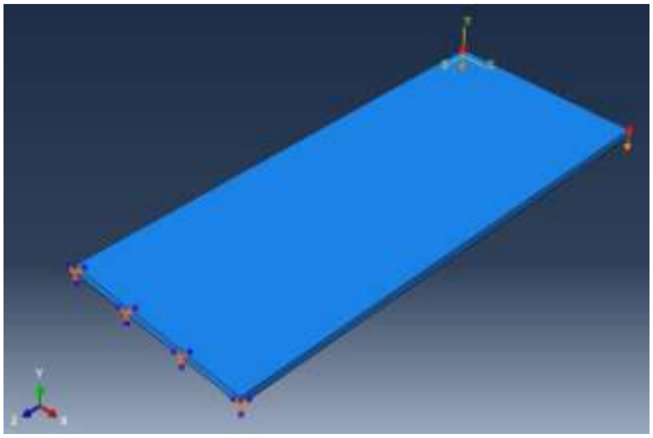

Fig 1 : Static Analysis on a flat plate

Where one end is fixed and the other end is applied with the concentrated load of 100N.Using ABAQUS the simulation is being carried out for finding the maximum deflection.

3.2 Dynamic Analysis

For doing Dynamic Analysis, Sinusoidal force should be given as force.

- Frequency 1 Hz and Time period = 1s, circular frequency=2π
- Frequency 1.5 Hz and Time period = .67s, circular frequency= 3π

Specification	
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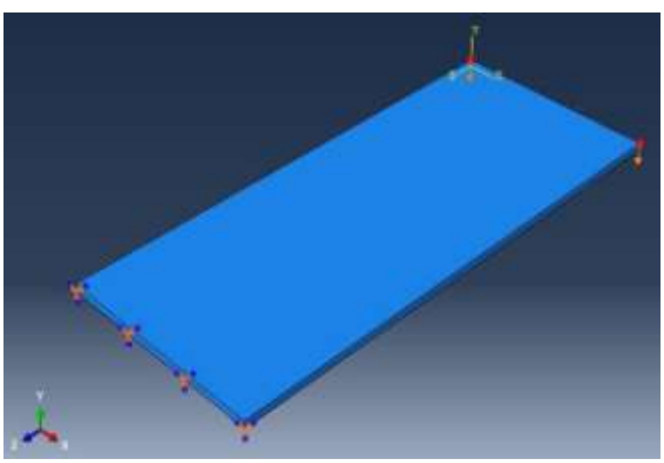


Fig 2 : Dynamic Analysis on a flat plate

3.3 Fracture Study on Dynamic Loading

In this, the main objective is to study Fracture on a Structure when it is Subjected to Dynamic Load.

3.3.1 Predicting the Maximum Safe Load

In this, flat plate is being Subjected to Dynamic load in all three Directions (X,Y,Z) ,having Certain Crack length and Crack Positions ,the analysis is been carried out on two different material Aluminium and Titanium ,the reason for choosing this material it is one of most commonly used material in manufacturing aircraft structure.

For doing this, we have chosen two crack locations

- Bottom Edge Crack
- Bottom Centre Crack

With Two Different Crack Length

- 20% (Width of the Structure)
- 30% (Width of the Structure)

Bottom Centre Crack

Dynamic Force is applied in (X, Y, Z)-Direction (Indicating When the flight is in cruise condition, Axial force, Lift force), what is the maximum safe load of the Structure.

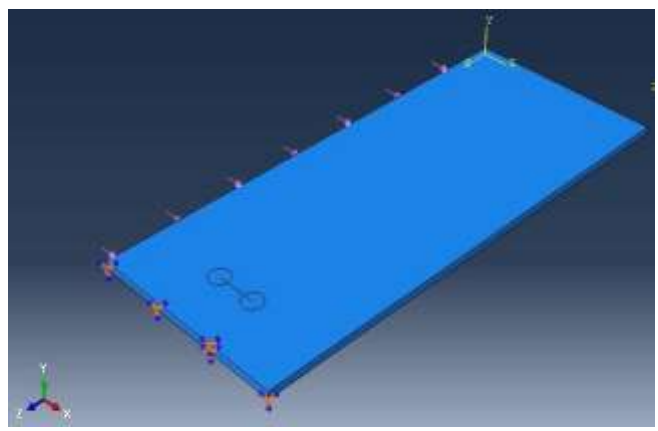


Fig 3: *Dynamic Force is applied in X*

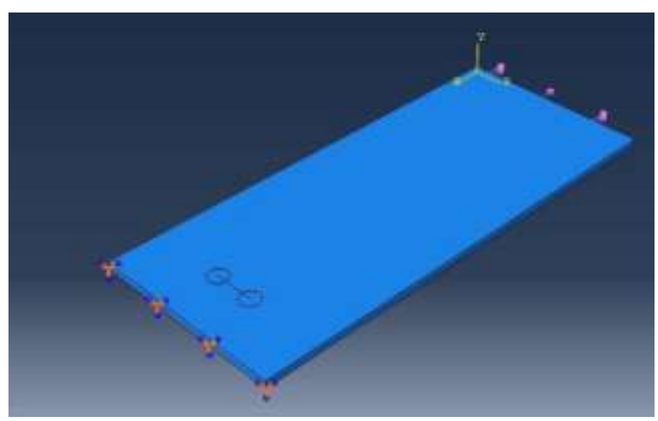


Fig4 : Dynamic Force is applied in Y

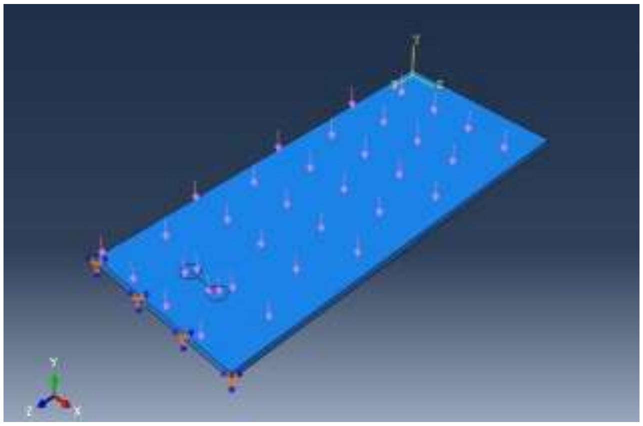


Fig 5 : Dynamic Force is applied in Z

Bottom Edge Crack

Dynamic Force is applied in (X, Y, Z)-Direction (Indicating When the flight is in cruise condition, Axial force, Lift force), what is the maximum safe load of the Structure.

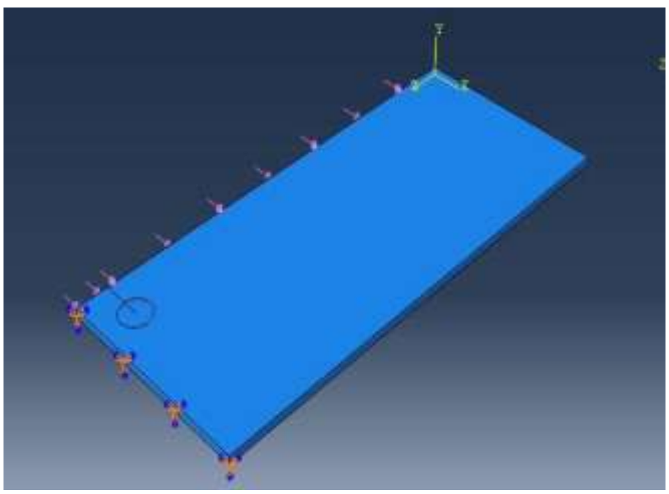


Fig 6: Dynamic Force is applied in X

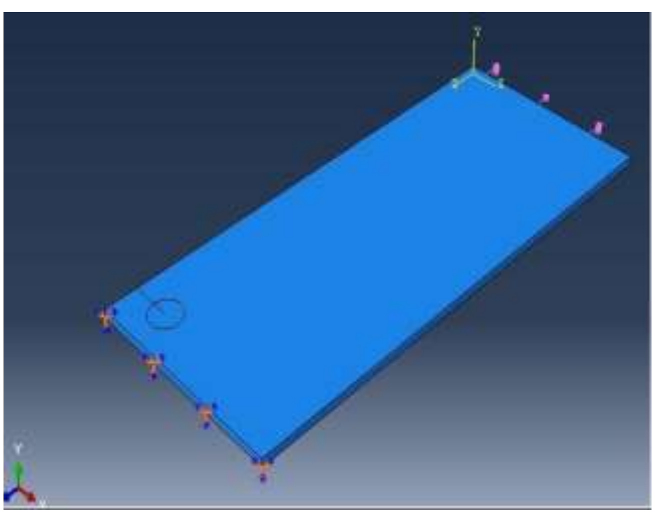


Fig 7: Dynamic Force is applied in Y

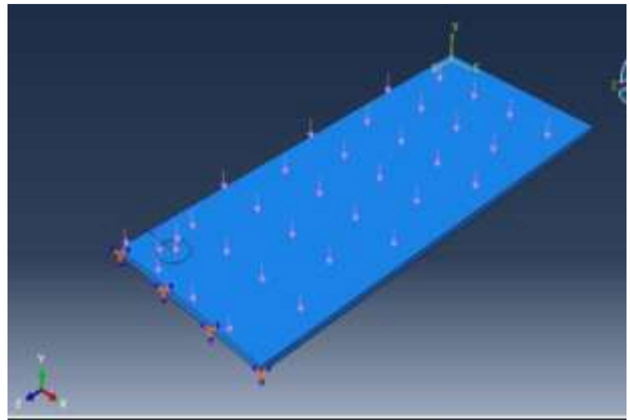


Fig 8: Dynamic Force is applied in Z

3.3.2 Fracture Study on different angles of Crack

In this, a constant dynamic load of 80N,60N,40N is been applied in all (X, Y, Z) Directions with Varying Centre Crack angles (0,22.5,45,72.5,90). in two different material Aluminium and Titanium

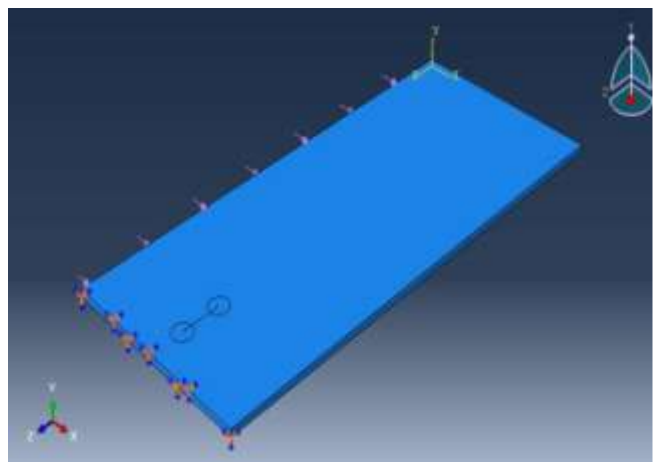


Fig 9: 0^o Crack angle

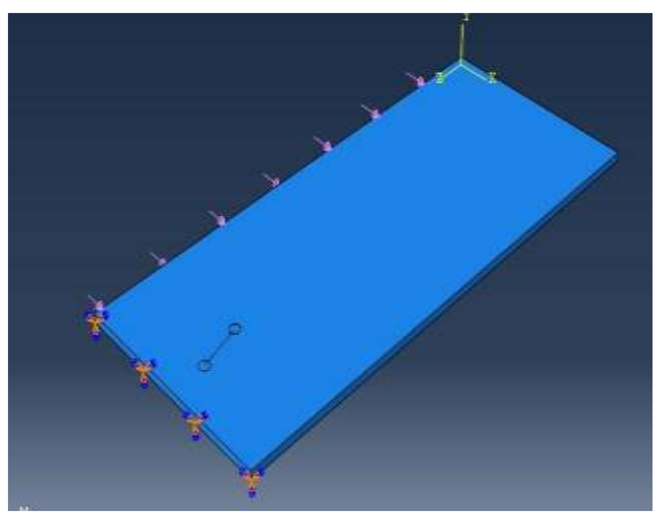


Fig 10: 22.5^o Crack angle

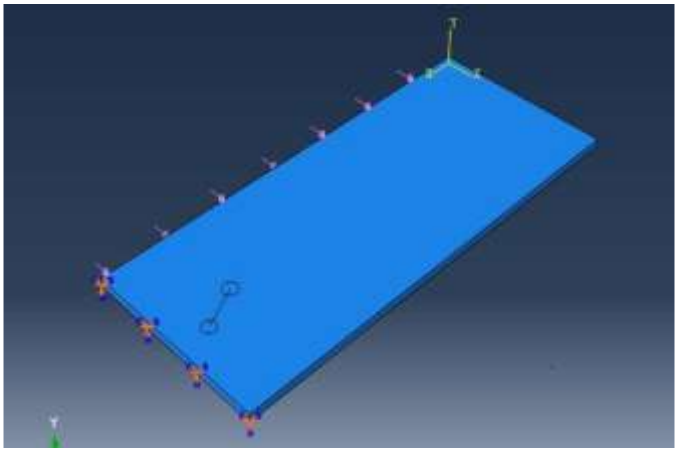


Fig 11: 45^{o} Crack angle

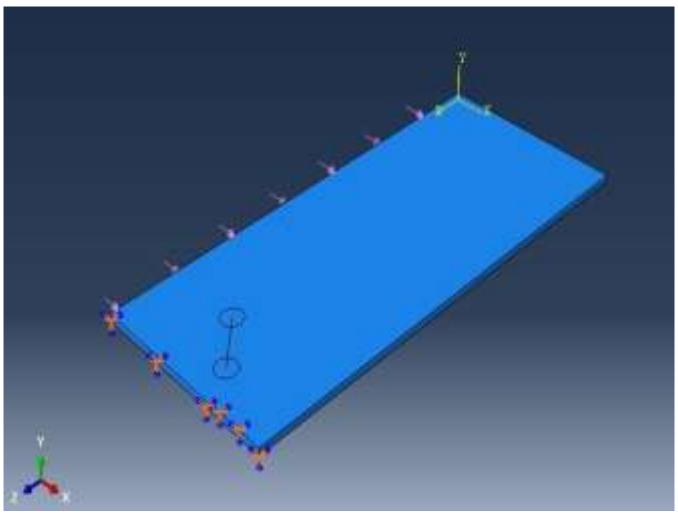


Fig 12: 72.5^{o} Crack angle

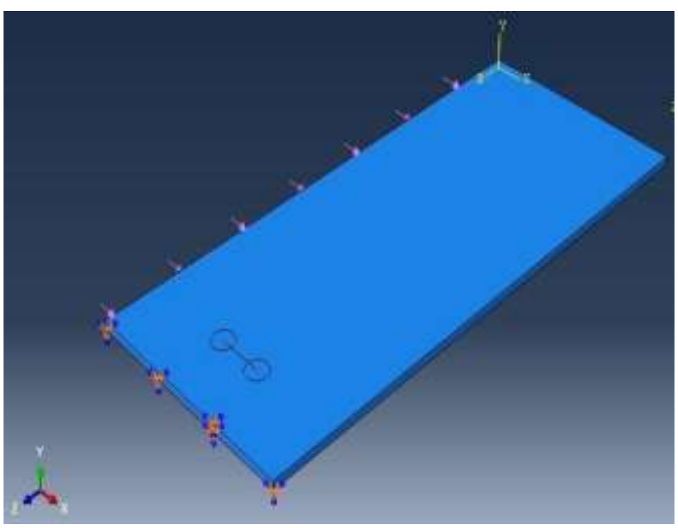


Fig 13: 90^{o} Crack angle

The Same procedure is followed for 60N and 80N force in two different materials (Aluminium and Titanium).

IV. RESULTS AND DISCUSSIONS

4.1 Static Analysis of a Cantilever Beam

Theoretical Calculations

Deflection $=PL^3/3EI$

Where P=force, Length of the flat plate, E = Young's Modulus, I= Moment of Inertia Deflection= $100*(.7)^3/3*(70*10^9)*((.3*(.01)^3)/12)) = 6.533 * 10^{-3}$ m

Numerical Result

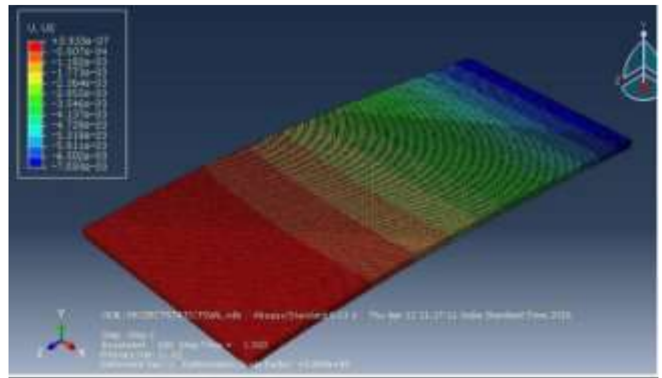


Fig 14:Static Analysis of flat plate

Deflection of the beam is $= 7.093* 10^{-3}$m

Error% =Numerical Value – Theoretical Value/Numerical value *100

$= 7.093* 10^{-3} - 6.533 * 10^{-3}$ m/$7.093* 10^{-3}$ m *100

= 7.89 %

4.2 Dynamic Analysis of Cantilever Beam

4.2.1 Frequency =1 Hz , Time Period = 1s , Excitation frequency = 2 rad/s

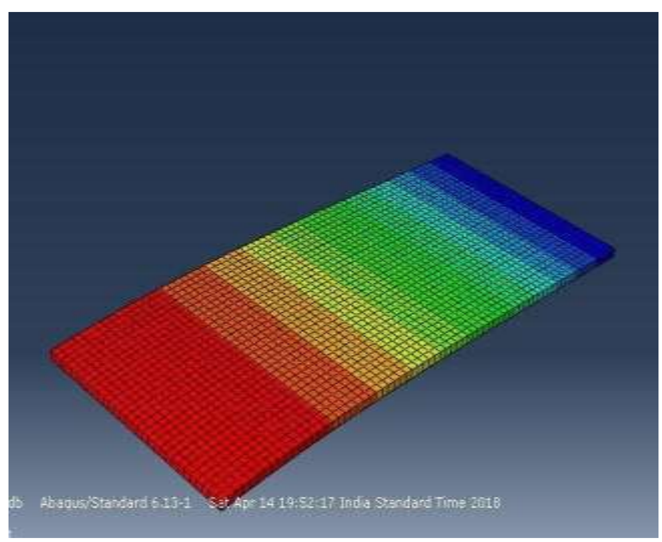
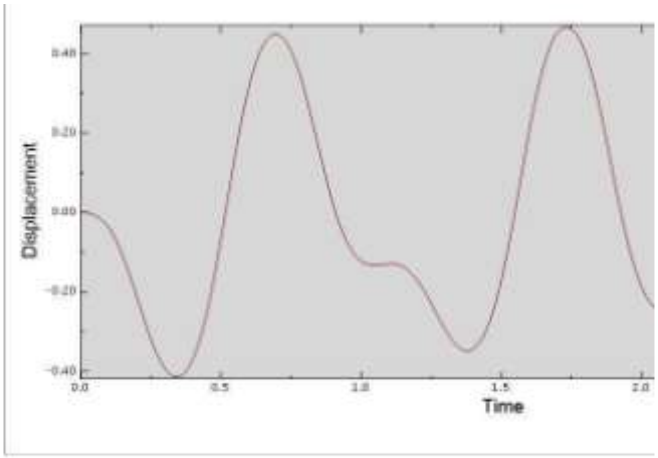


Fig 15: Dynamic Analysis of flat plate

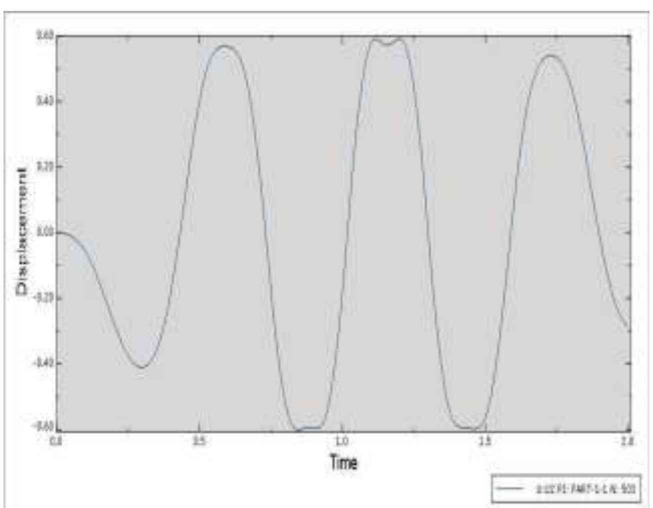


Graph 1 : Displacement Vs Time

Time	Displacement	Time	Displacemnt
.1	-0.0386	1.1	-0.1296
.2	-0.2116	1.2	-0.1713
.3	-0.3928	1.3	-0.2953
.4	-0.3691	1.4	-0.3437
.5	0.0680	1.5	-0.1695
.6	0.3169	1.6	0.2075
.7	0.4482	1.7	0.4525
.8	0.3023	1.8	0.4006
.9	0.01977	1.9	0.0911
1	-0.1228	2	-0.1869

Table 1: Displacement Vs Time

4.2.2 frequency =1.5 Hz , Time Period =0.66s , Circular frequency = 3 rad/s



Graph 1 : Displacement Vs Time

Table 2: Displacement Vs Time

Time	Displaceme nt	Time	Displacement
.1	-0.0561	1.1	0.57748
.2	-0.27408	1.2	0.5915
.3	-0.4107	1.3	0.0022
.4	-0.179397	1.4	-0.58823
.5	0.4420	1.5	-0.5649
.6	0.56	1.6	0.0834
.7	0.2643	1.7	0.5256
.8	-0.51788	1.8	0.44787
.9	-0.59477	1.9	-0.0105
1	-0.1864	2	-0.287429

Discussion:

From the Graph, it is clear that with the increase of Circular Frequency / Excitation Frequency the maximum deflection also increases. In the first case when Excitation Frequency of 2 is given, the maximum deflection is 0.45m at 1.7 seconds and when Excitation Frequency of 3 is given, the maximum deflection is .59m at 0.9seconds.

4.3 Fracture Study on Dynamic Loading

4.3.1 Predicting the Maximum Safe Load

Table 3 : Fracture Study on Centre Crack

Material (Crack length)	Safe Force(X-Direction)	Safe Force(Y-Direction)	Safe Force(Z-Direction)
Aluminium(30%)	26 N	3 N	40 N
Aluminium(20%)	43 N	5 N	63 N
Titanium(30%)	70 N	7.5 N	99 N
Titanium(20%)	98 N	12 N	147 N

Table 4: Fracture Study onCentre Edge Crack

Material (Crack Length)	Safe Force(X-Direction)	Safe Force(Y-Direction)	Safe Force(Z-Direction)
Aluminium(30%)	27 N	2.5 N	8 N
Aluminium(20%)	38 N	4 N	10 N
Titanium(30%)	60 N	7 N	22 N
Titanium(20%)	90 N	10 N	30 N

Discussion:

Through this Analysis, one can find the Maximum Safe load of a Given Structure having a certain crack. Each 10% increase in Crack Length leads to 1.3-1.7 times decrease in Maximum Safe Load. Centre Edge Crack is more prone to failure than Centre Crack. In the Given Structure, the Bending

Force is more prone to make the structure to fail. Titanium shows better resistance to failure because of its high stiffness.

4.3.2 Fracture Study on Different Crack Angles

The Constant force is applied on the structure with the varying crack angle, stress intensity factor (K) at the crack tip is found, when the force is applied in X, Y, Z directions, in two different material.

Table 5 : Constant Dynamic Force =60 N, Length =.06m, Material =Aluminium Kc=24Mpa(m)$^{1/2}$

Crack Angles	K(X-Direction Force)	K(Y-Direction force)	K(Z-Direction Force)
0	36.12782861	95.5064461	0.06551307
22.5	30.2129631	47.674941	6.65019298
45	31.5532885	115.543741	16.40067072
72.5	31.9073652	129.4369119	17.73738989
90	34.1235535	150.2393091	18.78725632

Table 6: Constant Dynamic Force =60 N, Length =.06m , Material =Titanium Kc=56Mpa (m)$^{1/2}$

Crack Angles	K(X-Direction Force)	K(Y-Direction force)	K(Z-Direction Force)
0	36.650220	94.9631152	0.065515900
22.5	30.213125	46.07793218	8.4493723
45	31.553335	114.2360522	17.78726031
72.5	31.907352	127.4393336	18.7373786
90	34.123927	148.215980	23.87006284

***Table 7:** Constant Dynamic Force =40 N, Length =.06m, Material =Aluminium Kc=24Mpa (m)$^{1/2}$*

Crack Angles	K(X-Direction Force)	K(Y-Direction force)	K(Z-Direction Force)
0	24.1708418	63.671147	0.0436799
22.5	20.14214487	31.78298811	4.43334561
45	21.035532	77.02899718	10.93370934
72.5	21.2715772	86.289375	11.825058
90	22.7489998	100.158593	12.524775

Table 8 : Constant Dynamic Force =40 N, Length =.06m, Material =Titanium, Kc=56Mpa (m)$^{1/2}$

Crack Angles	K(X-Direction Force)	K(Y-Direction force)	K(Z-Direction Force)
0	24.085433	63.289106	0.0436606
22.5	20.142092	53.206508	4.433463281
45	21.035471	76.157316	10.93381681
72.5	21.271583	84.959324	11.825051
90	22.7490087	98.810336	12.524865

Table 9 : Constant Dynamic Force =80 N, Length =.06m, Material =Aluminium Kc=24Mpa (m)$^{1/2}$

Crack Angles	**K(X-Direction Force)**	**K(Y-Direction force)**	**K(Z-Direction Force)**
0	40.28232	46.67683	0.08735988
22.5	41.99213	124.5722	8.86688596
45	42.64546	154.0566	21.8675726
72.5	45.54623	172.8923	23.6498232
90	48.12566	200.3113	25.0473523

Table 10: Constant Dynamic Force =80 N, Length =.06m, Material =Titanium Kc=56Mpa (m)$^{1/2}$

Crack Angles	K(X-Direction Force)	K(Y-Direction force)	K(Z-Direction Force)
0	40.283166	52.6195507	0.0873202
22.5	41.993164	106.4116882	8.8669053
45	42.485992	137.6036441	21.867601
72.5	45.565622	169.9196882	22.478743
90	48.122354	197.6203122	25.049730

Discussion:

This Analysis tells us which crack angle is dangerous in each direction of the force. From this analysis, it is clear that bending force make's the structure more prone to failure compared to other two directions of a force. As the force increase, the stress intensity factor also increases in all 5 crack angles. all these conditions were satisfied in both the materials that we used aluminium and titanium. From the analysis we found, the stress intensity factor in all three directions for both materials is approximately same. Then this value is compared with their respective material critical stress intensity factor, for knowing whether the crack will propagate

V. CONCLUSION

1) Found Significant Difference in Static and Dynamic Analysis of Cantilever Beam. Dynamic loading is more dangerous to the structure as it creates more deflection, acceleration and Velocity than static loading.
2) Dynamic Deflection increases with increase in excitation frequency/circular frequency. Makes the structure to vibrate more hastily and create damages.
3) Maximum Dynamic deflection for this given structure is 99.2% more than that of Maximum Static Deflection. (Excitation frequency of 2) , the percent may vary
4) Each 10% increase in Crack Length leads to 1.3-1.7 times decrease in Maximum Safe Load.
5) Bottom Edge Crack is more prone to failure than Bottom Centre Crack.
6) In the Given Structure, the Bending Force is more prone to make the structure to fail.
7) As the force increase, the stress intensity factor at the crack tip also increases in all 5 crack angles. This Satisfies for both aluminium and titanium
8) From the analysis we found, the stress intensity factor in all three directions for both materials is approximately same. Then this value is compared with their respective material critical stress intensity factor, for knowing whether the crack will propagate or not.

9 Stress Intensity Factor (X-direction force) and crack angle varies in this trend below ($22.5^o < 45^o < 72.5^o < 90^o < 0^o$)

10 Stress Intensity Factor (Y-direction force) and crack angle varies in this trend below ($22.5^o < 0^o < 45^o < 72.5^o < 90^o$)

11 As crack angle increases, value of Stress Intensity Factor (Z-direction force) also increases.This is true for both Aluminium and Titanium.
($0^o < 22.5^o < 45^o < 72.5^o < 90^o$)

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