Vol. 03, No. 4 (2021) 473-490, doi: 10.24874/PES03.04.011

Proceedings on Engineering Sciences

www.pesjournal.net

NUMERICAL INVESTIGATION OF CRACK GROWTH IN METALS AND COMPOSITES

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Keywords:

XFEM; ABAQUS; Fracture; Crack; Steel; Composites

A B S T R A C T

This work presents the simulation study of fracture behavior of steel and composites. The crack growth behavior of the material is simulated by extended finite element method (XFEM). XFEM allows the modeling of arbitrary geometric features independently of the finite element mesh. The crack surface elements are enriched by Heaviside function whereas, crack front elements treated by asymptotic functions. Ramberg-Osgood material model coupled with damage is used to simulate the crack propagation. The experimental data is obtained from extensive literature review of literature published in last five years. Numerical simulation is performed on the commercial software ABAQUS. A benchmark test specimen is used for numerical simulation, created as per ASTM standard in ABAQUS. 3D CT, SENB and DENT specimen have been chosen for simulation. The study aims at further extensive detailed study of fracture mechanics' design. Fatigue has been studied as mode 1 loading. Conformal meshing limitations with dynamic problems using classical FEM have been addressed. Paris law has been used as damage model. Mode I fatigue loading is used to analyze the crack growth in the both steel and composite problems. A specimen with initial crack is loaded till failure and therefore fracture mechanics design is extended to newly introduced class of materials. Number of cycles till failure is evaluated and visualized. The design considerations are further evaluated using benchmark literature tests like four-point bend and compression-tension tests. The knowledge has been extended to solve some practically important problems like turbine disk and surface cracking. A design feature leak before break has been given due consideration by solving the problems with high pressure pipes with internal cracks.

1. INTRODUCTION

Classical solid mechanics using traditional theories of failure have been used traditionally for design of structures (Callister, W. D. 1997). With marginal miniaturization in design and viable economical design it has been observed that elements with initial cracks and discontinuities have not been designed satisfactorily (Melenk et al., 1996). Such design procedure does not consider the material discontinuities and initial cracks in structures, as such these design considerations have not been able to present the complete picture of material design (Babuska et al., 1998). Fracture mechanics design have come to the fore during World War II and we have

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been able to handle such design irregularities to the greater extent (Belytschko et al., 1999). Material properties such as fracture toughness have been introduced to take care of such irregularities in structures (Moes et al., 1999). Fracture mechanics design assumes crack as the initial material input and design is based on that assumption. So, a complete design picture can be well expected with such design (Dolbow et al., 1999).

Material engineers and mathematicians have come up with computational techniques and procedures for numerical simulation of fracture mechanics' design (Dolbow et al., 2000). Researchers have contributed to the diversification of fracture mechanics with computational simulation and modelling analysis. FEM has been main tool for numerical simulation of solid mechanics' design (Daux et al., 2000). However, due to obvious reasons the method cannot be extended to fracture mechanic's design (Sukumar et al., 2000). Other methods have also been developed for studying the static and dynamic variety of problems relating to fracture mechanics. A novel numerical tool of XFEM (extended finite element analysis) have been used in this work for the simulation of crack growth in material specimen (Stolarska et al., 2001). The failure of materials in structures under cyclic stress or strain application is not only a matter of technical interest, but also of industrial significance (Sukumar et al., 2001). A real challenge for scientists is the knowledge of fatigue mechanisms (damage) and the formulation of constitutive equations for damage propagation that lead to crack initiation and propagation as a function of loading history (Beltyschko et al., 2001). In general, the method of fatigue cracking starts from places where discontinuities occur or where plastic strain accumulates preferentially in the form of slip bands. In most cases, fatigue failures occur in the typical stress concentration areas, such as sharp notches, non-metallic inclusions, or pre-existing cracks or similar defects (Chessa et al., 2002). Cracks first begin when failures occur at sharp notches or other stress raisers, and then spread to critical scale, and then failure occurs (Gravouil et al., 2002).

There are many causes and types of fracture, and knowledge of the component nature, service loading, conditions, and structure-property relationship are required for careful study of fractured sections (Moes et al., 2002). Knowledge of sound material experimental and numerical simulation techniques and the analysis and interpretation of fracture surfaces are very relevant. At a shallow angle to the surface, most micro cracks are arrested, but some may continue to spread parallel to the surface, producing a fatigue crack on the macro scale (Moes et al., 2002). In order to simulate the application conditions, several experimental methods were developed. Control of numerous influencing parameters was made sure (Sukumar et al., 2003). Numerical simulations have been developed for smooth and proper analysis of crack growth. The failure process can be divided into three stages: A brief initial stage of material bulk changes. A long, stable stage where there are only micro-scale changes (Chopp et al., 2003). The final stage when a macro-crack is growing. Bulk variations in the material structure develop in the highly stressed material under the contact path during the first step (Stazi et al., 2003). Deformation bands, defined as white etching areas, are formed due to micro-plastic flow in the second stage (Babuska et al., 1998). Deformation bands, defined as white etching areas, are formed due to micro-plastic flow in the second stage (Moes et al., 2003).

This work aims at the numerical simulation and modelling analysis of crack growth phenomenon for a fracture mechanics design consideration. Wide varieties of practically important phenomenon have been simulated for wider scope (Sukumar et al., 2003). Wide range of problems have been attempted and solved. Problems related to design failure in turbine disks have been presented. Turbine disks are prone to corrosion and fretting fracture and have a huge practically importance (Huang et al., 2003). This problem has been solved. Surface cracking is a phenomenon commonly found in various tribological applications. Surface cracks grow over loading and stress concentration factors and cause substantial wear and tear to the surfaces. Such problems have also been solved (Huang et al., 2003). In this work static constant and dynamic cyclic loading have been considered to analyze the crack growth (Belytschko et al., 2003). Variety of typical materials has been tested ranging from planer to 3-D geometries. Some benchmark test specimen has been solved (Ventura et al., 2003). Also attempt has been made to evaluate composite materials (Marian et al., 2003). Fatigue is responsible for more than 70% of mechanical failure (Bellec et al., 2003). Fatigue in materials can occur in various forms (Budyn et al., 2003). Fatigue is main reason for failure and it has been given due consideration (Chessa et al., 2004). Fatigue refers to load reversals and ultimately leaved material tired of sort (Ji et al., 2004). Fatigue is dangerous because this can lead to the failure of material very below its yield point (Babuska et al., 1998). In fact, failures have been reported wherein scientists were not able to comprehend what could cause the failure of material below its ultimate failure with proper factor of safety (Sukumar et al., 2004). However, it has been established since that fatigue can cause failure of material well below its yield point thereby making it the cause of concern (Lee et al., 2004). Initial crack has been assumed throughout this work. Therefore, crack initiation part has been mainly been not dealt with in numerical simulation as experimental methods are required for such laboratory tests (Liu et al., 2004). For crack growth sufficient loading is required. Since ABAQUS limits to low cycle fatigue it is mandatory that high loads be applied for calculations (Areias & Belytschko 2005). Also, cycle's amplitude of cycles in fatigue loading is always positive and constant (Areias & Belytschko 2005). Variation in amplitude is mainly dealt with crack imitation phase (Bechet et al., 2005). The other variables which can affect the fatigue life and its properties are 1. Mechanical properties of the material (Legrain et al., 2005). 2. Loading conditions (Rethore et al., 2005). 3. Stress concentrations (Khoei et al., 2006). 4. Corrosion (Bordas et al., 2006). 5. Overload (Fries et al., 2006) 6. Residual stresses (Hettich et al., 2006) 7. Temperature (Khoei et al., 2006)8. Notches & Scratches (Elguedj et al., 2006) 9. Metallurgical structure (Ventura G, et al., 2006) 10. Surface condition of the specimen. (Moes et al., 2006) 11. Surface roughness. (Vitali et al., 2006) 12. Compressive residual stress from heat treatments and machining can oppose a tensile load and thus lower the amplitude of cyclic loading (Xiao et al., 2006). Fracture toughness has been introduced as the material property to replace the young's modulus of classical solid mechanics' design (Bordas et al., 2007). A ductile material with high strength has been found to have high toughness value experimentally (Rabinovich et al., 2007). Surface behavior of material is mainly explained by material property hardness (Unger J, et al., 2007). A material with high hardness has low fracture energy and therefore more resistant to fracture (Belytschko et al., 2007). This property has found use in various tribology applications also (Miegroet et al., 2007). Hardness is not basic property of material as the property can be altered with various laboratory treatments (Zlotnik et al., 2007).

2. NUMERICAL ANALYSIS

The crack growth behavior of the material is simulated by extended finite element method (XFEM). XFEM allows the modelling of arbitrary geometric features independently of the finite element mesh (Zlotnik et al., 2007). The crack surface elements are enriched by Heaviside function whereas, crack front elements treated by asymptotic functions (Khoei et al., 2008). Ramberg-Osgood material model coupled with damage is used to simulate the crack propagation (Anahid & Khoei, 2008). The experimental data is obtained from extensive literature review of literature published in last five years (Nistor et al., 2008). Numerical simulation is performed on the commercial software ABAQUS. Benchmark test specimen is used for numerical simulation, created as per ASTM standard in ABAQUS (Ginera et al., 2008). 3D CT, SENB and DENT specimen have been chosen for simulation, as suggested by literature (Wyart et al., 2008).

The simulation study of functionally graded composite material is carried out as the part of this work (Yan et al., 2008). Composite specimen is simulated in commercial software ABAQUS (Ventura et. al., 2009). The aim is to extend the fracture mechanics design considerations to the newly introduced Composite materials (Tarancon et al., 2009). Extended finite element analysis (XFEM) is used as a numerical technique (Belytschko et al., 2009). Conformal meshing limitations with dynamic problems using classical FEM have been addressed (Zilian et al., 2009). Paris law has been used as damage model. Mode I fatigue loading is used to analyze the crack growth in the composite specimen (Fries TP, et al., 2010). A specimen with initial crack is loaded till failure and therefore fracture mechanics design is extended to newly introduced class of materials (Baietto et al., 2010). Number of cycles till failure is evaluated and visualized (Zamani A, et al., 2010). The design considerations are further evaluated using benchmark literature tests like four-point bend and compression-tension tests (Khoei & Amir, 2015).

A detailed simulation study has been carried out (Huang et al., 2003). Analysis of steel for both monotonic and fatigue loading has been done. A detailed analysis of crack growth has been studied and visualised in both monotonic and fatigue loading (Marc Duflot et al., 2004). Composite materials have been subject to fatigue loading only. Some typical problems of crack growth have been solved (Marc Duflot et al., 2004). Plate with initial crack has been chosen. A constant static general loading has been used (Fries et al., 2010). Only mode I loading have been considered. A thin plate problem is typically a plane stress problem. Stress contours have been obtained for static general case scenario (Zlotnik et al., 2007). Two hundred quadrilateral elements have been used for analysis with proper boundary conditions (Zamani et al., 2010). Length of crack is in relation to dimension orientation is mostly feasible to practical applications and the angle of crack varies from 0 degree to 90 degrees (Babuska et al., 1998). Problems solved are mostly laboratory specimen and ASTM standards have mostly been referred to for crack dimension and orientation (Fries et al., 2010). Loading is essentially static constant. Material property used for analysis are given as, Young's modulus=5000N/m^2, Poisson ratio=.3, Maximum principal stress=60Pa Displacement after fracture=.4mm (Zamani et al., 2010).

2.1 Thick Plate

In figure 1 the crack growth is shown in thick steel plate. A plane stress condition is used for analysis. 5341elements have been used for the analysis. Each element is quadrilateral 8 noded. Figure 2 shows the vonn misses stresses. A thick plate has lot of industrial applications. Therefore, the fracture mechanics design considerations have been studied (Huang et al., 2003).

2.2. A cantilever beam

In figure 3 a typical cantilever beam is shown (Huang et al., 2003). A cantilever is the structural elements pinned from one side such that it's all degree of freedoms are zero and loading is applied on one boundary only (Fries et al., 2010).

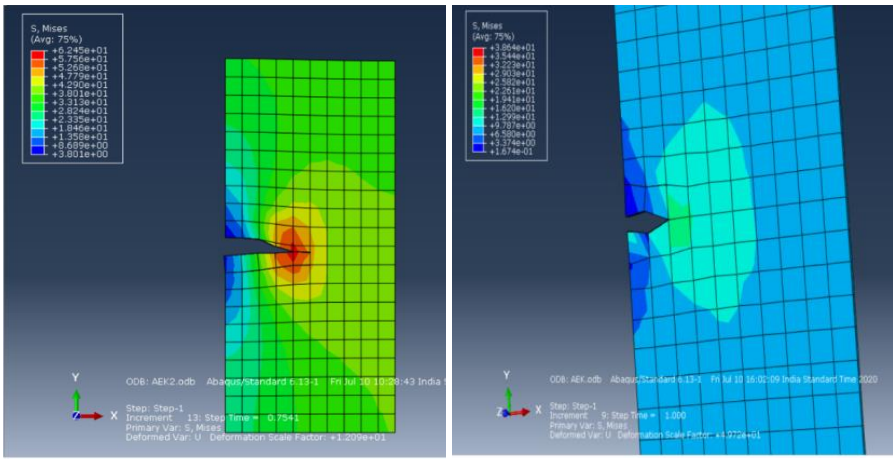

Figure 1. Static general: thin plate misses plot.

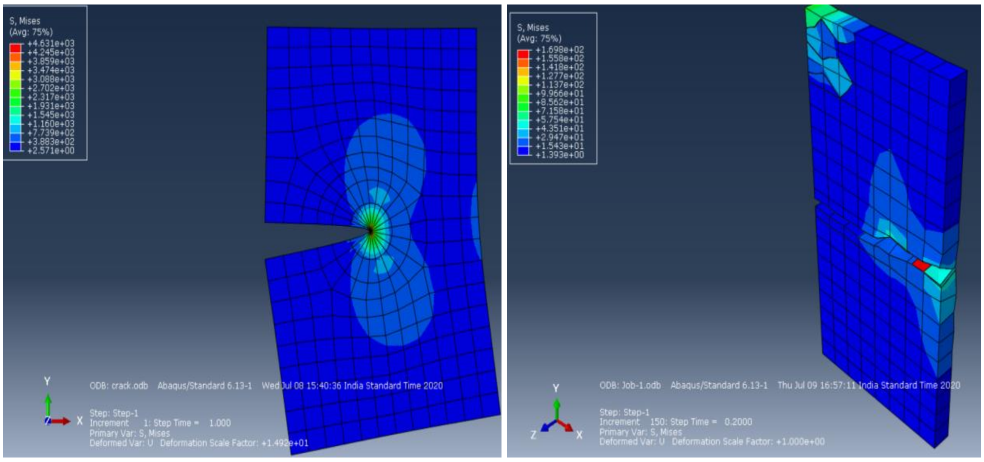

Figure 2. Thick plate: misses stress plots

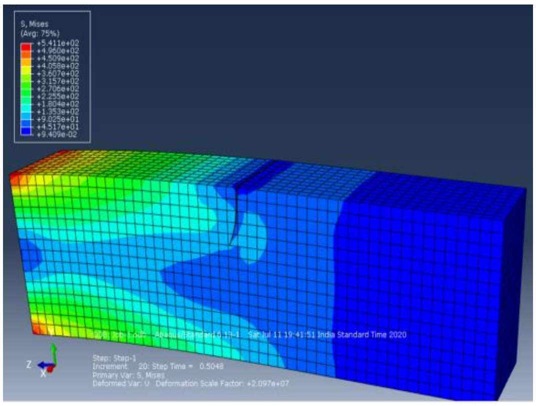

Figure 1. A cantilever beam: misses stress plots

2.3. A compression-tension specimen

A compression–tension(C-T) specimens are widely used non-destructive testing (NDT) purposes (Legrain et al., 2005). In fracture mechanics these specimens are used for crack laboratory crack growth data by convention (Chopp et al., 2003). They are also used for fracture toughness testing. We present the numerical simulation and modelling analysis of such specimen in detail (Babuska et al., 1998). Figure 4 shows the simulation of steel compression tension specimen (Fries et al., 2010). The simulation is performed on using the mode I static general loading. Boundary conditions have been chosen as per the fracture mechanics literature for proper results. 160x160 quad elements has been used. Following material properties have been used for the analysis of compression-tension specimen (Wyart et al., 2008).

Young's modulus=7200N/m^2, Poisson ratio=.3, Maximum principal stress=120Pa, Displacement after fracture=.2mm (Fries TP, et al., 2010).

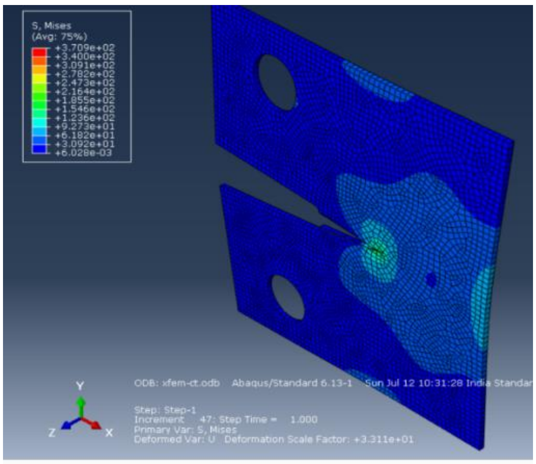

Figure 2. A C-T Specimen: misses plot

2.4. A thin pipe

In figure 5 a pipe with initial crack bursting under internal fluidic pressure is shown. Quadrilateral elements have been used for simulation with proper boundary conditions using proper data.

Young's modulus=210e9N/m^2, Poisson ratio=.3, Maximum principal stress=96e6Pa, Normal mode fracture energy=42200 Nmm/mm^2, Shear mode fracture energy first direction=42200 Nmm/mm^2, Shear mode fracture energy second direction=42200 Nmm/mm^2.

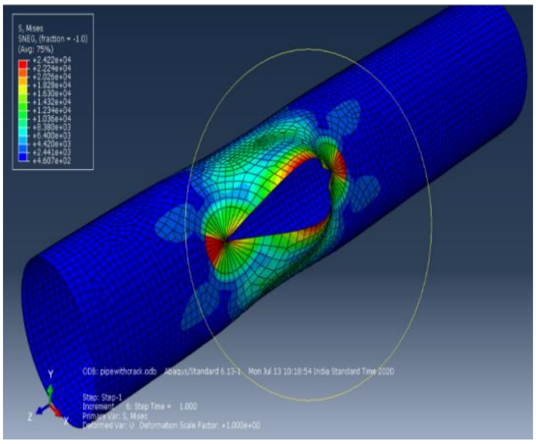

Figure 3. Misses stress plots of a thin pipe

2.5. Point bending test

In figure 6 is shown the typical 3 point bending test simulation. XFEM has been used as the numerical technique (Zamani et al., 2010). Static constant loading has been used with proper boundary conditions and load points for successful test (Huang et al., 2003). crack length, orientation and position are taken randomly. Length of crack is in relation to dimension; orientation is mostly feasible to practical applications and the angle of crack varies from 0 degree to 90 degrees (Legrain et al., 2005). Problems solved are mostly laboratory specimen and ASTM standards have mostly been referred to for crack dimension and orientation. 100x50 elements, each quadrilateral has been used with following material properties (Fries et al., 2010).

Young's modulus=5000N/m^2, Poisson ratio=.3, Maximum principal stress=80Pa, Displacement after fracture=.2mm (Wyart et al., 2008).

2.6. Fatigue test specimen

In the figure 7 is shown the fatigue specimen subject to fatigue loading.

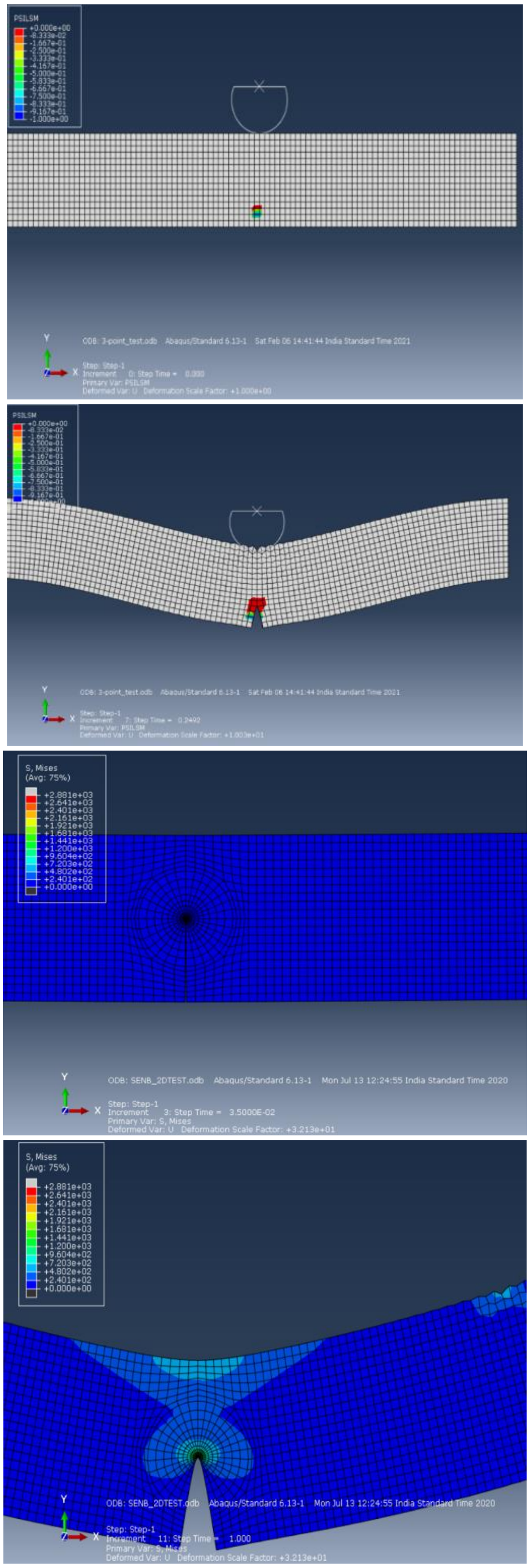

Figure 4. 3-Point bending test stress plot (Misses)

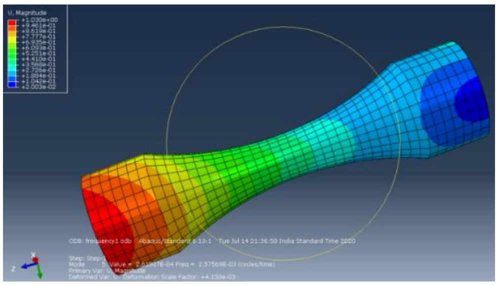

Figure 5. Fatigue test specimen: Misses plot

2.7. Plate with hole

Timoshenko has solved the problem of plate with hole analytically using theory of elasticity concepts (Babuska et al., 1998). We present the numerical simulation results of such analytical results (Wyart et al., 2008). Plate with hole has wide practical applications (Huang, et al., 2003). Holes are drill in plates to reduce weight that is not required, save material and also when actually required for installing bolts screws (Fries et al., 2010). Dimension of wide range can be expected. We solve 100x20 cm plate with 5 cm hole (Legrain et al., 2005).

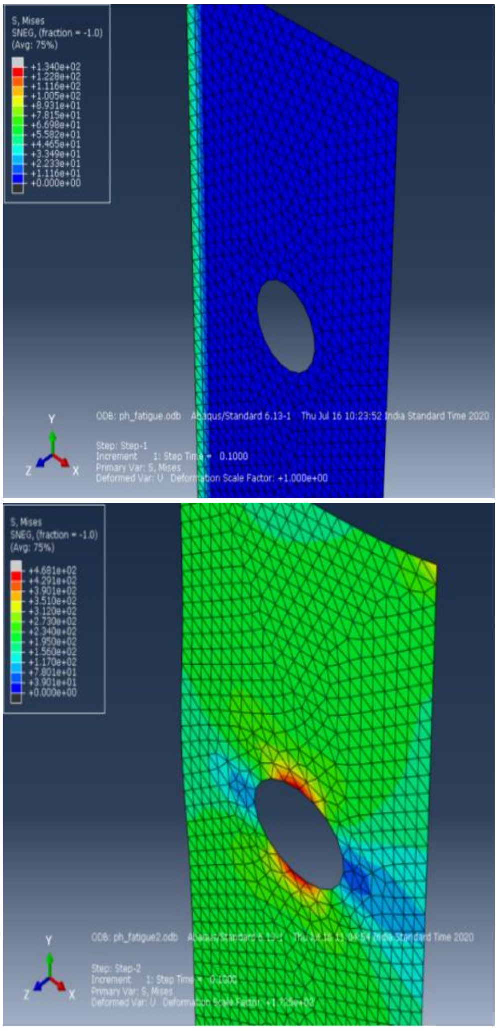

Figure 6. Plate with hole: Misses stress plots

2.8.A thin plate with crack at an angle

In figure 9, a thin plate is shown (Fries et al., 2010). The plate has the central crack inclined at 45 degrees to the vertical normal (Wyart et al., 2008). We present the fracture mechanics of such plate using normal static constant loading (Legrain et al., 2005). Data used for simulation (Chopp et al., 2003). Young's modulus=210e9N/m^2, Poisson ratio=.3, Maximum principal stress=96e6Pa

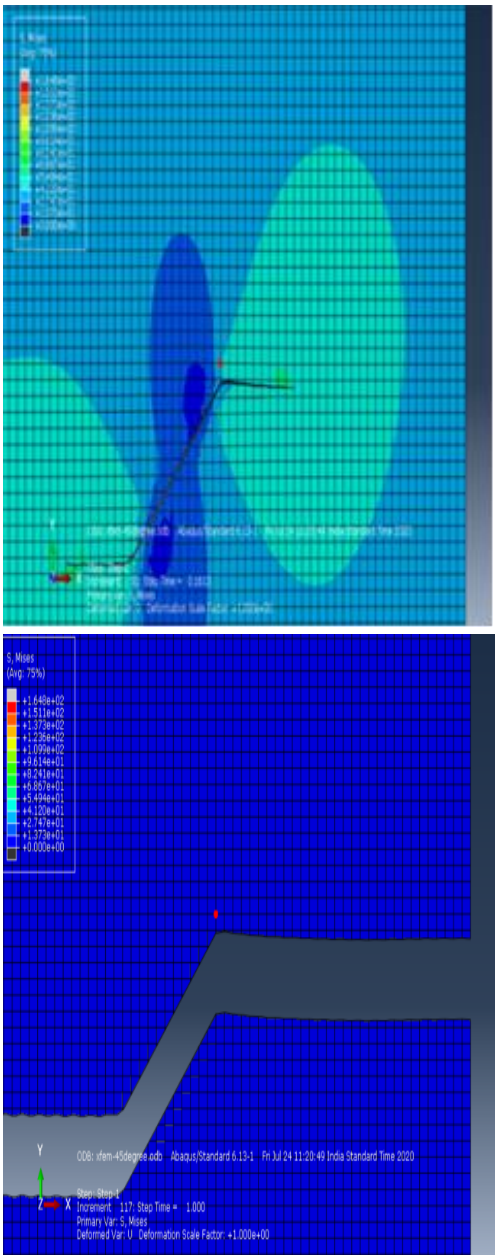

Figure 7. Crack at an angle: Misses stress plot

2.9. A thick pipe with internal crack

Fracture mechanics knowledge has been extended to wide range of practical applications. one of the vital fields is high pressure vessel industry mainly used in nuclear reactors. Nuclear fuel is highly radioactive and a catastrophic failure can cause threat to humanity. Leak before break serves as the major design criteria in such industry. With fracture crack growth life estimation, we can predict the leak and design the vessels for safe time under proper maintenance (Legrain et al., 2005). A thick pipe under pressure is shown below with the crack on its circumference. Young's modulus=210e9N/m^2, Poisson ratio=.3, Maximum principal stress=480Pa, Normal mode fracture energy=4220 Nmm/mm^2, Shear mode fracture energy first direction=4220 Nmm/mm^2, Shear mode fracture energy second direction=4220 Nmm/mm^2, Viscosity coefficient=.05

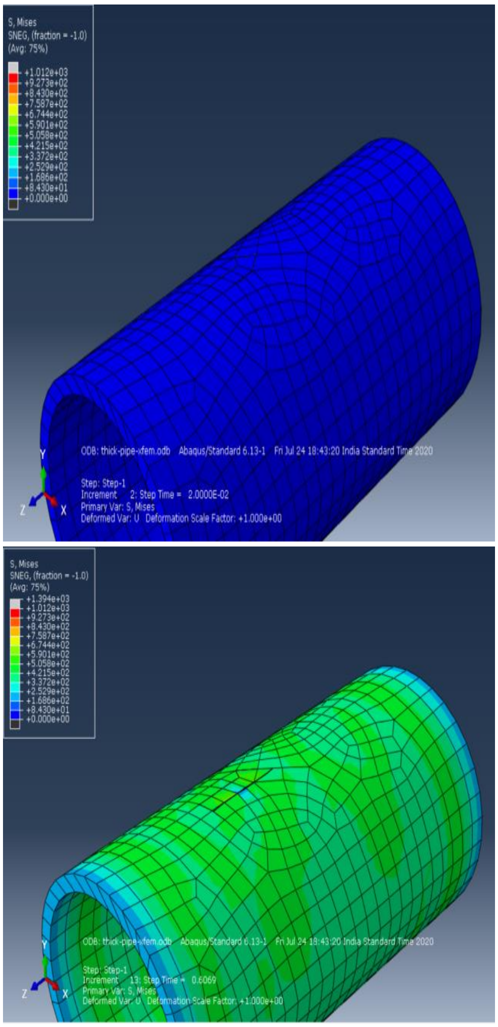

Figure 8. Thick pipe under pressure: Leak before break Misses plot

2.10. Dynamic cyclic step loading

In this section dynamic cyclic step has been used. Therefore, fatigue loading has been used. The amplitude is constant and the loading is low cycle fatigue. Paris law has been used as the damage model. Elements chosen are 4 or 8 noded quadrilaterals and boundary conditions are problem specific, however some material properties that remain common are given as: Young's modulus=210e9N/m^2, Poisson ratio=.3, Maximum principal stress=96e6Pa, Normal mode fracture energy=42200 Nmm/mm^2, Shear mode fracture energy first direction=42200 Nmm/mm^2, Shear mode fracture energy second direction=42200 Nmm/mm^2.

2.11. Thin plate

In the figure 11 is simulated the thin plate using XFEM. Loading applied is fatigue dynamic cyclic.100x20 quad elements have been made and loads are applied. Also, appropriate boundary conditions are used. Material used is steel and all the properties remain same as preceding heading (Legrain et al., 2005).

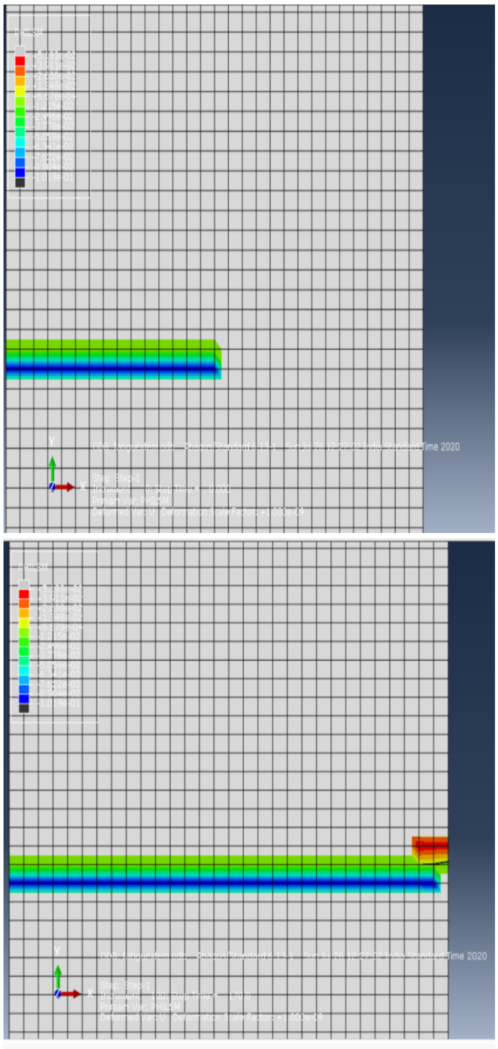

Figure 9. Thin plate: Dynamic cyclic Misses plot

2.12. A 2-D (thin) compression tension (CT) specimen

Figure 12 shows the MISSES plot of 2-D thin compression–tension specimen. A C-T specimen is benchmark for fracture mechanics fatigue crack growth problems. A plane stress conditions prevail for analysis. XFEM has been used as the numerical technique. Since the problem is dynamic in nature a classical FEM is not computationally favourable. It is due to the reason of conformal meshing which means in classical FEM we would actually be remeshing the whole problem again in a time dependent step. Such problems have been handled in XFEM (Chopp D, et al., 2003).

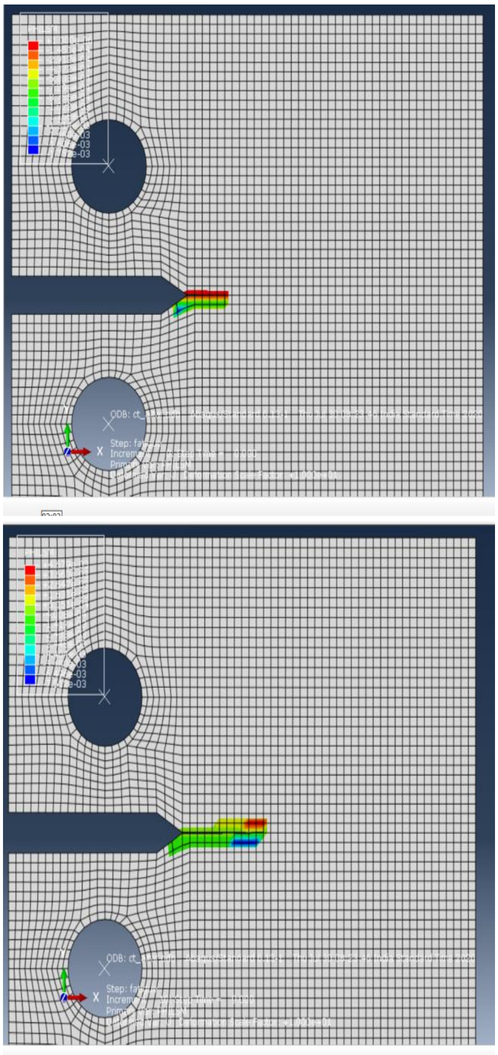

Figure 10. A thin (2-D) C-T specimen: Misses plot

2.13. A thick (3-D) plate

In the diagram below is shown the thin plate with initial crack subject to fatigue loading. XFEM has been used the numerical tool to find the crack growth mechanics of the problem. Since the plate is thick the plane strain conditions have been utilized for computational analysis. 8 noded quad elements have been used 20x10x2. Length of crack is in relation to dimension; orientation is mostly feasible to practical applications and the angle of crack varies from 0 degree to 90 degrees. Problems solved are mostly laboratory specimen and ASTM standards have mostly been referred to for crack dimension and orientation. 100x50 elements, each quadrilateral has been used with following material properties (Wyart et al., 2008).

Young's modulus=5000N/m^2, Poisson ratio=.3, Maximum principal stress=80Pa

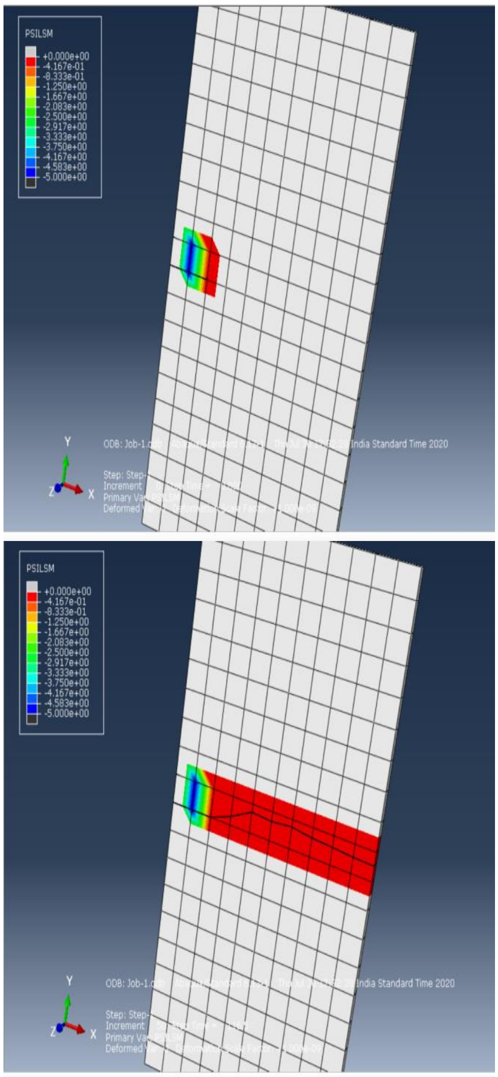

Figure 11. A thick plate: Misses plot

2.14. A SENB (side edge notch) specimen

SENB specimens are widely used non-destructive testing (NDT) purposes. In fracture mechanics these specimens are used for crack laboratory crack growth data by convention. They are also used fracture toughness testing. These specimens have essentially found applicability in welding applications. We present the numerical simulation and modelling analysis of such specimen in detail.in the diagram below is shown the thick (3-D) SENB specimen. Plane strain conditions prevail. We present fatigue crack growth simulation of such specimen (Legrain et al., 2005).

Young's modulus=210e9N/m^2, Poisson ratio=.3, Maximum principal stress=96e6Pa, Normal mode fracture energy=42200 Nmm/mm^2, Shear mode fracture energy first direction=42200 Nmm/mm^2, Shear mode fracture energy second direction=42200 Nmm/mm^2

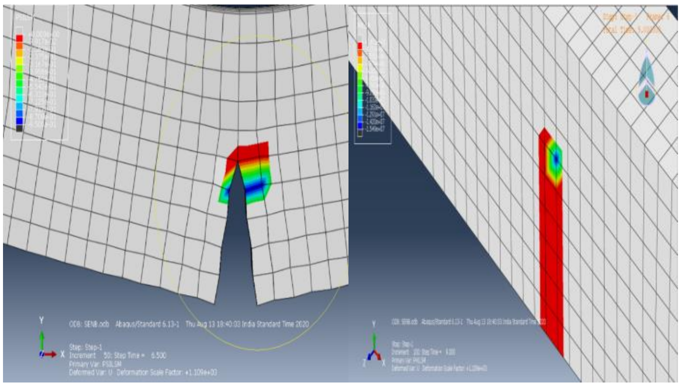

Figure 12. A SENB specimen: Misses plot

2.15. A 4-point bending test

4-point bending test is widely used experimental method for fracture calculations. This method has found wider applicability since shear forces are not generated on test specimen.as such brittle materials is widely tested with such tests. In such as test a material specimen is held on two load points pinned to surface and two load points are pinned to the top. Vertical direction of motion is allowed for testing (Wyart et al., 2008).

Young's modulus=210e9N/m^2, Poisson ratio=.3, Maximum principal stress=96e6Pa, Normal mode fracture energy=42200 Nmm/mm^2, Shear mode fracture energy first direction=42200 Nmm/mm^2, Shear mode fracture energy second direction=42200 Nmm/mm^2

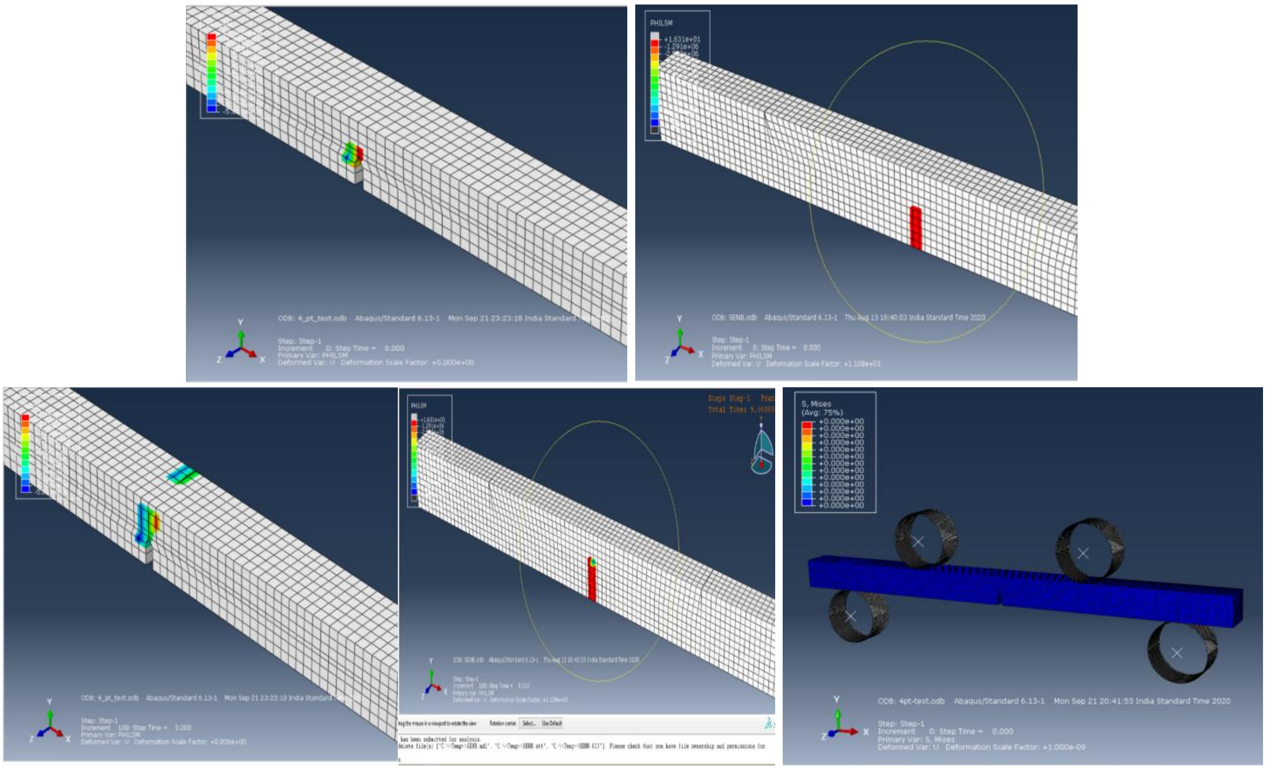

Figure 13. A 4-Point bending test: Misses plot

2.16. A thick (3-D) C-T specimen

XFEM have been used for the simulating the CT specimen. Exact model along with the fatigue loading condition is used in the simulation by XFEM. Paris law coupled with damage model based on crack growth energy criterion have been used to model the crack growth. The domain is discretized by 8 noded quadratic elements. The discretized model used for simulation is shown below. A total of 5229 and 10898 elements and nodes are generated for simulation. Misses stress distribution obtained in the simulation is presented in diagram below. The higher value of stresses at crack tip signifies the higher growth resistance towards crack growth. A 3—D model have been numerically analysed. Plane strain conditions prevail (Legrain et al., 2005).

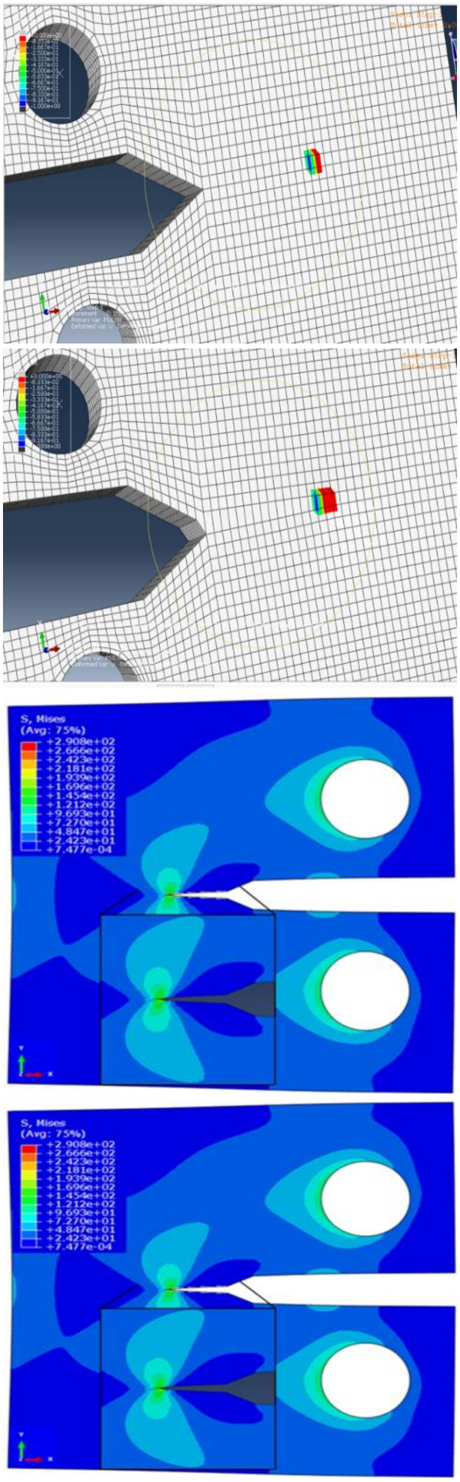

Figure 14. A C-T specimen (3-D) Misses stress plot

2.17. Cantilever beam

Cantilever is typical structural element. We have extended fracture knowledge to analyse fatigue crack growth in such specimen. A typical cantilever is pinned in such a way that it's all degree of motion are arrested on a pinned plane. A load is applied on top plane uniformly. Boundary conditions and loading are defined by the definition of the problem.in the diagram below is shown the typical cantilever specimen with initial crack subject to fatigue loading. 8 noded quad elements have been used for numerical simulation (Chopp et al., 2003).

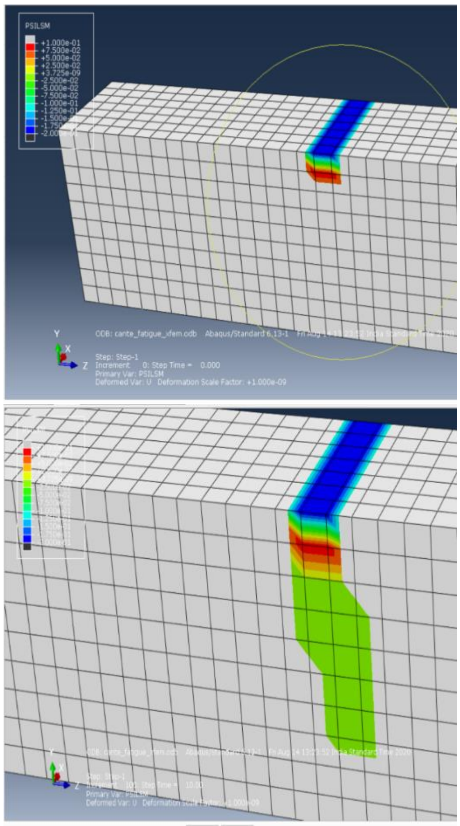

Figure 15. A Cantilever specimen: Misses plot

2.18. A turbine disk

Turbine disk (figure 18) is a major part of a fighter jet engine. It has been shown by experience that the micro cracks were initiated frequently at the slot in bottom in a disk, but the crack growth was slow.in the diagram below is shown the quad element of complete disk for computation. Due to symmetry such approximation has been made. This has reduced the computation cost and time. Since the crack is very minute an extremely fine mesh has been designed to capture the crack growth properly as suggested by literature (Chopp et al., 2003).

2.19. Surface cracking

Surface crack growth is typical phenomenon that has wider range of applicability. Surface cracks are typically formed on the surface of material. Due to sufficient fatigue loading over time. The crack grows in such a way that chunk of material is removed from the surface. This has been called as fatigue wear also.in the example below has been visualized such typical wear phenomenon using numerical simulation. Crack growth is shown in figure 19. XFEM has been used as crack growth numerical tool. And Paris law has been used as damage model. Material chosen is steel (Legrain et al., 2005).

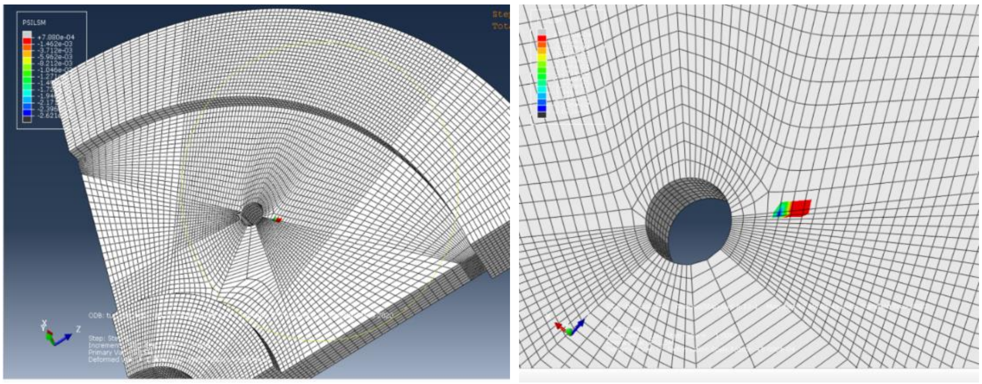

Figure 16. A Turbine disk: Misses stress criterion

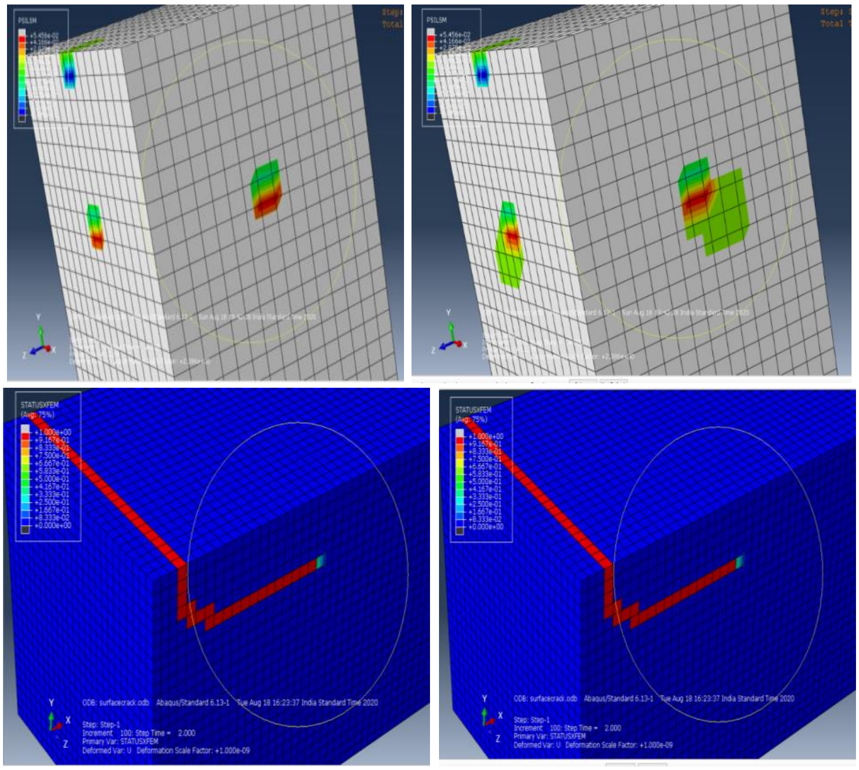

Figure 17. Surface cracks Misses plot

2.20. A 3-D DENT(double edge notch tension) test

In the figure 20 is shown the DENT specimen subject to dynamic cyclic loading. A typical DENT specimen has notches cut from two opposite directions. Dimensions and specific boundary conditions for successful test have been used in numerical simulation software ABAQUS.in the diagram below is shown the complete and symmetrical part of typical DENT specimen. For intelligent computation at low cost a half DENT has been simulated under proper selected boundary conditions. Fatigue crack growth is visualized in 3-d test specimen using XFEM. Also, Paris law has been used for damage. Elements are 8 noded quadrilaterals (Stazi et al., 2003).

2.21. Composite materials

Newly introduced composite materials have been proposed to have improved mechanical properties. Higher tensile strength and lower weight are the attractive properties for design considerations. Also, it has been noticed the crack growth resistance is improved with synthetic alteration of constituent material having characteristic properties.in this section we aim at studying the fracture mechanics design of composites. Few typical examples have been chosen for showing the fracture behavior of composites. Specimens subject to static loading and dynamic loading have been chosen. Crack growth has been done using XFEM as the numerical technique. Paris law is the damage model. Elements have been chosen as per the geometry of the problem with loading and proper boundary conditions for successful results. However, the material property remains almost the same throughout the problems attempted successfully and are given below. Metal matrix composites (MMC) are typically used as structural construction composite and therefore fracture mechanics study become necessary. T/300/977-2 carbon fibre reinforced laminate has been considered for fracture behavior. Such composites are light in weight and improved mechanical properties have find applications in construction, aerospace and other fields (Chopp et al., 2003).

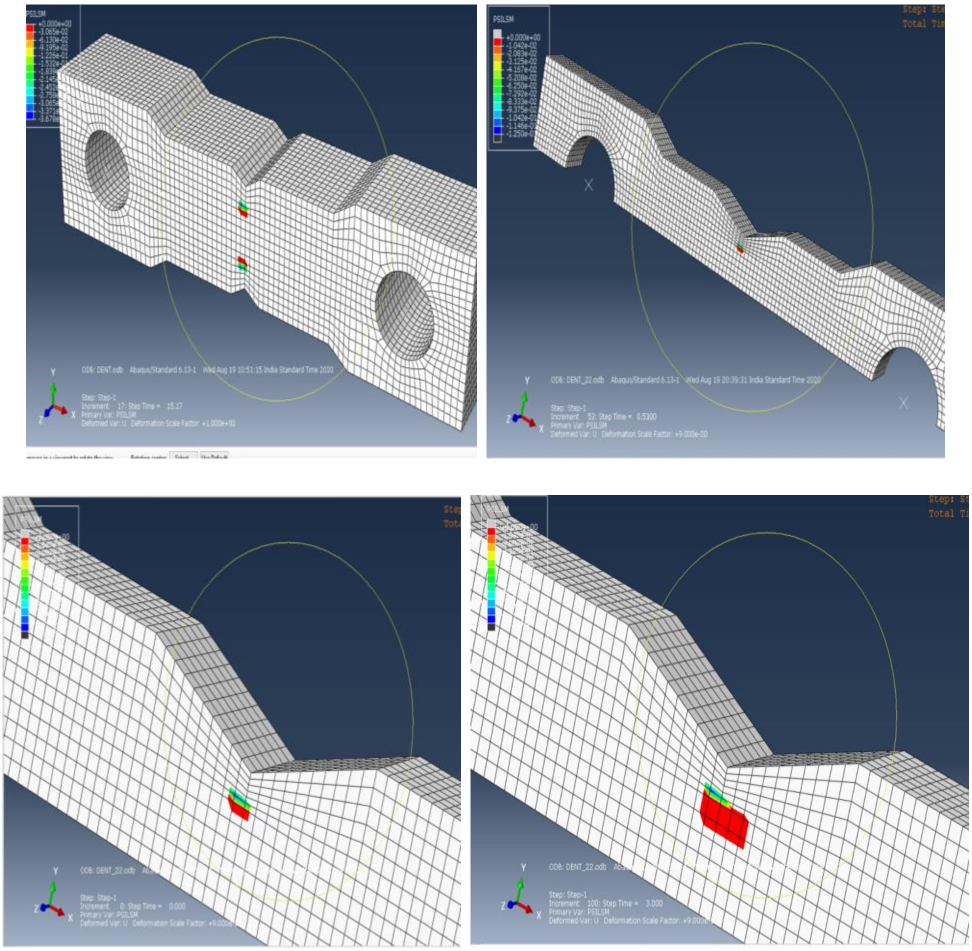

Figure 18. A DENT Specimen test: Misses plot

2.22. Static loading

In this section problems subject to static constant loading have been studied. Such problems have been solved using the constant loading with position and time. A composite specimen with initial crack is analyzed. Crack growth is analyzed using XFEM.

2.23. A plate lamina

In the diagram is shown the typical composite lamina. Misses stress plot has been shown. The data used for crack growth simulation has been provided in preceding section. Boundary conditions and loading conditions are specific to the problem.

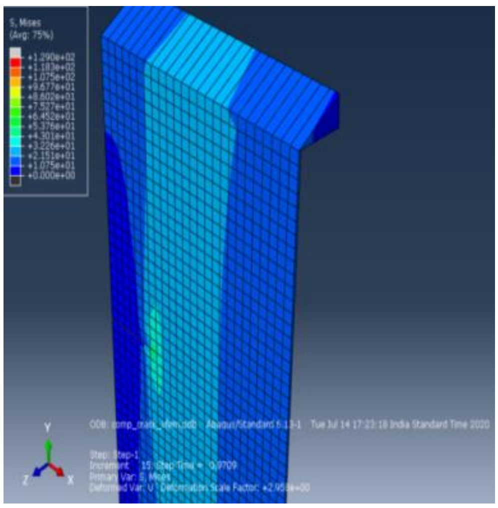

Figure 19. A Composite lamina: Misses plot

2.24. A thin plate

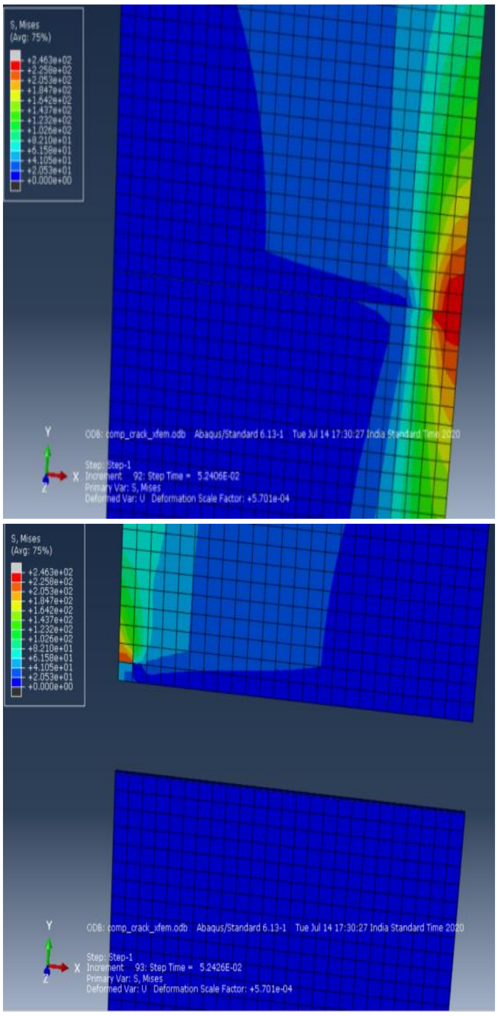

Figure 20. A Composite plate: Misses stress plot

2.25. Dynamic cyclic loading

In this section material composites are subject to fatigue loading and crack growth is observed. Constant amplitude sine loading is applied. Amplitude of loading remains constant and positive always. Paris law have been used as the crack growth law.

2.26. A tensile test specimen

In fracture mechanics tensile testing are used in a sense somewhat different to conventional testing. Tensile tests in solid mechanics are primitive fundamental tests to obtain stress-strain data and find out young's modulus as elastic properties. Also, a wide range of properties are confirmed and extended to theories of failure. Plastic zones, onset of plasticity and strain energy can be obtained. However, in fracture mechanics such tests are usually load or displacement and controlled and therefore selective degree of motion are allowed-a load - displacement plots are obtained. Fracture properties are verified and obtained. A non-destructive testing (NDT) simulation is performed on the specimen. A specimen with initial crack is subject to fatigue loading crack growth is monitored using the simulation software ABAQUS.XFEM has been used as the numerical technique (Stazi et al., 2003).

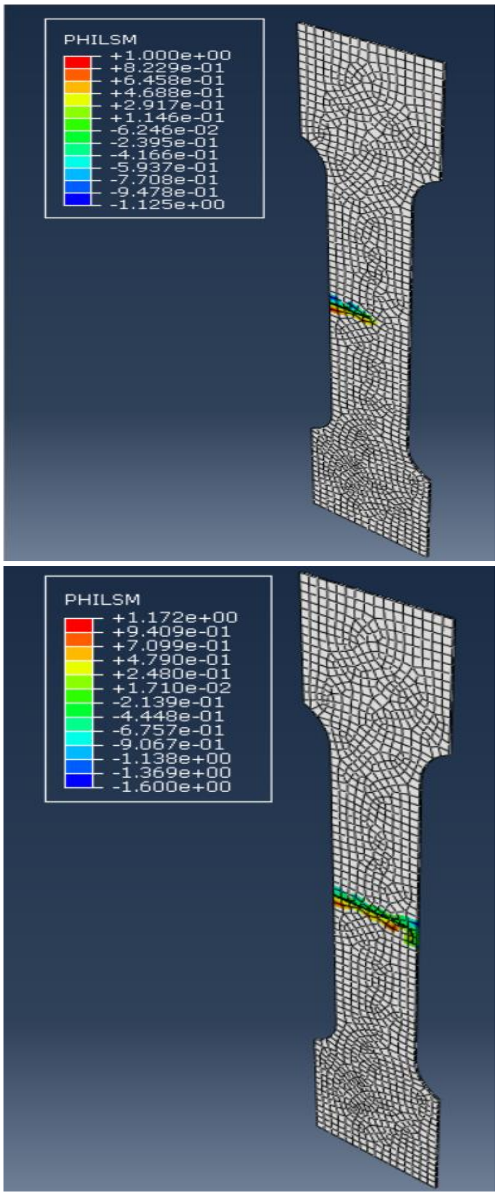

Figure 21. Composite tensile test specimen: Misses stress plot

2.27.4-point bending of composite lamina

In the diagram below is shown the functionally graded composite 3-D lamina. A typical 4-point bend test is performed numerically. 4 point bending tests are classical tests used for analysis of structural members by convention. In such as test a material specimen is held on two load points pinned to surface and two load points are pinned to the top. Vertical direction of motion is allowed for testing. A functionally graded material with three layers of material such that properties vary at different angles for each given layer has been simulated in ABAQUS. A hard rigid contact analysis is done suitably. Misses' plots are shown below

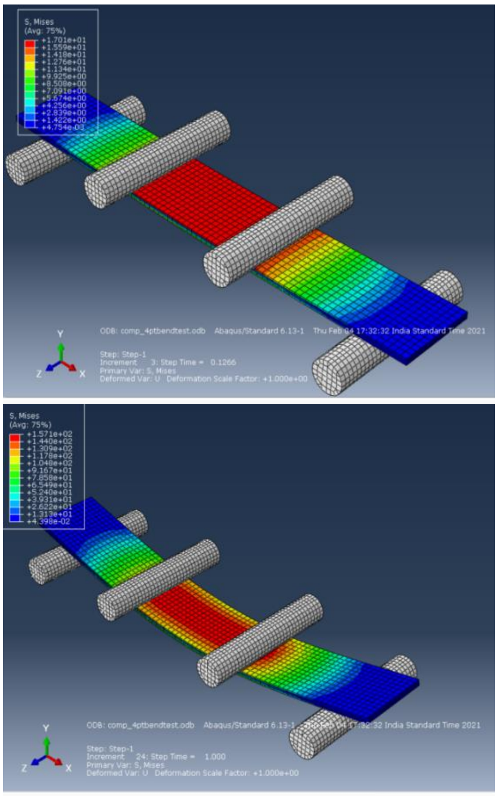

Figure 22. 4-Point bending of 3-D functionally graded composite: Misses plot

3. CONCLUSION

In this work simulation of crack growth has been done using commercial software ABAQUS. XFEM has been used for the numerical technique. Static constant and dynamic cyclic loading have been used to visualise the crack growth numerically. Each problem has been successfully run-in simulation software. Further newly introduced composite material have also been given due attention. Fracture mechanics designs assumes initial crack for life estimation. An initial crack in every problem has been assumed and thereby providing the further numerical evidence in support of fracture mechanics' design. The knowledge can be used for the safety design of equipment, hard to remove with proper maintenance over estimated life period after cracking. Also, problems related to design feature leak before break has been given attention. Such problems arise in high pressure vessel systems. Poisonous fuels leaking from vessels containing such fuels are threat to humanity. Engineering fracture mechanics has been extended to such problems numerically. For each successful solution a depiction of MISSES stress has been plotted.

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