FEA PROCESSES FOR THERMAL-FATIGUE OF MONOCRYSTALLINE HEAT-RESISTANT SUPER ALLOYS

Deepak Kumar Kanaujia[1], Shiv Singh[2]

[1]*M.Tech.(CAD CAM) Scholar, Mechanical Engineering department, Ambalika Institute of Management & Technology Lucknow, India*

[2]*Assistant Professor, Mechanical Engineering department, Ambalika Institute of Management & Technology Lucknow, India*

[1]Email-deepak.kanaujia020@outlook.com [2]Email-shivsinghyadav@ambalika.co.in

Abstract: *In this present work, the accurate and efficient calculation method thermal elasticity, plasticity, creep of a Super alloy(heat-resistant mono nickel-based alloys Nimonic PE16.*

Research objective: *Simulation is going of the thermal fatigue strength of monocrystalline Nemonic PE16 super alloy at different thermal co-structural conditions at variable exposure times.*

Purpose of the study:

1. Determination of non-stationary temperature fields during heating sample and comparison with experimental data for different temperature conditions monocrystalline Super alloys.

2. Investigations into the effect of exposure time on thermal fatigue durability, taking into account the processes of inelastic deformation for various temperature regimes, Nimonic PE16 alloys, and their comparative analysis. In the course of work, the FE packages ANSYS 18.0 are used. Because of the study, the calculated temperature distributions showed good correlation with experiment for all modes, for various alloys and at various temperature conditions, calculated curves of the influence of the holding time on the thermal fatigue strength. Which were verified using experimental data and they also showed good correlation with it. Then use the 3D model created by Solidwork software to import ANSYS for geometry and mesh processing. Finally, the ANSYS software is used to solve the finite element, and the response of the structure to displacement stress under different loads and dynamic environments is obtained. Carry out structural strength.

Keywords: Thermal and Structural boundary value problem, Parallel Analysis, Deformation criterion thermostatic failure, finite elemental simulation, Ansys.

1. INTRODUCTION

Aviation is one of the most knowledge-intensive industries. Modern winged vehicles are equipped with the most powerful gas turbine engines capable of lifting up to 120 tons into the air. Technical engine characteristics are determined by a set of measures, including design features and materials. Aviation development materials science allows designers to bring to life the most daring fantasies. Of course, this entails increased requirements for a number of material parameters - working temperature, strength, endurance, heat resistance, manufacturability. Some of the hottest, literally and figuratively, zones the engine is a combustion chamber and a high-pressure turbine. For parts of these assemblies use heat-resistant nickel, and for promising engines - nickel inter metallic alloys, capable of operating at temperatures up to 1200 ° C. These materials define the maximum temperature of the "working fluid" of the engine, and hence its resource work, power and specific gravity.

The mechanical properties of metals are greatly affected by high temperature for structures that have been working under high temperature conditions for a long time. When the temperature exceeds about 0.5 times the melting point of the metal material (Kelvin), the metal material is subjected to continuous stress, and a slow plastic deformation phenomenon will occur, which is called metal creep. Engineering and metallurgical industries usually pay more attention to the creep failure behaviour of structures under high stress and high temperature. The purpose of this dissertation is to study the behaviour of use heat-resistant nickel-Titanium based single crystal materials with a modified crystal matrix in wet-thermal fatigue conditions.

This study is very relevant because it allows use available experimental data on performance heat-resistant alloys for real operating conditions of parts, turbines and, in particular, aircraft engines.

The object of this research: thermal fatigue strength monocrystalline and polycrystalline nickel-titanium alloys at different temperature conditions and variable holding times at maximum temperature.

2. LITERATURE REVIEW

A.V. Savikovskiiet al. in this paper has order to improve the safety of mobile cars, we need to carry out simulation and analysis. From the dynamic characteristics of the car rear-view mirror. In addition, we must also consider Geometry, standards and requirements, reasonable choice of mirror size and installation Position, the dynamic characteristics of the car rear view mirror in the design of the rear view of the car a mirror in this article, we use ANSYS finite element software to simulate the frequency. The model of the car rear view mirror under excitation conditions. Based on This and the strength analysis results of the rear-view mirror, we made the best design Rear view of the mirror design. We get five models and analyze them under working conditions. Displacement and strain values and dynamic characteristics. The results show that Low modal frequency, car rear view mirror is very easy to be inspired by the engine, transmission system and the road to . In addition, the deformation and deformation distribution of the rear view mirror is not evenly. Therefore, we must control the modal frequency of low level flexibility within a certain threshold. The frequency at which the structure is designed. a slight change in total Due to the optimization of the design, the maximum equivalent load of the rear-view mirror is reduced by 30.5%.l.[2]

L.B. Getsov2 et al. the goal of the project is to observe the latest trends and the latest growth rates based on experimental modal analysis. In order to reduce the of the door, there are two methods in the analysis, namely, modal analysis by FEM method and experimental analysis by FFT analyzer. First, using the FEM method, the doors were created using CATIA V5 R20 software, and analyzed using Hyper Works 12.0 software, and the FEM method was performed using a free analysis method to obtain different frequencies. And form a pattern in different nodes. The analysis is performed in two ways: stiffeners and no stiffeners; stiffeners are used to reduce elemental. The Opti-struct solver is used to get its own frequency. Second, modal analysis was performed experimentally using an FFT analyzer to obtain the results of frequency and mode shape. Third, in order to reduce , one of the methods for changing the structure frequency by adding a rib in the door design is again subjected to modal analysis in the FFT analyzer technique with enhanced conditions without loose lines. Finally, compare the results. [4]

Wook Jin Lee1et al. carried out Structural analysis stage and its behaviour prediction including developing appropriate mathematical models for the structure Geometry and material behaviour. Because any mathematical model is an approximation of the real structure Behaviour analysis based on this model always introduces errors Depends on the model accepted. Quantify these errors it is important for accurate structural failure analysis that it needs develop these wrong models. Discuss the misclassification in modeling Random loads and undefined errors caused by mathematical modelling. The structure will be introduced in the next lecture. [3]

Semenov S. Get al. optimized and reduced weight of universal yoke by using composite material. The dynamic frequency is also expanded by small parameters, solving the long-term problem. In 1890 Po in care proved that the solution of Lindstedt is asymptotic. 1918 Duffing used harmonic balance method and successive iteration method to study the forced of hard spring. In 1920 van der Po l proposed a slow variation system. The development of nonlinear approximation analytical method is not limited to the range of dynamics becomes a branch of applied mathematics, and its results are widely used in many physical and mechanical branches. Universal will be analyzing in the ANASYS and result will be compared. [6]

Sepideh Ghodrat al.The failure analysis of the The airborne electronic equipment (OER) currently under development (aircraft, tank, automobile) places high demands on the operating time of the equipment, during which it must remain operational. The mechanical properties of the block structures and the printed circuit board (PC), represented as a set of plate and rod elements, are needed to determine the parameters of the vibration effects in the RE, and then the analysis of the mechanical properties of the RE to determine the time upon fatigue failure to determine the conclusions that are ultimately necessary to make a decision about the need to ensure the long-term operability of the electronic device under the influence of vibration deformation, and various other parameters. The materials are compared, namely SAE 1050 and SM45C. The yoke CAD model was created using CREO PARAMETRIC3.0. For finite element analysis, import the model into ANSYS 14.0 Workbench for stress analysis. The materials SAE 1050 and SM45C are produced with different parameters. Better results were obtained using material SM45C, and the design was found to be safe.. [5]

3. NICKEL- TITANIUM BASED SUPPER ALLOYAND ITS NATURE IN THERMAL

Nimonic PE16

High-nickel alloys based on the Nimonic PE16 composition have been injected at temperatures of 525 ^{0}C· and 625 ^{0}C· with 1000 ppm helium to produce a high gas-bubble concentration and subsequently irradiated with 36 MeV nickel ions. Extensive heterogeneous nucleation of bubbles is observed on faulted interstitial loops and dislocations. Evidence is found in standard PE16 alloy·

Nimonic PE 16 ™ is Ni-Cr-Mo alloy· with lower nickel content, and belongs in the high· temperature and high strength alloy group. It is a not an expensive alloy. The aluminium and titanium present in this alloy makes it precipitation hardenable by heat treatment .

The following datasheet will provide more details about Nimonic PE 16 ™ .

Table 3.1: Chemical Composition

The following table· shows the chemical· composition· of Nimonic PE 16 ™ .

Element	Content in percentage
Iron,	31
Nickel,	42-45
Chromium,	15.5-17.5
Cobalt,	2
Molybdenum,	2.80-3.80
Titanium,	1.10-1.30
Aluminium,	1.10-1.30
Silicon,	0.50
Copper,	0.50
Manganese,	0.20
Zirconium,	0.020-0.040
Carbon ,	0.040-0.080
Sulfur,	0.015
Boron,	0.0050

Table 3.2: Physical Properties

Properties	Metric	Imperial
Melting point·	1310-1355°C	2390-2471°F
Density	8.02 g/cm³	0.290 lb/in³

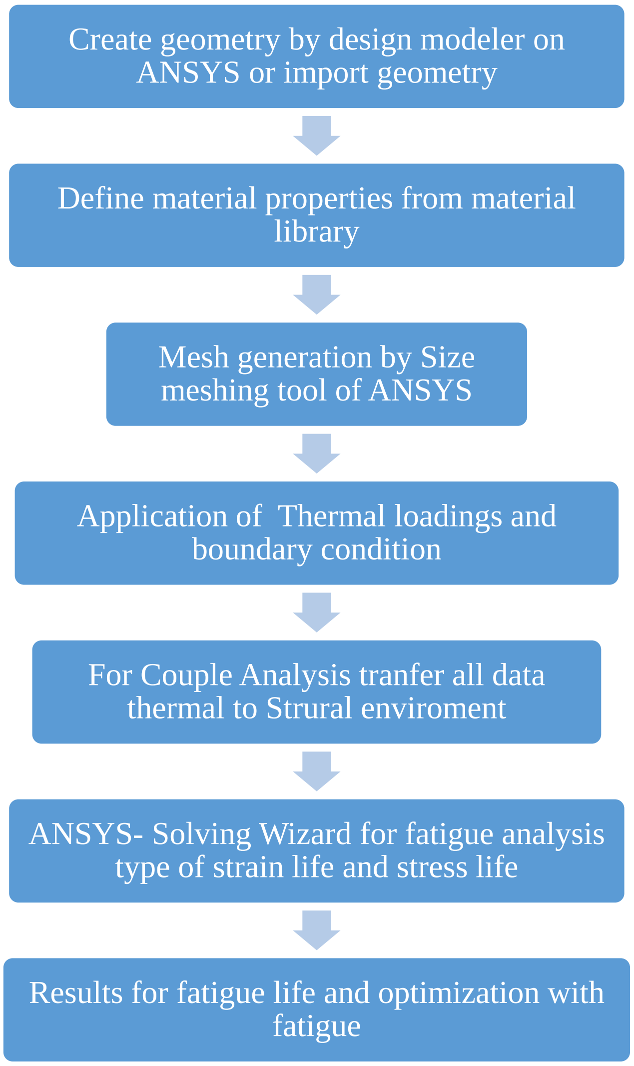
Table 3.3: Mechanical Properties

Properties	Metric	Imperial
Yield strength·	450 MPa	65300 psi
Tensile strength·	900 MPa	131000 psi
Elongation at break·	28%	28%

Table 3.4: Thermal Properties

Properties	Value
Thermal conductivity	11.72 W/mK
Thermal expansion· co-efficient (@ 21 - 100 °C/ 69.8 - 212 °F)	13.8 µm/m°C

Methodology



Process chart: Flow chart of FEA process in Ansys Workbench.

4. RESULT ANALYSIS AND DISCUSSION

Mechanical property of component for Nimonic PE 16 Alloy Material:

Table 4.1: Mechanical Properties

Properties	Metric	Imperial
Tensile strength· (value· at room· temperature)	900 MPa	131000 psi
Yield strength, value· at room· temperature)	450 MPa	65300 psi
Elongation at break·	28%	28%

Table 4.2: Thermal Properties

Properties	Metric	Imperial
Thermal expansion· co-efficient (@ 21 - 100 °C/ 69.8 - 212 °F)	13.8 µm/m°C	7.67 µin/in°F
Thermal conductivity	11.72 W/mK	81.34 BTU in/hr.ft².°F

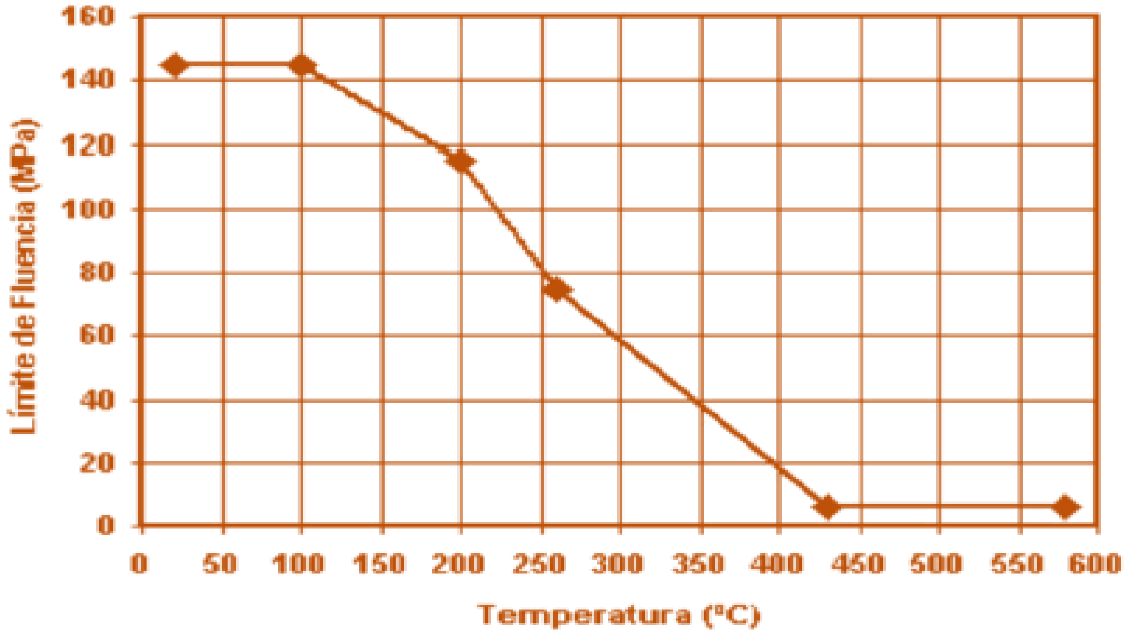


Fig. 4.1. Thermo -dependent yield strength of Nimonic PE16.

4.1. Analysis process

Physical and Mechanical Properties of Nimonic PE16

A major problem during Thermal load modeling work is to establish, as precisely as possible, the thermo-dependent physical and mechanical properties of the material in question. On many occasions this information is not available in a complete way, with the thermo-dependent properties from room temperature to the melting temperature of the material.

The key property in the thermal run is thermal conductivity and in this work the values offered by the ASME code for Nimonic PE16 were taken, extended according to the trend line up to a temperature of 700 ºC (solid temperature), which agrees with the values provided by the Eurocode for Nimonic PE16 alloys The conductivity was doubled for any temperature above the liquid temperature of the alloy to simulate the physical effect of convection heat transfer that occurs in the Thermal load pool.

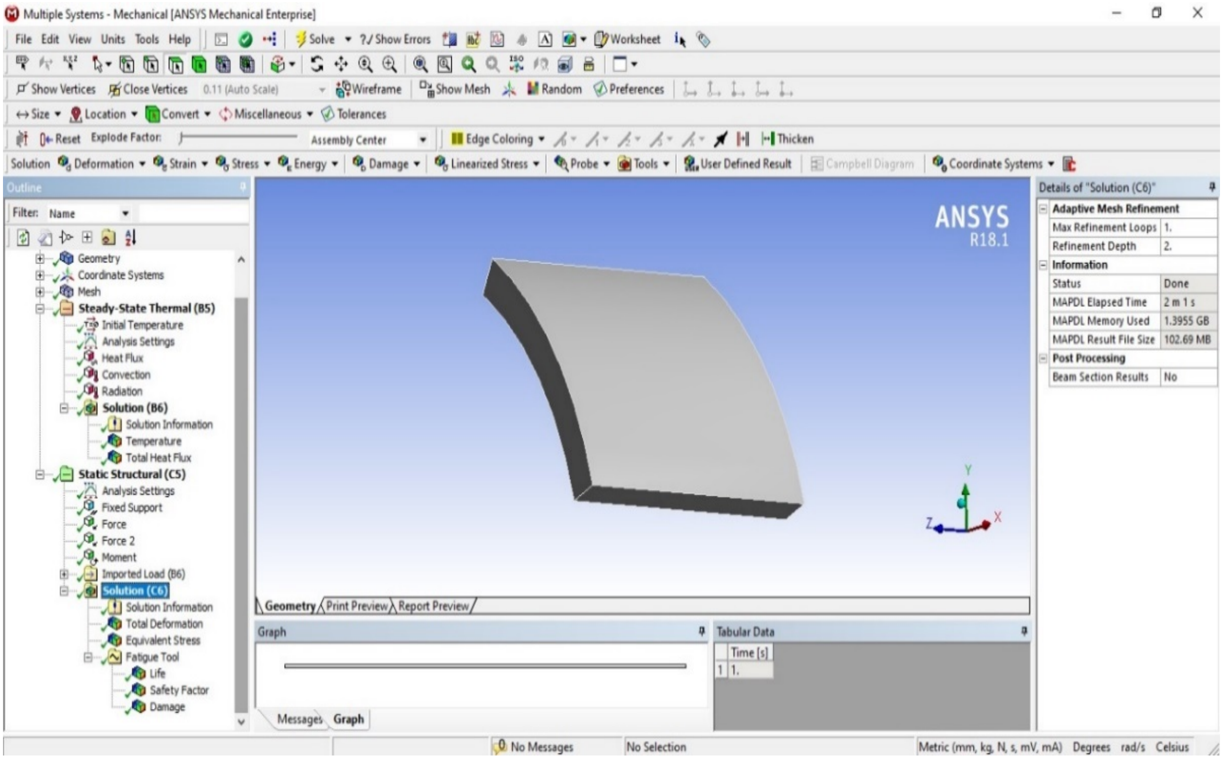


Fig. 4.2 Ansys Couple Simulation Environment GUI.

4.2. Results and Discussion

In fig. 4.1. is shown as an example the thermal field on the upper surface of the junction, obtained for a time of 17, 7 s from the start of temperature, with source movement from right to left and by intermediate mesh model. The elongated isotherms characteristic of the temperature process are observed, with a front where the elements of the bead are deactivated, as there is no filler metal in the actual physical process .

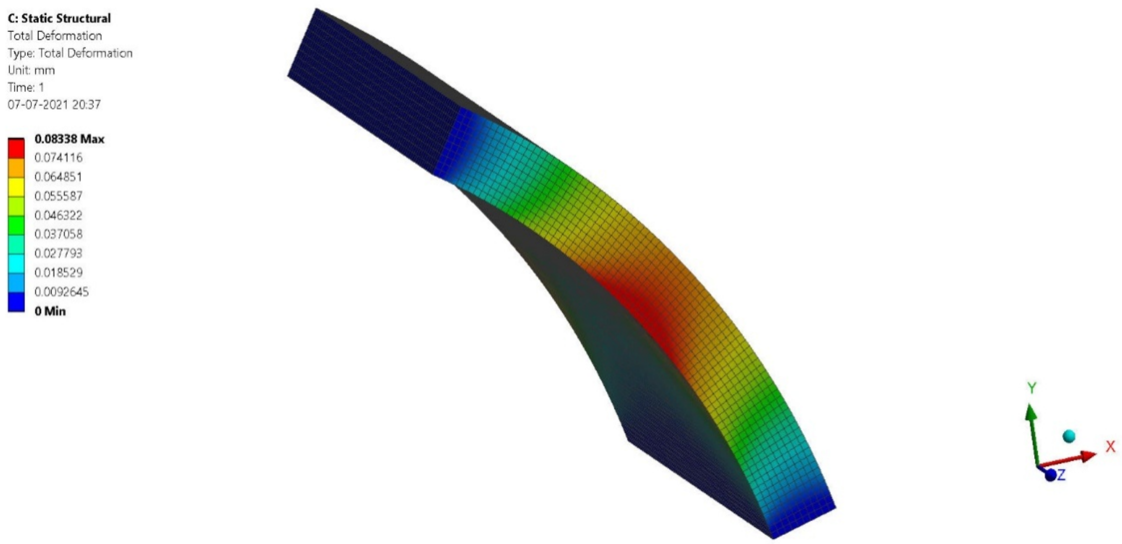


Fig.4.3: Model> Static Structural > Solution >Total deformation

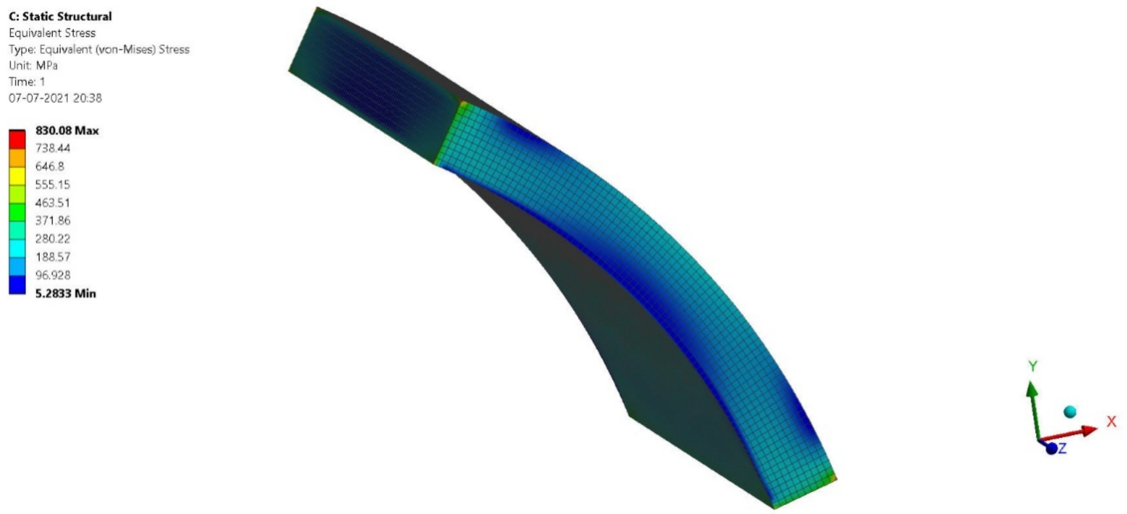


Fig.4.4: Model> Static Structural > Solution > Equivalent Stress.

Table 4.3: Alternating temperature with Mean Stress.

Alternating Temperature ^{0}C	Cycles	Mean Stress MPa
800	10	0
780	20	0
700	50	0
670	100	0
610	200	0
441	2000	0
262	10000	0
214	20000	0
138	1.e+005	0
114	2.e+005	0
86.2	1.e+006	0

Table 4.4: Alternating Stress Mean Stress.

Alternating Stress MPa	Cycles	Mean Stress MPa
3999	10	0
2827	20	0
1896	50	0
1413	100	0

1069	200	0
441	2000	0
262	10000	0
214	20000	0
138	1.e+005	0
114	2.e+005	0
86.2	1.e+006	0

The rest of the properties were basically assumed based on those proposed an alloy similar to Nimonic PE16. Table 4.1 & 4.2 summarizes the physical-mechanical properties used in the modeling.

k - thermal conductivity; c- specific heat; ρ- density; E- modulus of elasticity;

a - secant coefficient of thermal expansion; s f - yield stress; Et- tangent module.

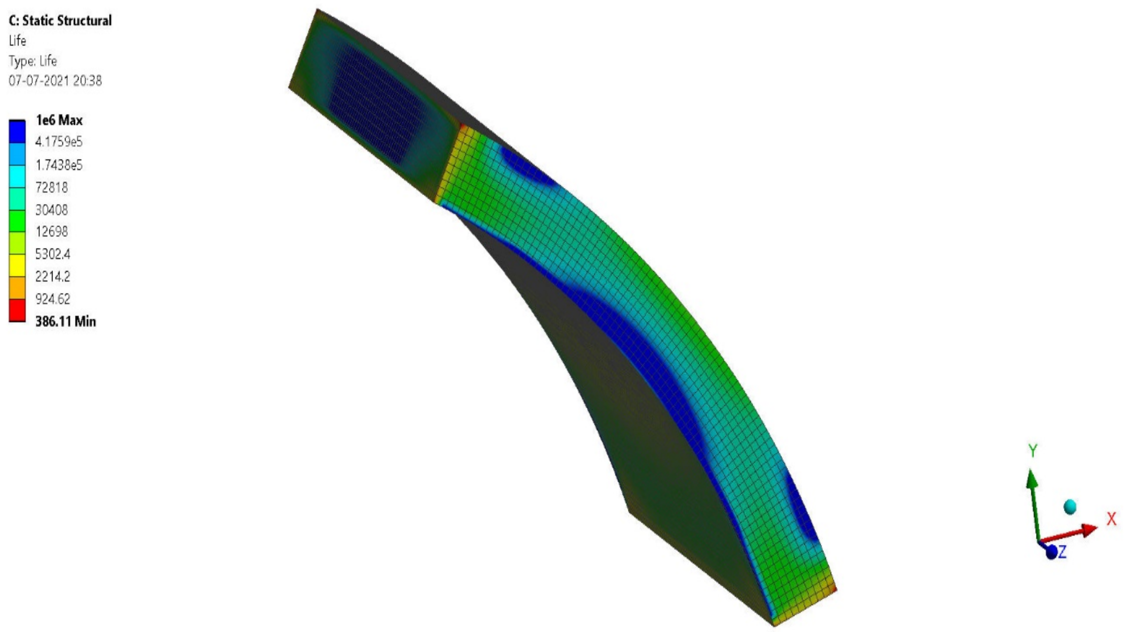


Fig.4.5: Residual stresses effect on fatigue life intermediate mesh model.

4.3. Post-processing of results

Table 4.5: Strength Calculation of thermal System based on cycle Strain-Life Parameters.

Strength Coefficient MPa	Strength Exponent	Ductility Coefficient	Ductility Exponent	Cyclic Strength Coefficient MPa	Cyclic Strain Hardening Exponent
920	-0.106	0.213	-0.47	1000	0.2

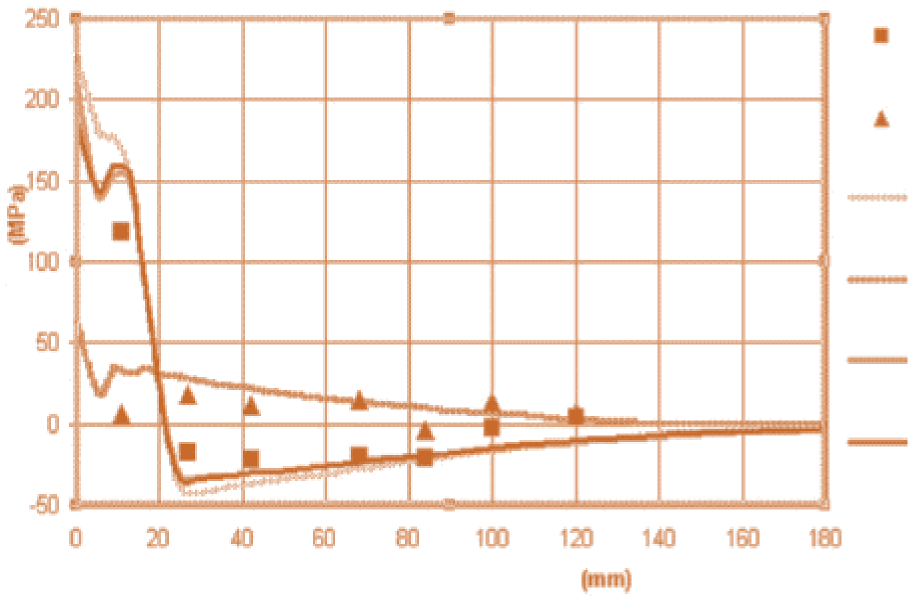


Fig .4.6 Residual stresses effect of fatigue coarse mesh model.

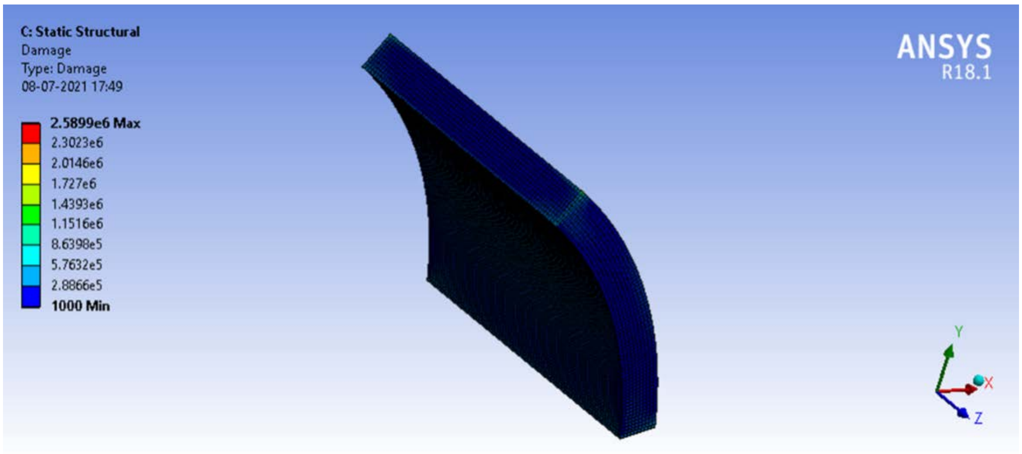


Fig .4.6: Solution> Fatigue Tool > Damage Ansys

The geometric models, using the three types of meshes, gave quite similar results for · each case of material model · (kinematic, isotropic and no hardening). Only the coarse mesh fails due to the jump shown by the longitudinal and transverse residual stress graphs in the Thermal load area, which is logical because in this mesh half of the Thermal load cross section is represented by a single finite element. He intermediate and fine meshes do coincide practically over the entire width of the Thermal load and conform to the experimental values of A.V. Savikovskii1. So it is considered that in both types of models the solution practically converges and therefore a further refinement. which would only increase calculation times; the relative error between the two models in the longitudinal stress on the thermal axis is less than 10%.

Although the three material models (Thermal, isotropic and no hardening) conform to the experimental data measured by A.V. Savikovskii1.It is considered that the models with Thermal and no hardening are the ones that most accurately describe the phenomenon, taking in consideration that the other model is somewhat further away from the experimental data of the longitudinal stress in the compression zone. Therefore for this single pass temperature on Nickel aluminium-magnesium alloy both models are considered suitable.

All the models produced results similar to those reported in the literature for the longitudinal residual stress, with the maximum tensile values close to the yield point of the material in the zone close to the highly heated Thermal load and compression in the zone more far from it [5].

In fig.4.6. shows the results of residual stresses which produced a structural model in which the elements of the Thermal load is activated so that always existed two active elements (10 mm) ahead of the element on which the source is of heat. In this case, and in other studies that are not shown here, there was an over sizing of the transverse stress with respect to the experimental values, so this variant was discarded. The reason for this is that the elements activated in front of the heat source cause a greater degree of restriction to the free expansion and contraction of the metal · in the transverse direction, which is reflected in these exceeded values.

The isobars shown in confirm the completely three-dimensional character of the residual stress fields characteristic of the temperature process. It can be observed that the longitudinal stresses that are greater in absolute value are tensile and act in a wide middle area of the length of the Thermal load, with an approximate value of 166 MPa, while in Fig. the greatest transverse stresses are of compression and are found in the reduced start and end zones of the Thermal load, with a value of almost 200 MPa, which is why they are the most critical, which corresponds to that reported in the literature. It is therefore considered that no two-dimensional model is capable of recording these variations in stress levels in the cross-sections of the Thermal loaded.

5. CONCLUSION

According to the temperature and stress distribution of the single crystal blade under service conditions, the creep of the material can be roughly divided into two categories: high temperature low stress creep and medium temperature high stress creep. In the past, researchers paid different attention to these two types of creep. Due to the continuous improvement of the temperature resistance of nickel-based single crystal super alloys in the past 30 years, a large number of research results have been concentrated in the high temperature region, and relatively little research has been conducted on the medium temperature many region.

- The distribution of thermal stresses depends on it. Themselves that produces low-frequency thermal fatigue from heating and cooling cycles during starts, stops, or load changes. Now, one of the fundamental objectives of the project is to estimate.
- However, with the deepening of the research, the researchers found that the working temperature of the blade roots of the turbine blades and the inner wall of the air-cooled channel is mainly concentrated at 650~850℃. Generally speaking, centrifugal stress in this temperature range is difficult to cause obvious creep deformation of the blade. However, due to the geometric effect of the blade, stress concentration may occur in a local area, resulting in obvious medium temperature and high stress creep deformation of the blade. Ignored by researchers at home and abroad to view the equivalent stress under the project tree, select for the scale factor, and solve the result. Showing a probability of 68.269%, the maximum equivalent stress does not exceed 741.158 MPa.
- It is computationally efficient and leads to accurate results to use geometric models with a fine mesh only in the highly heated zone, where the thermal and stress gradients are high, and which becomes much coarser as you move away from it. Always the minimum possible of nodes and elements guarantees a more efficient calculation time.
- Activate the temperature elements, both in the thermal and structural run, in the time step in which the heat source is on them, combined with the use of a reference temperature of the same temperature elements at the melting temperature of the metal ·, it leads to accurate results in the computation of the thermal history, stresses and Thermal load deformations, avoiding false elasto-plastic deformations in the elements that make up the Thermal load. On the other hand, activating the temperature elements in front of the heat source causes a certain over sizing of the transverse tension.
- The use of the material model · with bilinear elastoplastic behaviour leads to precise results, and to · define it, it is only necessary to declare the variation of the yield point, the modulus of elasticity and the tangent modulus in relation to temperature. Although the three material models (kinematic, isotropic and no hardening) fit the experimental data, it is considered that

the models with kinematic hardening and without hardening are the ones that most accurately describe, in this case, the thermo deformation phenomenon of the GMAW temperature of aluminium-magnesium alloys.

- The use of a cutting temperature in the structural run equal to the melting temperature of the alloy avoids quantifying false elastoplastic deformations at higher temperatures, when in the real physical process the metal is in a liquid or solid-liquid phase, avoiding also the need to be exquisite in adjusting properties to higher temperatures, which could represent some difficulty.
- It is considered that only three-dimensional models are capable of accurately reproducing the stress behaviour of Thermal loaded s, and allow determining the maximum value of compressive transverse stress that occurs in the areas at the beginning and end of the Thermal load, which is practically unattainable for · two-dimensional models.
- This work confirms that the ANSYS Multiphasic Software version 18.0 for general use can be used satisfactorily in the modelling of the thermal history, stresses and deformations of Thermal loads, providing results as reliable as any finite element code specialized in this process.

5.1. FUTURE SCOPE

The objective of this study is to investigate new techniques for believes that most of the current researches on the creep deformation mechanism of single crystal alloys are aimed at near-ideal defect-free single crystal alloy materials. However, in fact, due to the influence of blade geometry, alloy composition, solidification process and other factors, single crystal blades are prone to small-angle grain boundaries, streaks, miscellaneous crystals, looseness, freckles and recrystallization during directional solidification and subsequent heat treatment. In addition, other defects. In the service process of single crystal blades, the above-mentioned defects are vulnerable to cracks, leading to premature failure or fracture of the blades. Therefore, it is urgent to carry out research on the creep deformation mechanism of defect-containing single crystal alloys.

- At the same time, in addition to creep damage during service, single crystal super alloys also, suffer from obvious fatigue, oxidation, and thermal corrosion damage.
- For this reason, it is very necessary to conduct in-depth research on the creep behaviour of single crystal super alloys containing typical defects and the effects of oxidation and hot corrosion on the creep-fatigue deformation and damage mechanisms of single crystal alloys.

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