

Study the effect of Crack Length on Stress Intensity Factor under Dynamic Fracture Loading Conditions

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ABSTRACT:The fuselage is one of the main component in any aircraft and its function is to hold all parts together and carries passengers. This fuselage part experience a different loads like static, fatigue, dynamic, buckling during landing, flying and take-off conditions. Now a day's aircraft undergo different type of failure modes, due to improper design, pilot error, weather conditions etc. In the present work, study the effect of crack length on stress intensity factor under both static and dynamic fracture loading conditions. The result shows that the dynamic SIF curve is similar to that of static load curve while the peak point of SIF curve under dynamic become little later compared to peak value of SIF curve under static due to the inertia effect.

KEYWORDS:Fuselage, crack length, stress intensity factor.

I. INTRODUCTION

An aircraft is a machine that is able to fly by gaining support from the air and driven by jet engines or propellers. The main sections of an aircraft, the fuselage, tail and wing, determine its external shape. The load-bearing members of these main sections, those subjected to major forces, are called the airframe. Fuselage is based on French word fuseler, which means "to streamline". The fuselage, or body of the airplane, is a long hollow tube, which holds all the parts of an airplane together. The fuselage is hollow to reduce weight.

In order for an airplane to fly straight and level, the following relationships must be true by Anderson et al.[1]:

- Thrust = Drag
- Lift = Weight

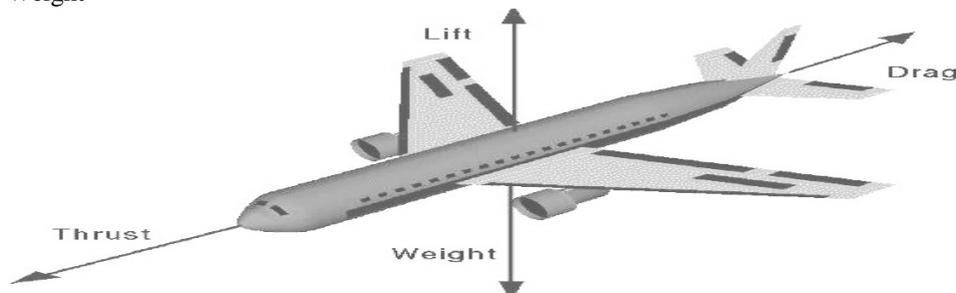


Fig. 1 The forces acting on aircraft

For analysis purpose Airbus A321 is used. It is a largest member of A320 family's. The Airbus A321 single-aisle medium range-airliner is the largest aircraft in the A320 range.

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Fig. 2 Airbus A321

Airbus A321 Specifications from www.Airbus.com[2]

Dimensions	
Length	44.5m
Wingspan	34.1m
Height	11.8m
Wing area	122.4m ²
Weight	
Maximum take-off weight	83000-93500kg
Maximum landing weight	73500-77800kg
Operating empty weight	48100kg
Maximum zero fuel weight	71500kg
Maximum payload	23400kg
Standard fuel capacity	23700-29680Litres
Performance	
Range with max payload	5000-5500km
Cruise speed	840km/h
Maximum speed	890km/h
Maximum operating altitude	11900m
Take-off field length	2180m
Landing field length	1580m
Engines	CFMI CFM56-5A/5B, 2*30000-33000 lb IAE V2500-A5, 2*30000-33000 lb
Fuel efficiency	18.2g/pass*km
Fuel flow rate	3200kg/h
Cabin Data	
Passengers	220(1-class)
Passengers	185(2-class)
Cabin width	3.7m

II. RELATED WORK

Many researchers have worked on designing this part through various techniques like finite element method, experimental method and analytical method. The researchers have carried out different analysis related to aircraft fuselage structure such as static, buckling, dynamic fracture, fatigue analysis etc., The static analysis can be made by different ways such that different conceptual designs that included as frames spacing was smaller compared to stringers spacing, frames spacing was larger compared to stringers spacing, frames and stringers spacing was approximately equal proposed by Yusuf et al. [3] and laminate constructions for stiffened fuselage panels in aircraft design proposed

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by Linde et al.[4]. The buckling analysis can be made by different ways such that post buckling response behavior of stiffened panels under compression proposed by Lynch et al. [5] and post buckling response of stiffened panels under shear proposed by Murphy et al.[6]. The researchers are also made analysis related to predicting the service durability of aerospace components proposed by Grbovic et al. [7], residual strength pressure tests analysis of stringer and frame stiffened aluminium fuselage panel with longitudinal cracks proposed by Young et al.[8], weight comparison analysis between a composite fuselage and an aluminium alloy fuselage proposed by Rossi et al. [9], impact of engine debris on fuselage skin panel proposed by Knight et al. [10], damage analysis of aircraft structure due to bird strike proposed by Smojver et al.[11], damage prediction in airplane flap structure due to bird strike proposed by Smojver et al. [12], and analysis of high energy impact on a sheet metal aircraft structures proposed by MacDonald[13]. The fatigue analysis can be made by different ways such that damage tolerance analysis of aircraft reinforced panels proposed by Carta et al. [14], fatigue cracks at many rivet locations in the skin panel proposed by Karthik et al.[15], and fatigue analysis for upper and lower folding beams on the rear fuselage proposed by Giglio[16]. The dynamic fracture analysis can be made by different ways such that dynamic fracture analysis of aircraft fuselage with damage due to two kinds of blast loads proposed by Ju et al. [17], blast response of metal composite laminate fuselage structures with two material configurations such as aluminium and GLARE proposed by Kotzakolios et al.[18]. In their analysis they considered only a some part of fuselage structure as flat panel, due to this it cause inaccuracy in results and difficult to find critical area in fuselage structure under dynamic fracture loading conditions. Hence, the scope of this work reported in this paper is to study the effect crack length on stress intensity factor under dynamic fracture loading conditions.

III. GEOMETRY OF THE MODEL

In dynamic fracture analysis, aircraft fuselage panel containing pre-existing crack, in order to determine fracture quantities such as the stress intensity factor under blast load. The crack of initial length 80mm is located parallel to stringers. To enable the calculation of the dynamic stress intensity factors during the crack growth phase, it is necessary to analyze a given panel at a number of different crack lengths that is four different lengths during the growth from 160mm to 400mm considered in analysis.

Due to space constraints, a fuselage panels with 160mm crack parallel to stringers as shown in figure 3.

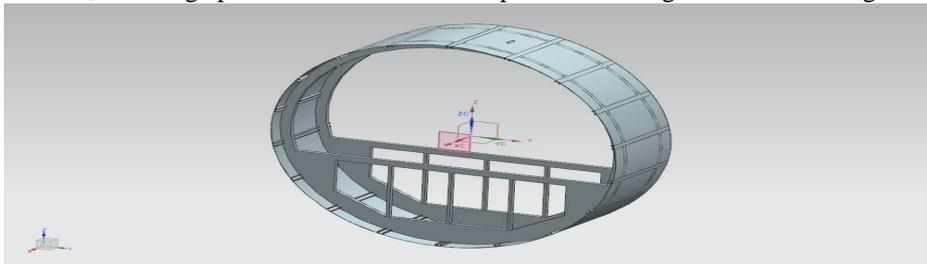


Fig. 3 Fuselage panel with pre-exist crack model

IV. MESHING OF THE MODEL

The dynamic fracture model is meshed with 8 noded hexahedron elements is as shown in figure 4.

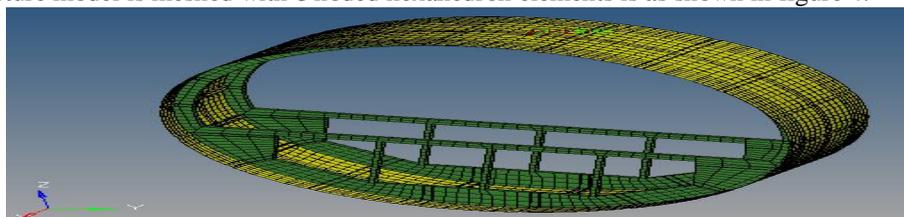


Fig. 4 Meshed model of fuselage panel with pre-exist crack

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Elements used:-8 noded hexahedron element

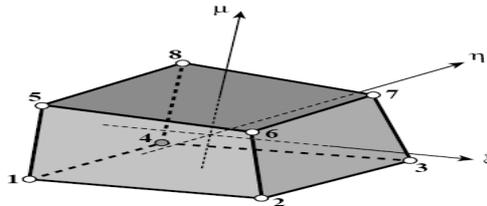


Fig. 5 8 noded hexahedron element

The 8 noded hexahedron element is a three dimensional element with 8 nodes at its corners. The element is defined by 8 nodes having three degrees of freedom at each node: translations in the nodal x, y and z directions (UX, UY, UZ). Hexahedron element is also called Brick element. The figure 5 shows an 8 noded hexahedron element.

V. MATERIAL SELECTED

After the meshing process next step is to assign the material properties and its behaviour. Selection of materials in aircraft construction is rather complex and is based on trade off amongst conflicting requirement of high strength, low density and easy of fabrication or processing. The material used in various parts of vehicle structures generally are selected by different criteria. The material used in the fuselage structure is Aluminium alloy 2024-T351 and its composition as shown in table 1.

Table 1 Composition of Aluminium alloy 2024-T351

Composition	Wt. %
Al	90.7-94.7
Cr	Max 0.1
Cu	3.8-4.9
Fe	Max 0.5
Mg	5.2-5.8
Mn	0.3-0.9
Si	Max 0.5
Ti	Max 0.15
Zn	Max 0.25
Others	Max 0.15

VI. LOAD AND BOUNDARY CONDITIONS APPLIED

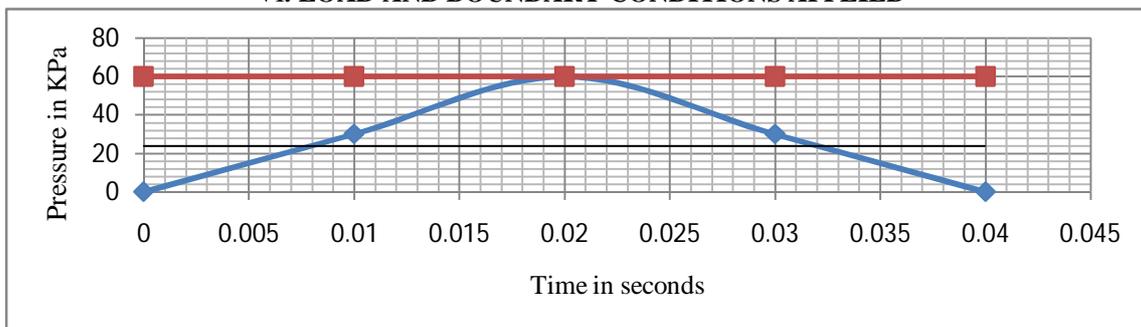


Fig. 6 Graph of triangular blast load and same peak load

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In aircraft, the cabin pressure vary with altitude, as altitude increases cabin pressure also increases and during landing process cabin pressure become equal to ambient pressure. The blast is a very short process, its variation like a triangular load as shown in figure 6 with respect to time and static load with the same peak value as the blast load as shown in straight line in same figure 6.

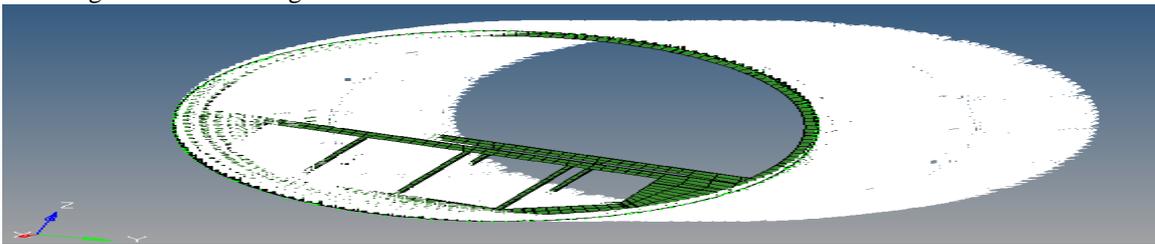


Fig. 7 Load & BCs for fuselage panel with pre-exist crack model

In dynamic fracture analysis, after meshing the next step in FEA is applying load and boundary conditions. Here load and boundary conditions are a pressure of triangular load with respect to time is applied around the fuselage panel with pre-exist crack as shown in figure 7.

To apply a pressure load, a load collector of name TABLED1 is defined, to apply constraints on a location of frame and skin panel combination a load collector of name SPC is defined, to provide different mode of frequency a load collector of name EIGRL is defined, to provide time steps a load collector of name TSTEP is defined, to provide a damping effect a load collector of name TABDMP1 is defined, and also a load collector of names DAREA and TLOAD1 is defined in software. The next step in the analysis is deck preparation that means preparing final model for solving. By using the control card TRANSIENT, the analysis type is set to dynamic fracture analysis and similarly using SOL, PARAM and GLOBAL_OUTPUT_REQUEST control cards, the required output parameter like SIF is clearly defined. Then this final FEA model which is ready for solving is fed to the solver. Before that the FEA model which is in .hm file format is converted to .bdf or .dat file format because, it is the required input file format for MSC NASTRAN solver.

The solver takes around 35 to 40 minutes of time for solving in a Pentium dual core processor, 2GB RAM equipped PC. The solving time can be minimized by using high configured computer. A number of output files were generated after solving, among which a file of .bdf and .op2 format are used to generate the contour plot of SIF in the Hyperview v11.0 software, which is the Post processor used in the analysis.

VII. MATHEMATICAL MODEL

For Aluminium alloy 2024-T351, load rating range $KI^{Dyn}(t,v) = 1*10^4$ to $2*10^6$ MPam^{1/2}/sec. Plane strain fracture toughness = 30MPam^{1/2} by Ravi-Chandar[19]

Quasi-static value at low loading rate $KI^{Dyn}(t,v) < 1*10^4$ MPam^{1/2}/sec, $KI^{Dyn} = 77MPam^{1/2}$.

Dynamic stress intensity factor $KI(t, l, l^*) = K(l^*) KI(t, l, o)$ by Freund[20]

$$KID = KID(l^*)$$

Dynamic stress intensity factor depends on instantaneous crack tip speed l^* and load history.

VIII. RESULTS AND DISCUSSIONS

For Aluminium alloy 2024-T351

Plane strain fracture toughness $KIC = 30MPam^{1/2} = 948.68MPamm^{1/2}$.

Dynamic fracture toughness $KID = 77MPam^{1/2} = 2434.95MPamm^{1/2}$.

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Table 2 Results of SIF for different crack lengths with respect to time under dynamic loads

Time in sec	SIF for different crack lengths in fuselage panel in MPamm ^{1/2} under dynamic loads				
	80	160	240	320	400
0	0	0	0	0	0
0.005	58.66	117.5	176.3	234.8	305.9
0.01	112.6	225.6	338.7	451.3	582.4
0.015	83.17	166.1	249	332	415
0.02	55.08	106.6	161.8	219.4	281.9

The table 2 shows SIF for different crack lengths in fuselage panel is fluctuates with respect to time due to triangular pressure load in fuselage panel. Here results are tabulated in time step of 0.005 seconds and carried out upto 800 trials that is upto 4seconds.

Table 3 Results of SIF for different crack lengths with respect to time under static loads

Time in sec	SIF for different crack lengths in fuselage panel in MPamm ^{1/2} under static loads				
	80	160	240	320	400
0	0	0	0	0	0
0.005	42.42	96.97	154.1	211	275.2
0.01	42.42	96.97	154.1	211	275.2
0.015	42.42	96.97	154.1	211	275.2
0.02	42.42	96.97	154.1	211	275.2

The table 3 shows SIF for different crack lengths in fuselage panel is constant with respect to time due to static load with the same peak value as the blast load.

Due to space constraints, the stress intensity plot for different crack lengths in fuselage panel under dynamic loading conditions are shown only for failure load cases.

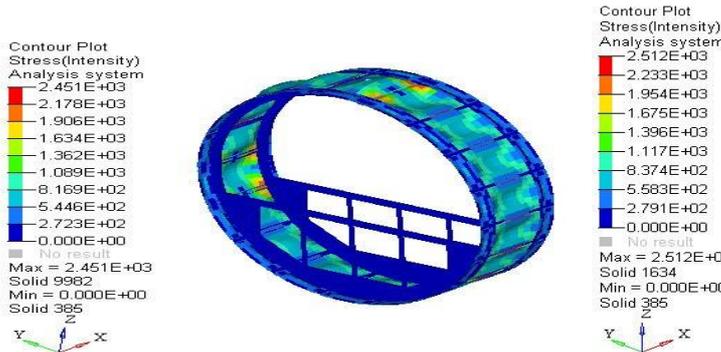


Fig. 8 SIF > KID for 80mm crack

Fig. 9 SIF > KID for 160mm crack

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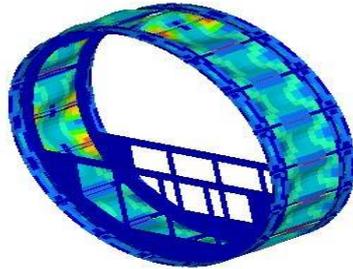
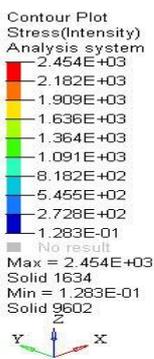


Fig. 10 SIF > KID for 240mm crack

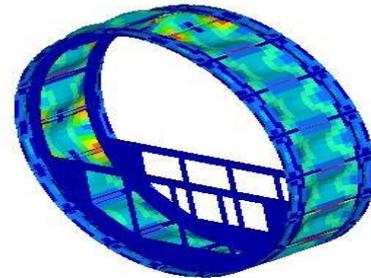
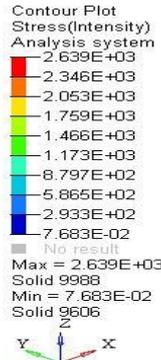


Fig. 11 SIF > KID for 320mm crack

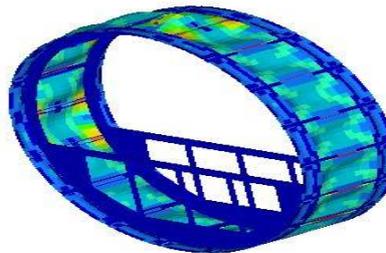
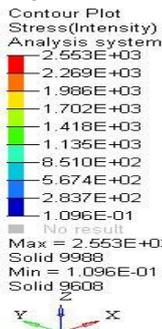


Fig. 12 SIF > KID for 400mm crack

Due to space constraints, the stress intensity plot for different crack lengths in fuselage panel under static loading condition at a time of 0.005 second as shown in figures from 13 to 17.

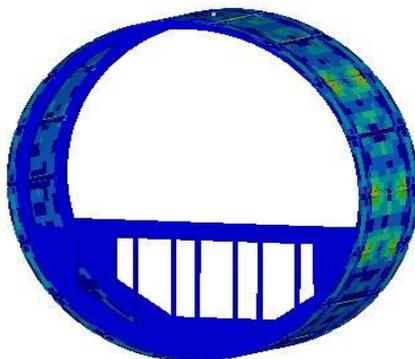
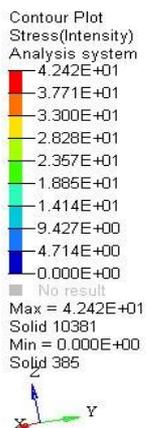


Fig. 13 Constant SIF for 80mm crack

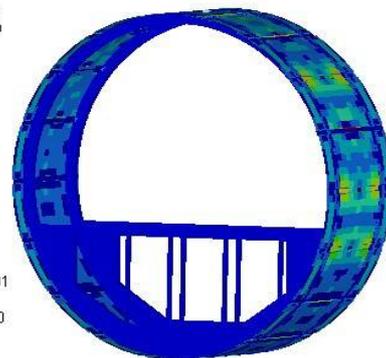
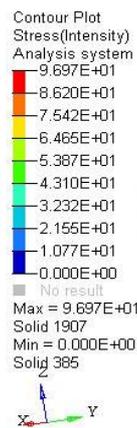


Fig. 14 Constant SIF for 160mm crack

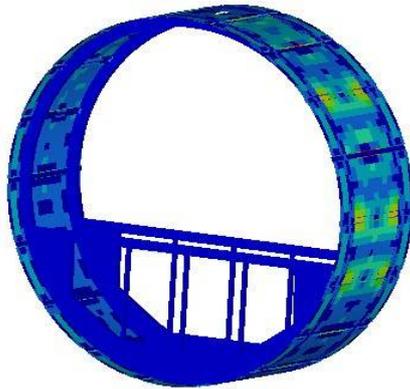
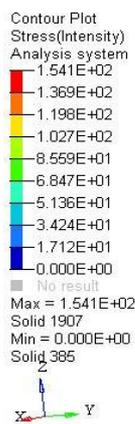


Fig. 15 Constant SIF for 240mm crack

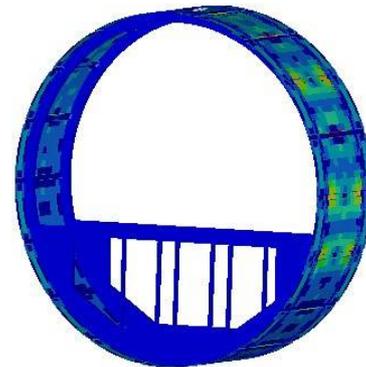
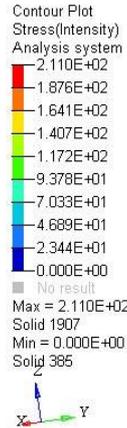


Fig. 16 Constant SIF for 320mm crack

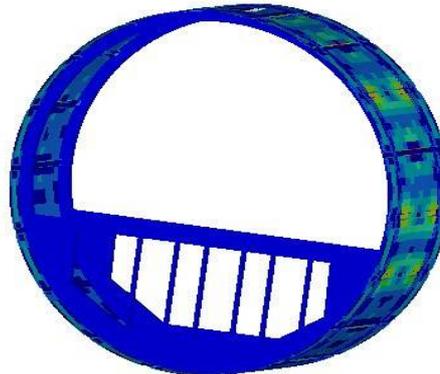
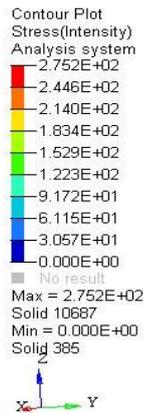


Fig. 17 Constant SIF for 400mm crack

The results of dynamic SIF curves of five cracks with different lengths under triangular blast load case and static load with the same peak value as the blast load as shown in figures 18 and 19 respectively.

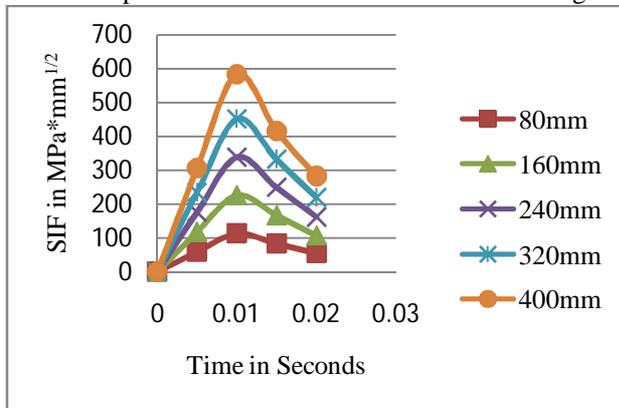


Fig. 18 SIF curves for different crack lengths under triangular blast load

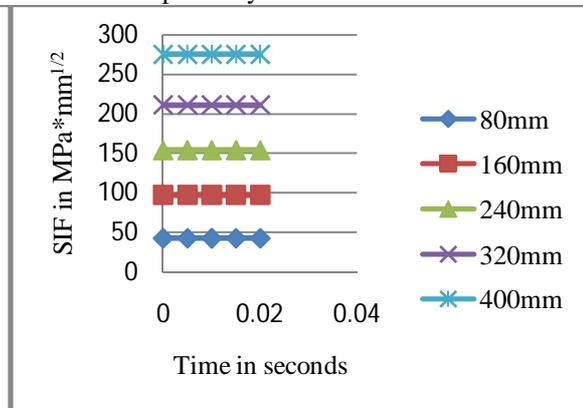


Fig. 19 SIF curves for different crack lengths under static load

The comparison SIF curves under dynamic and static load cases as shown in figure 20.

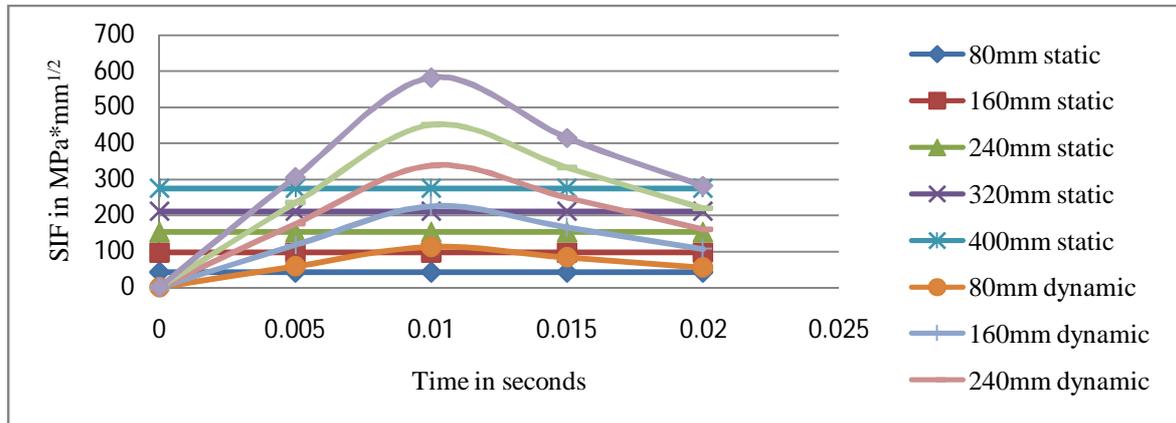


Fig. 20 SIF curves comparison under static and dynamic load cases

The SIF peak values for different crack lengths under dynamic triangular blast load case and under static load with the same peak value as the blast load at a time of 0.005second is as shown in figure 21.

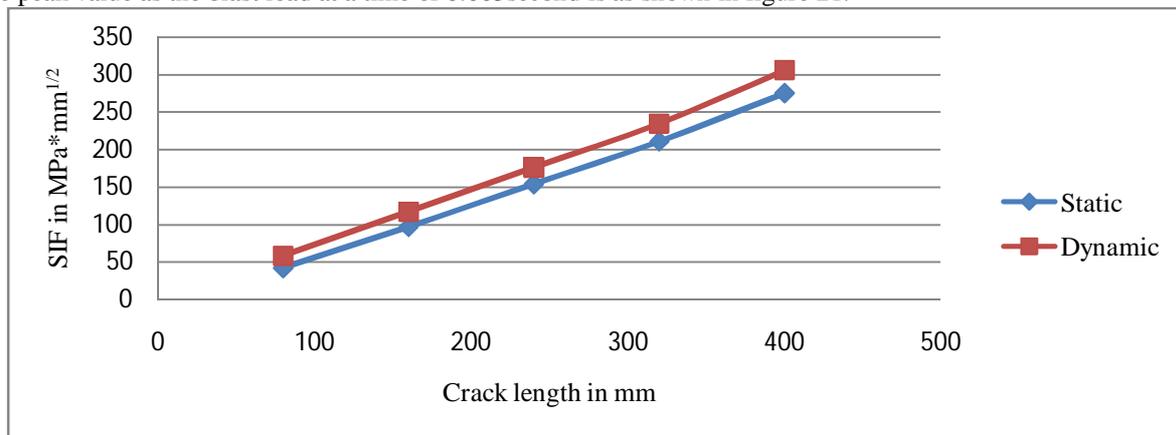


Fig. 21 SIF peak values of different crack lengths for static and dynamic load cases

IX. CONCLUSIONS

Some conclusions can be drawn from results of dynamic fracture analysis as follows:

- The dynamic SIF curve is similar to that of static load curve while the peak point of SIF curve under dynamic become little later compared to peak value of SIF curve under static due to the inertia effect.
- The peak SIF value of the crack under triangular blast load is bigger than that under static load for certain crack length, that is for crack of length 80mm have peak value under triangular blast is $58.66\text{MPa}\cdot\text{mm}^{1/2}$ and peak value under static load is $42.42\text{MPa}\cdot\text{mm}^{1/2}$. The crack is longer, bigger the difference between the dynamic peak SIF and static peak SIF value.

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