**Chapter 2**

**Literature Review**

* **David Simuneka et. ( 2015 )**

In components and structures, the assessment of fatigue crack propagation on the basis of the fracture mechanical approaches is fundamental to define periodic intervals for service inspections. This paper was focused upon the investigation of flat specimen which was made up of mild steel S355 with V-shaped and semi-elliptical notches under constant and variable amplitude fatigue loading so that we can analyze the effect of the influence of the load sequence on the crack propagation so that we can find the information about the remaining service life of the component. crack propagation may be accelerated, delayed or in some cases even stopped, depending upon the load sequence which is the main cause of the beach marks on the fractured area. Numerical and analytical linear-elastic fracture mechanics (LEFM) calculations based on two- and three-dimensional models were performed for constant and variable amplitude loads. the final comparison of the fractographic analyses and the numerical crack propagation calculations illustrated differences between the results and this provides us information to assess the fatigue crack growth and service inspection intervals of components under variable amplitude loading more precisely

* **Georg Schauera et. ( 2015 )**

This work was studied on the fatigue behavior of ferritic stainless steel 1.4005IA which was used to optimize the electromagnetic properties under varying environmental conditions. Fatigue-life of air-tested specimens were compared to specimens which were bell electro chemically hydrogen pre-charged and loaded in a pressurized gaseous hydrogen atmosphere. The fracture surfaces of broken specimens were investigated by using optical microscope and SEM so that we can analyze analyze the failure mechanisms. Furthermore, the hydrogen content in the specimen specimens before and after the static and cyclic testing in gaseous hydrogen was measured. On the basis of strain controlled fatigue tests using unnotched specimens, the influence of hydrogen gas on the cyclic material parameters was determined. Using those parameters, a fatigue-life estimation for notched specimens on the basis of the local strain approach has been carried out. The proposed approach concluded that the modified material model was in a good agreement with the experimental data. This opens up a pathway for a reliable component design process for the purpose of industrial applications. Different estimation approaches ware evaluated, by comparing the experimental data and hence we predicted the fatigue-lifes.

* **Amélie Malpota et. ( 2015 )**

This study is focused on the tensile-tensile fatigue behaviour of a woven glass-fibre-reinforced composite with polyamide 6,6 resin. As a preliminary step, mechanical properties of the material have been determined through static tensile test. Two layups have been studied, referred as [(0/90)3] and [(±45)3] in order to study the influence of fibre orientation in the material. An optimisation step has been necessary to revise the coupon geometry for fatigue tests. Dogbone specimens have been developed in that purpose, leading to the coupon failure in the gauge section. The S-N curves of both layups have been established at a stress ratio (R) of 0.1. These curves have been used as the basis for the identification of three fatigue life models: a model based on constant life diagrams, a hybrid model and a two-material-parameter model. S-N curve for the [(±45)3] composite has been used to validate the latter. Fatigue tests were multi-instrumented using infrared camera and acoustic emission monitoring to determine the maximum temperature and the cumulated number of events. Together with the secant modulus evolution, these three parameters are good indicators of the damage level in the composite. Finally, post-mortem SEM observations have been carried out in order to identify damage mechanisms which take place into the composite during fatigue tests.

* **Sohei Kannaa et. ( 2015 )**

In this study, fatigue tests and life prediction method for welded structures are proposed. Specimens were extracted from welded structures including embedded flaws detected by ultrasonic testing. The loading conditions of the fatigue tests were set to be identified as the operating conditions of the structures considering the crack closure effect due to welding residual stress distribution measured by strain gauges. The predicted results are well consisted with the experimental results within the factor of two scatter bands. Hence the fatigue life of the welded structures can be predicted within ±50 % accuracy in life. This study presents the methodology to estimate a remaining life of the structures to fatigue crack initiation by fatigue tests with specimens extracted from the structures. Operating conditions of the welded structures were investigated through the key-parameter of stress intensity factors for the weld flaws. On the other hand, the fatigue testing conditions were determined as the stress intensity factors of the fatigue specimens were consistent with those of welded structures. Testing conditions for the specimens extracted from the welded structures were assessed with the stress intensity factors as the key parameter. According to the defect sizes of the specimens, the testing conditions were determined so that stress intensity factors of the specimens were consistent with *K*max and *K*min

* **Thomas Svenssona et. ( 2015 )**

Fatigue bending tests have been performed on welded pipes made from an austenitic stainless steel. Four types of loading were used: 1) constant amplitude, 2) a load expected at pressure vessel environment, 3) a Gaussian load, and 4) a specially constructed two-level block load. The twenty-eight test results are evaluated using three different models: 1) the classical Basquin equation neglecting the fatigue limit, 2) the ASME model with a fatigue limit, and 3) a model with continuously decreasing fatigue limit. No significant differences between the three models were found. Predictions based on constant amplitude results appear to be non conservative. Fatigue experiments on austenitic stainless steel are typically performed on small, smooth test specimens in air, whereas little experimental data is available for austenitic stainless steel components. The limited amount of component data available is almost exclusively dealing with constant amplitude testing for low-cycle fatigue (LCF). Extremely little experimental studies were performed on austenitic stainless steel components in the high-cycle fatigue (HCF) regime with variable amplitude loading. Such testing conditions correspond to more realistic loading scenarios of real-life components. Austenitic stainless steels are challenging materials due to the non-linear material behaviour even for small amplitudes in a spectrum. At variable amplitude loading the material behaviour is history dependent. Austenitic stainless steels are also subject to secondary cyclic hardening. These complex features make it very difficult to find proper equivalence relations from simple specimens to components and it can be more efficient to find empirical strength properties by performing tests on component level

* **G. Pettersson et. (2012)**

In this paper a finite element model is developed and verified for weld fatigue evaluation. The investigated component is a welded A-stay beam structure in an Articulated Hauler. The investigation includes load data acquisition, strain measurements and full-scale fatigue test under spectrum loading. The FE model considers the non-linear geometrical effects and boundary conditions by including the adjacent screw connection and in some surfaces meshed with contact elements. The fatigue failures observed were in the weld root. An investigation of weld quality showed relatively large lack of penetration in the weld root. Different fatigue design concepts; nominal stress, structural hot spot stress, effective notch stress and linear elastic fracture mechanics are compared regarding work effort and analysis and life prediction accuracy. The comparison between the different fatigue design codes and concepts shows a large scatter in estimated fatigue life for the welded component. A common goal for manufacturers of welded structures, particularly for transportation vehicles, is to minimise weight in order to decrease fuel consumption and at the same time to prevent fatigue failure. The weight reduction is mainly accomplished by introducing thinner plates in combination with higher strength steels in welded components. However, welding without any post treatment gives rise to local stress concentration, residual stresses and different types of defects which in conjunction with complex service loading give rise to failure due to fatigue. Since weight reduction often leads to an increased stress level, this must be accompanied with a higher or improved weld quality in order to avoid fatigue failures. This will support the use of efficient and more accurate fatigue design methods which must be connected to quality requirements which can be understood and managed during design and production.

* **Zhenhua Wu et. (2014)**

Computation of the stress intensity factors (SIFs) at the crack tip is the basis for pavement crack propagation analysis. Due to the three-dimensional (3-D) nature of cracked pavements and traffic loading, twodimensional (2-D) finite element analysis (FEA) may be too simple to precisely predict SIFs, and the best choice for calculating the SIFs seems to be 3-D FEA programs. However, the 3-D FEA solutions are often

computationally heavy. We had previously developed a semi-analytical FEA with multi-variable regression approach to fill this gap, but its accuracy still needs to be improved. To address this problem, a neural network approach based on semi-analytical FEA is presented in this paper: firstly, a SIFs database was generated through analyzing varieties of pavement structures using elastic semi-analytical FEA program; secondly, from the results in the database, neural network (NN) based SIF equations were developed for practical applications. The determination coefficients (R2) of all the developed NN models were greater than 0.99 and mean square error (MSE) values were less than 1e\_4. The comparisons between the prediction results from NN models and multivariable regression models also showed the advantage of NN over multivariable regression on the prediction accuracy. This proposed NN SA-FEA SIF prediction approach has been developed as a pavement crack propagation analysis tool.

* **G. Ricciardi et. (2009)**

The aim of this study is to develop a tractable model of a nuclear reactor core taking the complexity of the structure (including its nonlinear behaviour) and fluid flow coupling into account. The mechanical behaviour modelling includes the dynamics of both the fuel assemblies and the fluid. Each rod bundle is modelled in the form of a deformable porous medium; then, the velocity field of the fluid and the displacement field of the structure are defined over the whole domain. The fluid and the structure are first modelled separately, before being linked together. The equations of motion for the structure are obtained using a Lagrangian approach and, to be able to link up the fluid and the structure, the equations of motion for the fluid are obtained using an arbitrary Lagragian Eulerian approach. The finite element method is applied to spatially discretize the equations. Simulations are performed to analyse the effects of the characteristics of the fluid and of the structure. Finally, the model is validated with a test involving two fuel assemblies, showing good agreement with the experimental data

* **Elisabeth Keim et. (2001)**

The integrity of the reactor pressure vessel must be maintained throughout the plant life and this helps us in extension of the plant life. Effective and radical approaches help us in good working condition and safe environment of the nuclear power plant and also it helps us in taking preventive and effective measures if necessary. A substantial study of this research paper helped us in analysing the thermal shock in a pressure vessel. This research paper deals with the various feild of the reactor pressure vessel for an instance thermal analysis, structural analysis and fracture analysis. For determining the spatial fluid temperature and wall-fluid heat transfer fluid transfer distribution in the new comer fluid-fluid mixing scenario is taken into account.

* **Robert Lang et. (2016)**

This paper presents two advanced methods for modelling the fatigue lifetime of welded components with an irregular distributed geometry and compares the results achieved. The first approach, applies a deterministic method in order to analyse implicit gradient models, whereas the second one examines a Weibull-based model using a stochastic method. Both models can be combined in order to encompass the stress gradient and the statistical size effect. In order to determine the parameters for both models, an examination of specimens from five different test series with different macro-geometries and from different test laboratories is performed. After measuring the geometry of the welded components using a laser scanning system with high accuracy and resolution, the linear-elastic notch stresses on the real geometries of each specimen are calculated using FEM. Effective stresses are calculated with different parameters using the implicit gradient model. These notch stresses and effective stresses are used as input parameters for a Weibull-based method to model the crack initiation phase. This initiation phase includes cracks with a length of 3–5 mm. Both methods can be applied on a standalone basis or in combination. However, it has been observed that either combining the two methods or using exclusively the implicit gradient model other than the Weibull model leads to no better results.

* **C. Fischer et. (2016)**

While a long stable crack propagation phase was observed during experiments of complex welded components, very conservative estimations of the fatigue life were achieved in the past. The difference was explained by the stress gradient occurring over the plate thickness. This paper deals with numerical crack propagation simulations which were performed for geometrically different variants. The variants differ in global geometry, boundary conditions and weld shape. The analyses aim to investigate how the crack propagation is altered if the structural configuration gets more complex. In conclusion, the stress gradient over the plate thickness, the effective plate thickness due to vertical web plates and high notch effects slow down the crack propagation rate if the same stress value being effective for fatigue appears at the weld toe. Thereby, the load-carrying grade of the weld, the weld flank angle and the geometrical configuration also have an impact on both the notch effect and the local stress concentration. This paper summarizes numerical and analytical crack propagation analyses performed in order to investigate the influence of stress gradients and complex geometry on crack propagation, crack shape and fatigue life.

* **S. Taheri et.(2016)**

The piping in some residual heat removal (RHR) systems in nuclear power plants, made of 304L stainless steel, is subjected to a multiaxial cyclic stress state in the cold/hot water mixing zone due to thermal fluctuations. In addition, residual stresses produced by welds and/or surface treatments can be large in magnitude and be tensile or compressive, depending on the proximity to the weld location. Crack networks have been observed to nucleate and grow under these stress states. Prominent cracks originating from micro-cracks on the order of grain size continue to grow to a length of about 2.5 mm. The thermal fluctuation is such that crack growth is in the high cycle fatigue regime. In this paper, the plane orientation and growth direction of these cracks with respect to the cyclic and mean stress states and their gradients are analyzed. The roles and interactions of shear, tensile, and compressive stresses with regards to the direction and orientation of the cracks are also discussed. Weld residual stresses (WRS) are decomposed into a local effect in tension near the weld and a structure effect in compression farther away, which also help explain some crack configurations in RHR systems. Moreover, a dependence of WRS field on spatial second derivative of weld temperature field is shown, which can have an important impact for comparison of measured and simulated WRS. Crack growth was also simulated with XFEM in the presence of WRS, with the principal hypothesis that mean stress acts only on crack opening.

* **Punit arora et. (2013)**

The objective of the present study is to understand the fatigue crack growth behaviour for austenitic stainless steel and carbon steel pipes, the study involves fatigue test of components and specimens. The Paris law has been used to determine the crack growth and determine the fatigue life for pipe (base), pipe weld and pipe. Paris law has also been applied on the three point bend (TPB) specimens machined from the actual pipe. fatigue crack growth life of these piping components having part through cracks on the outer surface. With the help of paris law stress Intensity Factor (*K*) has been evaluated through two different methods two points of the crack front i.e. maximum crack dep for the area averaged root mean square stress intense analytical procedure/results, experiments have been performed to determine the fatigue life of the circumferential crack. The tests have also been done on the depth of the pipe and pipe elbow component circumferential notch at intraction dos location and axial notch sensitivity has been evaluated using both schemes. Experiment has been used to compared using second scheme which gives better fatigue crack growth

* **J. Van Wittenberghe et. (2011)**

In the oil and gas industry threaded pipe couplings are commonly used to connect pipelines, risers, drill pipes, casings etc. When subjected to dynamic loads, the threads of the connection act like stress raisers that can initiate fatigue cracks. To increase the fatigue life, connection designs are continuously improved [1,2]. However, one of the main problems remains the online detection and monitoring of fatigue cracks even in laboratory conditions. Cracks tend to initiate in the contact interface at the thread roots away from the outer surface of the pipes. This makes it hard to have a clear distinction between crack initiation and propagation [3]. The most common techniques for crack sizing in threaded fasteners are alternating current field measurements (ACFM) [4] and magnetic flux leakage (MFL) [5]. Both techniques require the connection to be disassembled for the measurement, which makes continuous online monitoring impossible. When ultrasonic inspection is used for crack measurements in threaded connections, they can remain coupled. However, with conventional ultrasonic testing methods it is difficult to distinguish flaws from the signals reflected by the different threads. Therefore, advanced signal processing is necessary to make ultrasonic testing applicable for online monitoring of fatigue crack growth [6]. In this study the crack growth in a threaded pipe assembly is monitored through an optical dynamic 3D deflection measurement of the pipe. Using a beach marking technique the exact crack shape at three different reference times could be determined. These crack shapes were then introduced in a finite element model and the pipe deflection and crack opening simulations are compared with the measured observations.

* **R.A. Ainsworth et. (2016)**

This paper reports fracture assessments of large-scale straight pipes and elbows of various pipe diameters and crack sizes. The assessments estimate the load for ductile fracture initiation using the failure assessment diagram method. Recent solutions in the literature for stress intensity factor and limit load provide the analysis inputs. An assessment of constraint effects is also performed using recent solutions for elastic T-stress. It is found that predictions of initiation load are close to the experimental values for straight pipes under pure bending. For elbows, there is generally increased conservatism in the sense that the experimental loads are greater than those predicted. The effects of constraint are found not to be a major contributor to the initiation fracture assessments but may have some influence on the ductile crack extension. In a wide range of industries, the structural integrity assessmen of piping components containing defects is required to demonstrate safe and reliable operation. For example, leak-before-break (LBB) assessments of primary piping systems of some nuclear power plant assume the presence of cracks and demonstrate that such cracks lead to detectable leakage before pipe burst.

* **Tatsuo Sakai et. (2016)**

In S–N diagrams for high strength steels, experimental data in the usual surface fracture mode appears at higher stress levels with fewer loading cycles, whereas the data in the interior fracture mode tends to appear at lower stress levels with the very long fatigue life. Thus, the duplex S–N property was usually confirmed for those high strength steels in such a very high cycle regime. In the case of interior fracture mode, there can be several different types of the crack initiation with/without non-metallic inclusion at the crack initiation site, and different crack initiation types can be found even for the surface fracture modes in the conventional fatigue life region. In the present work, the authors have attempted to review the overall feature of these fatigue fracture modes appearing at the usual life regime and the very high cycle regime.

* **P. Nagapadmaja et. (2008)**

Piping elbows are one of the critical components of the cooling piping systems in power plants. This paper presents the details of fatigue crack propagation analysis based on code procedure and FEM and compares the results with experimental observations. The fatigue crack propagation was evaluated based on the inelastic range J integral, Js, which was obtained by applying the plastic correction factor (from RCC-MR code) to the elastic J-integral values obtained from the code as well as from the elastic finite element analysis. The fatigue crack propagation was also studied directly using the elastic–plastic J-integral value obtained from the finite element analysis. It was observed that the fatigue life calculated based on the modified Js-integral values was closer on the conservative side to the experimental results, than that from J-integral obtained directly from elastic–plastic finite element analysis. Piping elbows are one of the critical components of the cooling piping systems in power plants. Elastic–plastic fracture analysis of piping is increasingly important in life and structural integrity assessments. Significant efforts in developing fracture mechanics methodology have been made during the last three decades, together with validation against finite element results and experimental pipe test data

* **Y. Zhang et. (2016)**

With the development of nuclear power and nuclear power safety, high-cycle thermal fatigue of the pipe structures induced by the flow and heat transfer of the fluid in pipes have aroused more and more attentions. Turbulent mixing of hot and cold flows in a T-pipe is a well-recognized source of thermal fatigue in piping system, and thermal fatigue is a significant long-term degradation mechanism. It is not an easy work to evaluate thermal fatigue of a T-pipe under turbulent flow mixing because of the thermal loads acting at fluid–structure interface of the pipe are so complex and changeful. In this paper, a one-way Computational Fluid Dynamics-Finite Element Method (CFD-FEM method) coupling based on the ANSYS Workbench 15.0 software has been developed to calculate transient thermal stresses with the temperature fields of turbulent flow mixing, and thermal fatigue assessment has been carried out with this obtained fluctuating thermal stresses by programming in the software platform of Matlab based on the rainflow counting method. In the thermal analysis, the normalized mean temperatures and the normalized root mean square (RMS) temperatures are obtained and compared with the experiment of the test case from the Vattenfall benchmark facility to verify the accuracy of the CFD calculation and to determine the position which thermal fatigue is most likely to occur in the T-junction. Besides, more insights have been obtained in the coupled CFD-FEM analysis and the thermal fatigue damage assessment, and the normalized thermal fatigue damage rate D⁄ s is found to be positively related to the normalized RMS temperature TRMS/DT to some extent. The method proposed in this paper is the inheritance and development of the research studying thermal fatigue of the T-junction under turbulent fluid mixing of hot and cold fluid by analysing the temperature fluctuations, and may provide a promising way for the quantitative assessment of high-cycle thermal fatigue of the pipe structure induced by complex flow and heat transfer in practical engineering of the nuclear power plants (NPPs).

* **Ramesh Kumara et. ( 2014 )**

Thermal stratification is a phenomenon where a hot layer of fluid flows over a cold layer of fluid due to density difference. Thermal stratification is dominant in NPP piping where hot and cold fluids coexist or separated by a leaking valve. This phenomenon produces stresses in axial and tangential direction which causes damage during thermal cycling induced due to thermal stratification. These stresses produce additional damage during fatigue which is not incorporated in earlier plant piping design. This paper comprises a detail study of thermal stresses induced due to thermal stratification and its impact on fatigue life of piping. In this study the variation in support conditions are also analyzed along with their effect on the stress distribution of the pipe. The categorization of axial stress distribution is carried out with finite element model for a thermally stratified pipe. An analytical model for calculation of different thermal stress considering intermixing layer between hot and cold layer is formulated during a thermal stratification condition. The formulation is also validated with the results available in literature on thermal stratification. A case study for damage evaluation due to thermal stratification was carried out for a thermally stratified typical NPP surge line.

* **H.Y. Subramanya et.(2007)**

In this paper, a finite element study of 3D crack tip fields in pressure sensitive plastic solids (such as polymers or metallic glasses) under mode I, small scale yielding conditions is performed. The material is assumed to obey a small strain, Extended Drucker–Prager yield condition. The roles of pressure sensitive yielding, plastic dilatancy and yield locus shape on the 3D plastic zone development and near-crack front fields are systematically studied. It is found that while pressure sensitivity leads to a significant drop in the hydrostatic stress all along the 3D crack front, it enhances the plastic strain and crack opening displacements. The implications of these contrasting trends on ductile fracture processes are discussed in the light of some recent micro-mechanical simulations.

* **H.E. Coules et. (2015)**

Residual and thermal stress fields in engineering components can act on cracks and structural flaws, promoting or inhibiting fracture. However, these stresses are limited in magnitude by the ability of materials to sustain them elastically. As a consequence, the stress intensity factor which can be applied to a given defect by a self equilibrating stress field is also limited. We propose a simple weight function method for determining the maximum stress intensity factor which can occur for a given crack or defect in a one-dimensional self-equilibrating stress field, i.e. an upper bound for the residual stress contribution to KI. This can be used for analysing structures containing defects and subject to residual stress without any information about the actual stress field which exists in the structure being analysed. A number of examples are given, including long radial cracks and fully-circumferential cracks in thick walled hollow cylinders containing self-equilibrating stresses. Residual stresses strongly influence elastic fracture, but can be difficult and time-consuming to measure. Furthermore, accurate prediction of the residual stresses which result from manufacturing operations is challenging and usually involves the use of elastic eplastic finite element modelling

* **M.K. Sahu et. (2015)**

Total three straight pipes have been studied which are used in the Primary Heat Transport system of Indian PHWRs (Pressurized Heavy Water Reactor). The pipes have been fabricated with either circumferential throughwall crack or surface crack. Fracture tests have been performed on these pipes subjected to constant internal pressure and monotonically increasing four point bending load. Different experimental and finite element results like load vs. load line displacement, load vs. CMOD (Crack Mouth Opening Displacement), crack initiation loads are compared and found in good agreement. The experimental results have been used for calculation of fracture toughness i.e J-R curves for all three pipes. The differences in these J-R curves have been investigated in the light of prevalent crack tip constraints. Higher J-R curve of surface cracked pipe is attributed to prevalent lower crack tip constraint and vice versa is true for throughwall cracked pipes. In this program, only four point bending moment were applied during test to keep the experiment simpler. However, in actual service condition, the pipes are subjected to combined loading of internal pressure and bending moment. To address this combined effect for better simulation of service condition, another comprehensive test program, Advanced Component Integrity Test program was initiated by BARC in 2004. As a part of this test program, three numbers of pressurized pipes were tested under bending moment. Two pipes having nominal diameter of 8-inch sizes with throughwall cracks and one pipe having nominal diameter of 16-inch size with surface crack, have been studied in this paper.

* **Punit Arora et. (2011)**

The objective of the present study is to understand the fatigue crack growth behavior in austenitic stainless steel pipes and pipe welds by carrying out analysis/predictions and experiments. The Paris law has been used for the prediction of fatigue crack growth life. To carry out the analysis, Paris constants have been determined for pipe (base) and pipe weld materials by using CompactTension (CT) specimens machined from the actual pipe/pipe weld. Analyses have been carried out to predict the fatigue crack growth life of the austenitic stainless steel pipes/pipes welds having part through cracks on the outer surface. In the analyses, Stress Intensity Factors (K) have been evaluated through two different schemes. The first scheme considers the ‘K’ evaluations at two points of the crack front i.e. maximum crack depth and crack tip at the outer surface. The second scheme accounts for the area averaged root mean square

stress intensity factor (KRMS) at deepest and surface points. Crack growth and the crack shape with loading cycles have been evaluated. In order to validate the analytical procedure/results, experiments have been carried out on full scale pipe and pipe welds with part through circumferential crack. Fatigue crack growth life evaluated using both schemes have been compared with experimental results. Use of

stress intensity factor (KRMS) evaluated using second scheme gives better fatigue crack growth life prediction compared to that of first scheme. Fatigue crack growth in pipe weld (Gas Tungsten Arc Welding) can be predicted well using Paris constants of base material but prediction is non-conservative for pipe weld (Shielded Metal Arc Welding). Further, predictions using fatigue crack growth rate curve of ASME produces conservative results for pipe and GTAW pipe welds and comparable result for SMAW pipe welds.

* **P.K. Singha et. (2003)**

Studies have been carried out on carbon steel pipes to demonstrate the leak before break design criterion and validate the analytical procedures. Fatigue crack initiation, fatigue crack growth rate and fracture resistance behaviour of the pipes have been experimentally and analytically evaluated. The tests have been carried out on pipes of outer diameter 219 and 15.1 mm wall thickness having a part through notch in the circumferential direction. The aspect ratios ð2c=aÞ of the notches were 56, 28 and 18. Comparing the analytical and experimental results has validated analytical procedures. It has been observed that the analytical and experimental results compare well. The fatigue crack growth curve ðda=dN , DKÞ obtained from three point bend specimens and pipe tests have been compared with the fatigue crack growth curve in

ASME Section XI. The comparison shows that use of the ASME curve in analysis of components will give a conservative result in comparison to the curves obtained from the actual pipe tests. Fracture resistance behaviour of the pipe has been observed to be strongly dependent on the load histories to which the pipe has been subjected.

* **Subhasish Mohanty et. (2016)**

This paper discusses a material hardening models for welds made from 316 stainless steel (SS) to 316 SS. The model parameters were estimated from the strain-versus-stress curves obtained from tensile and fatigue tests conducted under different conditions (air at room temperature, air at 300 \_C, and primary loop water conditions for a pressurized water reactor). These data were used to check the fatigue cycle dependency of the material hardening parameters (yield stress, parameters related Chaboche-based linear and nonlinear kinematic hardening models, etc.). The details of the experimental results, material hardening models, and associated calculated results are published in an Argonne report (ANL/LWRS-15/2). This paper summarizes the reported material parameters for 316 SS–316 SS welds and their dependency on fatigue cycles and other test conditions.

* **Koen Van Minnebruggen et. (2015)**

Spiral welded pipes have gained interest for application in strain-based design related projects. However, there is a lack of fundamental knowledge about their performance in terms of tensile strain capacity. By means of parametric finite element analyses, the influence of pipe forming angle, weld strength overmatch and material strength anisotropy on the tensile strain capacity was investigated for (un-)pressurized pipe sections and wide plates. It is concluded that larger forming angles, when compared to lower angles, result in significant higher strain capacity and less sensitivity to anisotropy. Neglecting anisotropy in finite element analysis may overestimate strain capacity Spiral welded pipes gain interest for the transportation of hydrocarbons in strain-based design related projects due to economic benefits in comparison with traditionally used UOE pipes . Recent developments in steel coil production facilities have enabled the possibility to manufacture spiral welded pipes with sufficient wall thickness and of adequate steel grade quality (strength and toughness properties). Based on the work of several research groups it can be concluded that in comparison to UOE-pipes, spiral pipes can perform equal or better when considering the following elements: cold field bending, buckling resistance, fracture arrest, ductile tearing, plastic collapse, bending and burst fracture tests. However, the evaluation of spiral pipe performance and its applicability in a tensile strain-based design context has received little attention.

* **S. Liu et. (2015)**

Creep crack-tip constraints for inner circumferential surface cracks in pressurized pipes have been analyzed by three-dimensional finite element method and the constraint parameter R⁄ solutions have been obtained for different pipe geometries and crack sizes. It has been shown that the constraint level of circumferential cracks is lower than that of axial cracks, and the constraint effects need to be considered in creep life assessments of pressurized pipes. The benefits from incorporating constraint effects are greater for the circumferential cracks than for the axial cracks and for the shallower and shorter cracks than for the deeper and longer cracks. It has been well known that crack-tip constraint state has significant influence on fracture behavior of materials, and the loss of constraint causes the increases in fracture toughness. To improve accuracy in structural integrity assessments, the crack-tip constraint effect requires to be incorporated by suitable constraint parameter. The quantification of constraint has been widely investigated within the elastic–plastic fracture mechanics frame

* **Fei Yan et. (2016)** Welded details in cable-stayed orthotropic steel deck bridges are prone to fatigue damage and thus it is vital to fully understand their fatigue performance and effectively predict their fatigue life. In this study, fatigue life of welded joints is predicted based upon Miner’s damage rule and the histogram of stress range frequency with consideration of traffic data. Stress level and the influence surface at welded joints of interest are computed using a mixed-dimensional finite element method. To accurately evaluate the traffic effect on fatigue performance, Monte Carlo simulation is used to generate the vehicle-induced stress history at critical welded joints, in such a way to develop the stress range frequency histogram. The rain-flow counting algorithm is utilized to determine the stress cycles while fatigue damage is computed by formula of Miner’s rule. The proposed procedures for fatigue life prediction are implemented in a case study of a cable-stayed orthotropic steel deck bridge. Cable-stayed bridges have been gaining extensive attention due to their enhanced stiffness over suspension bridges. A typical orthotropic steel bridge deck consists of a great number of welded joints.
* **Subhasish Mohanty et. (2016)**

In this paper, we present thermal–mechanical stress analysis of a pressurized water reactor pressure vessel and its hot-leg and cold-leg nozzles. Results are presented from thermal and thermal–mechanical stress analysis under reactor heat-up, cool-down, and grid load-following conditions. Analysis results are given with and without the presence of preexisting crack in the reactor nozzle (axial crack in hot leg nozzle). From the model results it is found that the stress–strain states are significantly higher in case of presence of crack than without crack. The stress–strain state under grid load following condition are more realistic compared to the stress–strain state estimated assuming simplified transients

* **S. Mikheevskiya et. ( 2015 )**

It was shown that estimation of fatigue lives of welded joints can be successfully carried out by considering the fatigue process as a fatigue crack growth from the initial intrinsic crack size of a0=􀈡\* until the final crack af. Such an approach avoids a somewhat arbitrary division of the fatigue process into the crack initiation and propagation and concentrates on using only one methodology - the fracture mechanics theory. The stress intensity factors can be determined in such cases by the weight function method. The proposed methodology allows estimation of the fatigue life under both constant and variable amplitude loading.

* **Subhasish Mohanty et. (2015)**

This paper discusses a system-level finite element model of a two-loop pressurized water reactor(PWR). Based on this model, system-level heat transfer analysis and subsequent sequentially coupledthermal–mechanical stress analysis were performed for typical thermal–mechanical fatigue cycles. Thein-air fatigue lives of example components, such as the hot and cold legs, were estimated on the basisof stress analysis results, ASME in-air fatigue life estimation criteria, and fatigue design curves. Further-more, environmental correction factors and associated PWR environment fatigue lives for the hot andcold legs were estimated by using estimated stress and strain histories and the approach described inUS-NRC report: NUREG-6909.

* **P. Weisgraeber et. (2013)**

Up to now the failure load assessment of bonded joints is still not fully understood. This work provides a new approach for assessing the crack initiation load of bonded joints. A failure model for single lap joints is proposed that is based on Finite Fracture Mechanics. Only two basic fracture parameters are required: the tensile strength and the fracture toughness of the adhesive. A coupled stress and energy criterion proposed

in 2002 by Leguillon is used to model crack initiation in the adhesive layer. The theory of this criterion is outlined in detail, its relationship to other failure criteria is discussed and an overview of applications found in literature is given. An enhanced weak interface model that predicts a linear variation of the shear stresses in the adhesive layer is utilized to model the single lap joint. To compare joint designs and to reveal the limitations of the given approach a dimensionless brittleness number for mixed-mode loading is proposed. Along with a detailed discussion of the results for exemplary joint designs a comparison to experimental results from literature is performed. The two necessary fracture parameters are each taken from standard test results published in literature. A good agreement of the failure load predictions with the experimental results is observed. A remarkable outcome is that the presented failure model renders the adhesive thickness effect correctly. The paper concludes with a discussion of the limitations of the approach and the effect of material parameters

* **Gabriel Marsh et. (2016)**

Most fatigue loaded structural components are subjected to variable amplitude loads which must be processed into a form that is compatible with design life calculations. Rainflow counting allows individual stress cycles to be identified where they form a closed stress–strain hysteresis loop within a random signal, but inevitably leaves a residue of open data points which must be post-processed. Comparison is made between conventional methods of processing the residue data points, which may be non-conservative, and a more versatile method, presented by Amzallag et al. (1994), which allows transition cycles to be processed accurately. This paper presents an analytical proof of the method presented by Amzallag et al.

* **Yukitaka Murakamia et. ( 2014 )**

Fatigue failure of high strength steels mostly originates at nonmetallic inclusions. An optically dark area (ODA) beside the inclusion can be observed in specimens fractured at very high cycle fatigue (VHCF) regime. The present paper proposes fatigue life prediction models from low to VHCF regime. *The hypothetical cycle-by-cycle fatigue crack growth model* inside ODA has been developed in the VHCF regime based on *the master curve of ODA* where fatigue failure is caused by cyclic loading assisted by hydrogen trapped by inclusion. The fatigue crack growth law is proposed for a small crack outside ODA within the framework of the parameter model where the concept of *“continuously variable fatigue limit”* for small crack is introduced. The life and scatter of fatigue life originated at inclusions can be well evaluated by the proposed models.

* **Krasovskyy et. (2011)**

This paper presents a fatigue assessment for multi-pass welds based on the simulation of a welding process, a postweld heat treatment (PWHT) and a cyclic fatigue loading. The commercial software Virtual Weld Shop is used for the modelling of a welding process and PWHT. Welding induced residual stresses and the information about the

material state can then be used in the fatigue analysis of the entire engine structure by the submodeling technique in ANSYS. Based on this calculation procedure a more accurate prediction of the component lifetime is possible. In order to validate the proposed approach an experimental setup with multi-pass single bevel butt weld is investigated. Temperature evolution during welding and X-ray measured residual stresses were compared with the results of simulation as well as failure behavior after cyclic loading. The fatigue analysis, including the welding induced residual stresses based on the Findley criterion with critical plane approach, was able to predict the different crack initiation for specimens with and without PWHT.

* **E. Langa et. ( 2013 )**

This contribution deals with the low cycle fatigue behaviour of butt-welded joints of austenitic stainless steel (Type 347). Theninfluence of the geometrical notch of a butt weld on the fatigue life in LCF regime is of particular interest in this context. For the

purpose of comparison different weld geometries – as-welded and machined – are investigated. Fatigue tests reveal that the weld notch does not always constitute the failure location in the LCF regime. Accompanying numerical simulations are based on 3D scans with a resolution of 30 􀁐m in order to receive accurate local strain amplitudes at the weld notch or rather the failure location. The combination of experiments and numerical simulations results in local strain life curves.

* **Ludvík Kunza et. ( 2014 )** Initiation of fatigue cracks in materials with conventional grain (CG) size was investigated very thoroughly in the past. There is an extensive knowledge on the localization of cyclic plasticity and early crack development; however, it cannot be straightforwardly applied to the ultrafine-grained (UFG) structures with the grain size below 1 􀈝m, because the crack initiation mechanisms are related to dislocation structures, which cannot develop in UFG materials simply from the size reasons. The paper brings results of an experimental investigation of the cyclic strain localization and crack initiation by means of focused ion beam technique (FIB). Two substantially different materials as regards the crystallographic structure, namely UFG Cu and magnesium alloy AZ91 processed by equal channel angular pressing (ECAP) were investigated and the observed characteristic features of crack initiation were discussed. The observations bring evidence that in the high-cycle fatigue (HCF) region point defects generated by dislocation activity do play very important role in the fatigue crack initiation process in UFG Cu. Fatigue cracks initiate in slip bands which form in areas of near-by oriented grains and are characteristic by surface relief, consisting of extrusions and intrusions. Point defects and formation of cavities and voids along the active slip planes governs the HCF crack initiation. No grain coarsening and development of specific dislocation structure was observed in the regions of crack initiation in UFG Cu. The mechanism of the crack initiation in AZ91 alloy processed by ECAP was found to be similar to that known from CG alloy. The cracks initiate in cyclic slip bands which forms in individual grains due to their relatively large grain size. The initiated cracks propagate along the slip planes in a crystallographic way which corresponds to the quasicleavage mechanism often reported for CG Mg alloys
* **Daniel Spriestersbacha et. ( 2014 )**

Fatigue failure of high-strength steels still occurs beyond 107 cycles in the very high cycle fatigue (VHCF) regime. The reason for this late failure is that the fatigue properties in the long life region are strongly affected by flaws like non-metallic inclusions inside the material. In the case of VHCF failure a characteristic fine granular area (FGA) which is responsible for subsequent crack initiation can be observed in the vicinity of the inclusion on the fracture surface. It is still unclear how different inclusion types affect the initiation mechanis m. Our study aims to clarify the influence of different inclusion types on the crack initiation in the very high cycle fatigue regime. Additionally, the threshold value for crack initiation as a result of FGA formation shall be revealed.

* **Simone Sissaa et. ( 2014 )**

This paper aims at estimating the low-cycle and high-cycle fatigue life of a turbocharged Diesel engine exhaustnmanifold. First, a decoupled thermo-structural Finite Element analysis has been performed to investigate low-cyclenfatigue phenomena due to the thermal loadings applied to the exhaust manifold. High/low temperature cycles causesnstress-strain hysteresis loops in the manifold material whose related dissipated energy can be directly correlated tonlow-cycle thermal fatigue. Afterwards, a dynamic harmonic analysis has been performed aiming at investigating thenexistence of high-cycle fatigue phenomena due to vibrational loading applied to the exhaust manifold during thenduty cycle. Three direction acceleration experimental loadings have been applied to the model. An ad-hoc methodology has been developed to superimpose thermo-structural results to dynamic harmonic analysis results. In particular, quasi-static thermo-structural results have been employed to identify the mean stress values of vibration fatigue cycles, while alternate stress values have been derived from harmonic analysis. Different combinations of frequencies and phases of the acceleration input signals have been considered to create different high-cycle fatigue loadings. Each cyclic load case has been processed employing the multiaxial Dang Van fatigue criterion.

* **M.N. Batista et. ( 2014 )**

The present paper presents low-cycle fatigue results about cyclic behaviour, the evolution of the dislocation structure and the nucleation and propagation of microstructural cracks in commercial ferritic-martensitic steel AISI 410. Previous low-cycle fatigue studies on 9-12Cr ferritic-martensitic steels showed that cyclic softening occurs due to microstructural instability over a wide range of temperatures . This effect could become a serious engineering problem affecting creep, swelling and segregation phenomena during irradiation. Cyclic softening of 9-12Cr steels is associated with instability of the dislocation structure over the entire range of temperatures and, with the coarsening of carbides at high temperatures. Nowadays, the softening stage in 9-12Cr steels is clearly associated with the increase of the subgrain size regardless of the temperature. Moreover, the softening has been at least partially explained by lath and sub-grain boundary elimination. The aim of this paper is to correlate the microstructural evolution with microcracks nucleation and propagation

* **Paulo Chambela et. ( 2014 )**

Fatigue crack growth (FCG) could be encountered in many mechanical components, which can be made from either thin or thick steel plates (or shells) and, therefore, be subjected to a plane-stress or a plane-strain condition, respectively. The loads applied in a solid body containing a narrow notch or a sharp crack will induce a yield zone near its tip with a dimension that will depend on the mechanical properties of the material, as well as on the thickness of the body, the crack length and the magnitude of the loads applied. Crack propagation can then occur under mode I, II, III or mixed-mode for general loading. The paper presents JI, JII and JIII integral functions, which were correlated with the elastic stress intensity factors KI, KII and KIII, for thin and thick CT specimens. The evaluation of J-Integral values was carried out for different crack lengths, along the crack front, and using the Finite Element Method (FEM), with collapsed nodes and midside nodes dislocated to ¼ of the edge’s length, in order to simulate the crack tip singularity. Interaction between in-plane, in-plane sliding and out-of-plane modes are also discussed in the paper. In addition, FCG rates under mode I, mode III and a mixed-mode (mode I+III) were experimentally determined, at room temperature, for a high-strength Cr-Mn austenitic stainless steel

* **P. Weißgraeber et. ( 2014 )**

To study crack initiation at weak stress singularities classical Fracture Mechanics approaches do not suffice. In this work weak singularities are discussed and the obstacles occurring in fracture analysis are outlined. The concept of Finite Fracture Mechanics and the use of coupled criteria is explained. A brief discussion of coupled criteria is given and relationships to other analysis methods are adressed. As an example crack initiation in adhesively bonded joints is analyzed. Two different failure models are outlined and it is shown that both agree well with experimental results. In general there are two different kind of stress concentrations, finite concentrations as e.g. at holes or infinite stress concentrations, typically called stress singularities as they occur in sharp corners or at multimaterial points. Several local and non-local concepts have been developed to study such crack initiation processes with the aim to obtain the corresponding crack initiation loads. In this work we will briefly discuss the concept of Finite Fracture Mechanics (FFM) that considers the formation of cracks of finite size and does not require the use of non-physical length parameters. Two FFM failure models for the case of crack initiation in adhesive joints are given and the failure load predictions are compared to experimental result

**2.2 GAPS IN RESEARCH AREA**

* From the literature review, it is concluded that many author have used different technique to find out J-integral valve of 2-D element. But there is need a software method for easy calculation.
* The literature review portrays that the authors have worked more on analytical process but there is a few work on the software approach.
* Many author have worked upon different parameter in crack growth analysis but only few have work for J-integral calculation.
* Many author have work on software but they focus on life cycle, stress intensity factor and no. of load cycle calculation.

**2.3 OBJECTIVE OF THE STUDY**

**The primary goal in this research is to develop 2-D finite element analysis J- integral results using ANSYS. These results will be compared to existing solution. The second goal is to investigate the J-integral for other two materials. The third goal is to find out the maximum displacement and the maximum stress valve for the material at different crack length.**