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Joint Characteristic Study of a Typical Merman Band Joint used for Launch Vehicles using Non-Linear Fe Analysis

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Abstract-Long range missiles, artificial satellites & spacecrafts use multistage rockets as their carrier. Staging of rockets imparts necessary higher relative velocities to the stages or satellites. These stages are connected to each other with separation mechanisms which separate on command during the rocket ascent. Separation mechanisms play a vital role in fulfilling mission requirement. Hence design of these mechanisms shall be critically carried out. In this paper preliminary design & joint characterization study of a typical separation mechanism (merman band joint) used in attaching satellite with launch vehicles is done using FEA analysis.

Keywords-Merman band joint; FEA analysis; joint characteristics study; contact analysis; separation system

I. INTRODUCTION

Merman clamp band mechanism is a type of heavy duty joint. It does not have a mechanical fasteners or any type of adhesives in either of the components that are being mated and they are mainly used in the systems that requires remote separation of the components normally pyro technique devices are used for this separation . Due to this characteristics clamp band system is mainly used in spacecraft industry for wide range of applications that includes, as a launch release mechanism in twin liquid propulsion engines and also used for upper stage separation and payload fairing and for various spent stages separation.

Any type of failure in any of components of separation system will lead to the mission failure. Therefore the construction, development and improvement of separation mechanisms are important aspects of development of launch vehicles. Separation mechanisms shall be designed to withstand ultimate structural load without failure, Separation mechanisms shall also be designed to separate only on command without causing damage to any other parts. More complicated design of separation mechanisms are accompanied by higher requirement of their reliability.

II. LITERATURE SURVEY

Clamp band system are most commonly used for satellite separation because of some of its advantages over other systems, they are they don't have any moving parts, it produces uniform clamping force and excellent joint stiffness, releasing is comparatively fast and less shock producing. Therefore the construction, development and improvement of separation mechanisms are important aspects of development of launch vehicles. Separation mechanisms shall be designed to withstand ultimate structural load without failure, Separation mechanisms shall also be designed to separate only on command without causing damage to any other parts. More complicated design of separation mechanisms are accompanied by higher requirement of their reliability.

A. Different parts of Merman band joint

- Merman band: There are two bands are present in one assembly its function is to hold and apply necessary load on wedge block for holding the two flanges together
- Wedge block: The blocks provide the mechanical interlock between the spacecraft flange and the payload flange
- Bolt assembly: Bolt assembly is used to connect the two bands together, and apply loads to the band as tension.
- A tensioning mechanism is used to apply the tensile load on the band, and in order to measure load a load measurement system is also attached with bolt assembly

B. Different loads acting in the merman band joint

The main load acing on the merman band joint is due to the external bending moments acting during flight time of the lounge vehicle, and the spring thrusters used for separation of flanges also make a separation force in the joint. A pre tension is applied in the band by tightening the bolts to give sufficient stiffness for holding the flanges together.

III. MODELING AND ANALYSIS

A. Modelling

To study contact characteristics the merman band joint used for satellite separation is modelled using pro -E, which is necessary for analysis using FEM. The Fig.1 shows the clamp band assembly used for analysis.

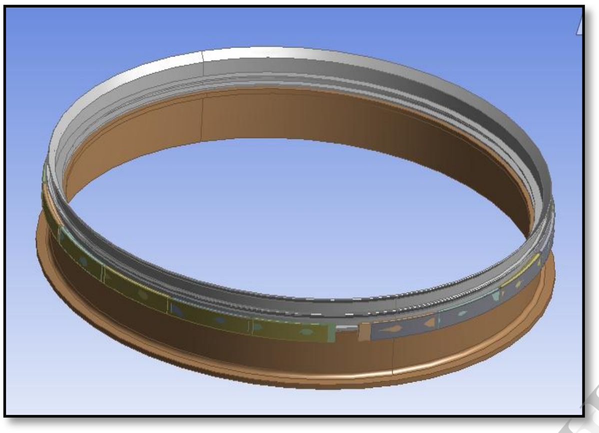

Fig .1, 3D model of Clamp band assembly created in pro-E

An axisymmetric finite element analyses have been used to assess clamp band design. Here we are using a simplified model of clamp band system because of computational limitations and modelling difficulties that made 3D analysis impractical.. A three- dimensional model permits evaluation of several effects that could not otherwise be assessed with axisymmetric models, primarily the non-axisymmetric loading. In this section the 3D finite element model and accompanying analysis strategies are described.

1) Calculation of band tension required for joint

To find the force acting against the clamping force first we converts all the bending moments acting on the joint to equivalent axial forces (F_{axial}) by using a relation

$$F_{axial} = 2M/R$$

M = Total bending moment acing on the joint

R = radius of the joint

The force due to the spring thrusters is denoted 'P'. The total axial force that tend to separate the joint is given by

$$F = \frac{2M}{R} + P$$

In order to compensate this axial separation loads we must apply tensile load in the band by tightening the bolts, and that is denoted by 'T_1', and is given by the relation

$$T_1 = \frac{F(\tan\theta - \mu)}{\pi(1+\mu\tan\theta)}$$

F = Total axial separation force acting in the joint
μ = Coefficient of friction between the flanges and the clamps.
θ = The wedge angle of the clamps

The temperature variation is also affects the joints. Tension required compensating temperature increase of 20°C for M250 steel is given by,

$$T_2 = \alpha EAt$$

α = Co efficient of thermal expansion
E = young's modulus
A = Cross sectional area of the band
t = Temperature difference
The total tension applied on the band is

$$T = T_1 + T_2$$

Tension that is applied on the band is not uniformly distributed in the band due to the friction. So we must apply additional load to compensate this effete. Tension to be applied in the tightening end to compensate this effect is given by,

$$T = (T_1+T_2)e^{\mu\theta}$$

During proof loading condition we are considering a proof load factor for safety normally it is taken as 1.25 then the total applied tension will be T x 1.25

The band is made as straight during assembly we bended this to make the joint this also induce one stress on the band but the magnitude of this stress is comparatively small. So we are neglecting that value during calculation.

2) Calculation of clamping force per unit length

Function of the wedge black is to hold the two flanges together; it is done by the clamping action between them. It is usually made up of aluminium alloys .Due to band tension a bending stress is generated in the wedge blocks .here they tensile force applier in the band in tangential direction ,it makes a radial compressive force in the wedge blocks ,it compresses the wedge blocks towards the flanges

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The radial force applied on the wedge blocks per unit length is,

$$Fr = \frac{T}{R}$$

T = Tensile force applied in the tangential direction
R = Radius of the wedge blocks
Fr= Radial force acting on the wedge blocks

The radial force is transmitted to the two flanges that is in the two sides of the wedge blocks, the radial force acting on the one side is,

$$Fr_1 = \frac{1}{2}\frac{T}{R} = \frac{T}{2R}$$

The tangential tensile force is converted in to clamping force in the wedge blocks it is acting on the two flanges in the same time. The clamping force provided by one side of the wedge block by unit length is,

$$Fv = \frac{Fr1}{\tan(\theta - \varphi)}$$

Where $\emptyset = tan^{-1}\mu$
And, μ =is the coefficient of friction

B. Analysis

The Finite Element analysis for the calculation of stress and strain due to different loading conditions is done using ANSYS 13.0.The external loaded condition and the preloading conditions are analysed. A simplified model is used for analysis to reduce computational difficulties

This analysis is carried out in two steps one is in the ground state (without an external load only pretension of the band is considered) In the second step the flight condition is analysed in this state external load are acted up on the joint in the form of bending moments .This Bending moments and other external forces are converted to equivalent axial load by the calculations mentioned above. Fig 3 and Fig 4 indicates different loading conditions.

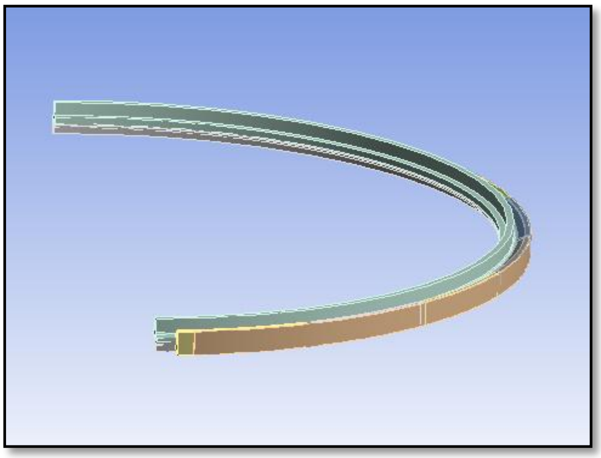

Fig .2, Simplified 3D model used for analysis

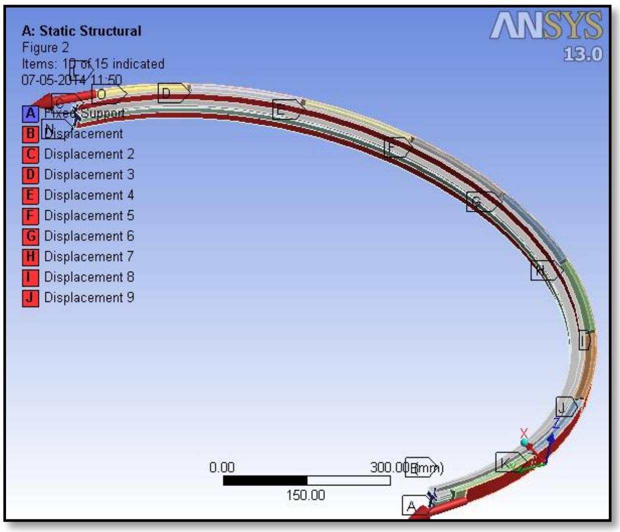

Fig .3, Loading and boundary conditions in Case 1

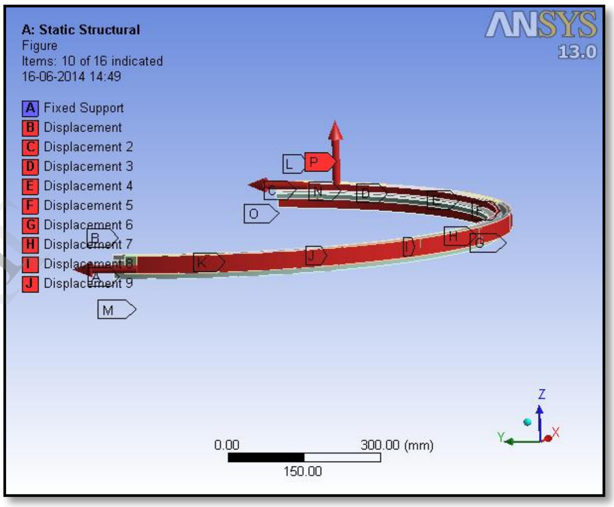

Fig .4, Loading and boundary condition in Case 3

1) Deformation Analysis

In this the deformation produced in each components in different loading conditions is calculated by FE analysis. The resuls obtained by considering each elements is shown below,

a. Case 1 (Without external load)

The total deformation produced due to the pretension load (loading and boundary conditions in Fig.3.) is shown in the results below. the pretension load is applied on the band to hold the entire assembly together. It is applied with the help of a tensioning mechanism and by the bolt assembly attached to the band.

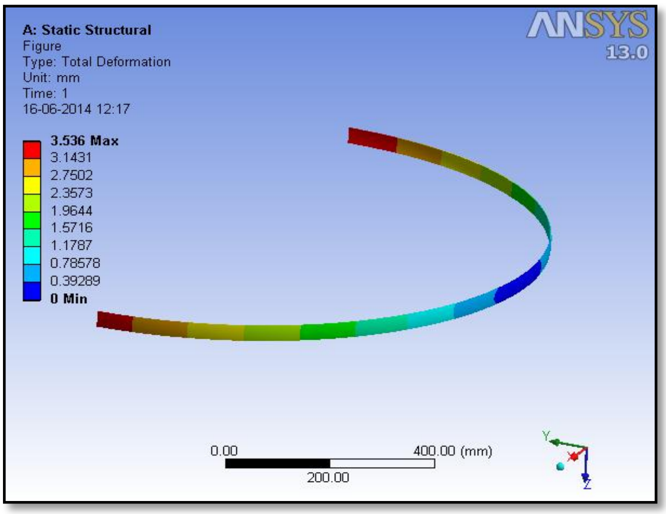

Fig.5, Deformation produced in the band due to pretension

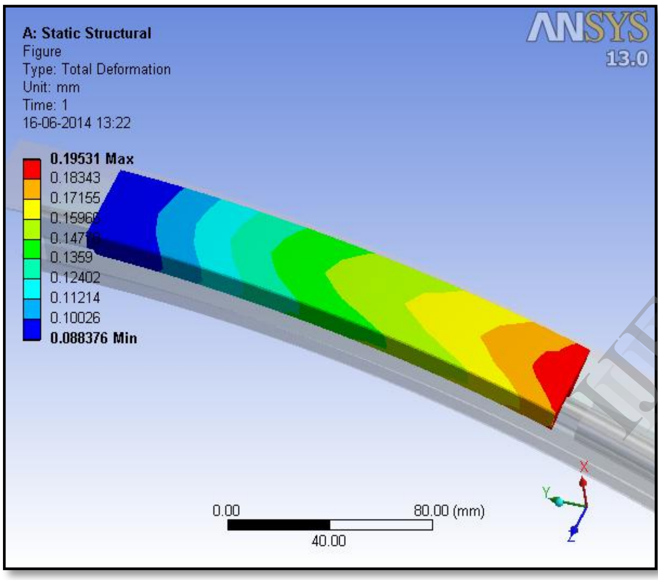

Fig .6, Deformation produced in the wedge block

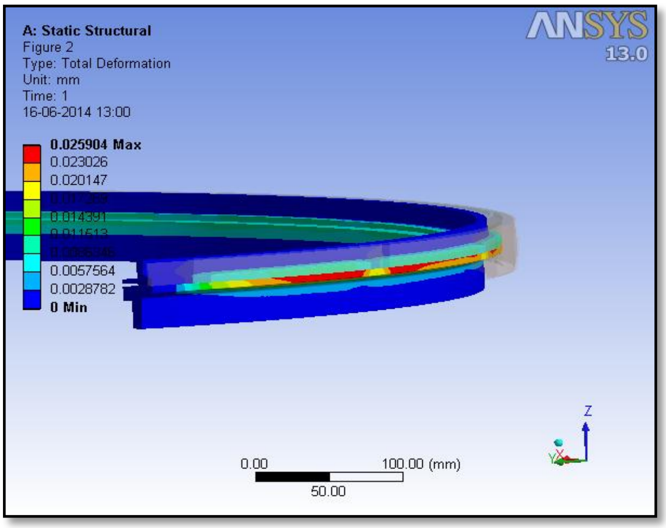

Fig.7, Deformation produced in the two flanges

b. Case 2 (With external loads)

Total deformation produced in the different components of the merman band joint with an external load and band pretension is shown in the results below.

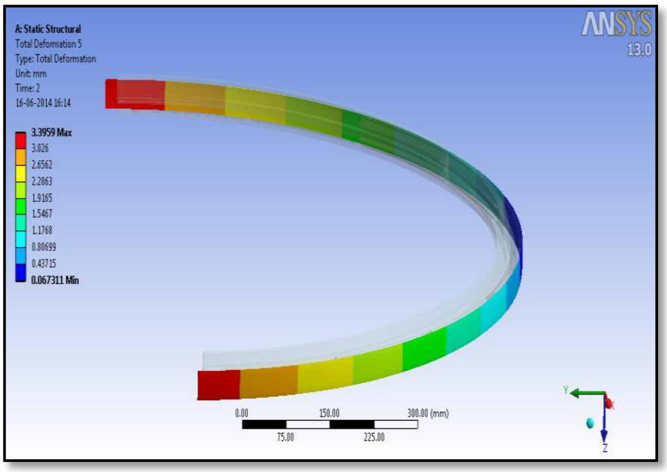

Fig.8, Deformation in the band with external loads

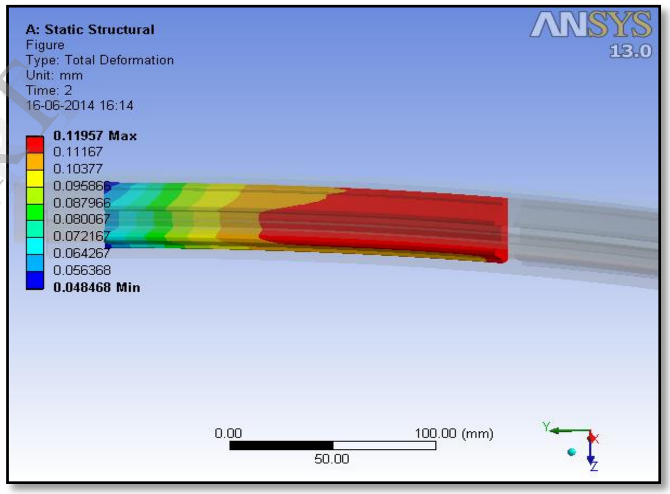

Fig.9, Deformation in the wedgeblock

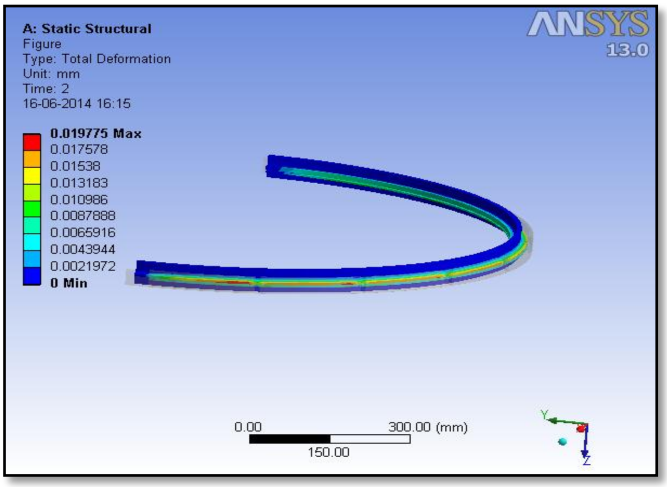

Fig.10, Deformation in the flanges

2) Stress analysis

Merman band, the wedge blocks and the two flanges are critical component of the system. Failure of the any element especially the band due to loading or any type of defects can be catastrophic to the entire launch vehicle. The stress level in the elements should be maintained well with in the design limit. The present section illustrates the various stresses acting on the elements under the similar operating condition as discussed in the previous section. Figures represent equivalent Von Mises stress for different parts of the joints,

a. Case 1(Without External loads)

In this part stress analysis of the components in pretension condition is carried out by finite element methods. The boundary conditions and meshing are the same mentioned in the above calculations.

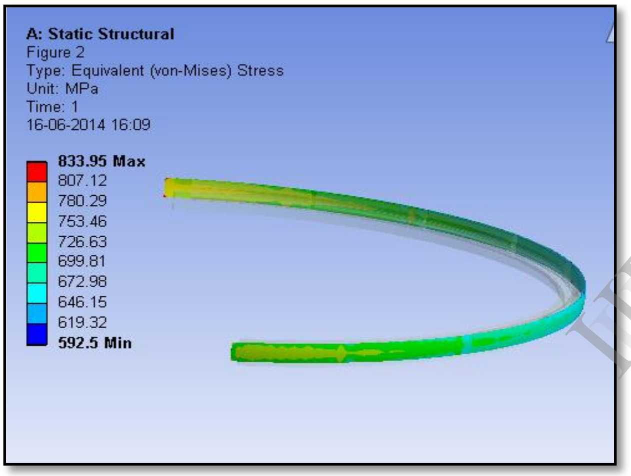

Fig.11, Equivalent von mises stress generated band

In this section the stress analysis of the band is done separately and the equivalent von mises stress calculated

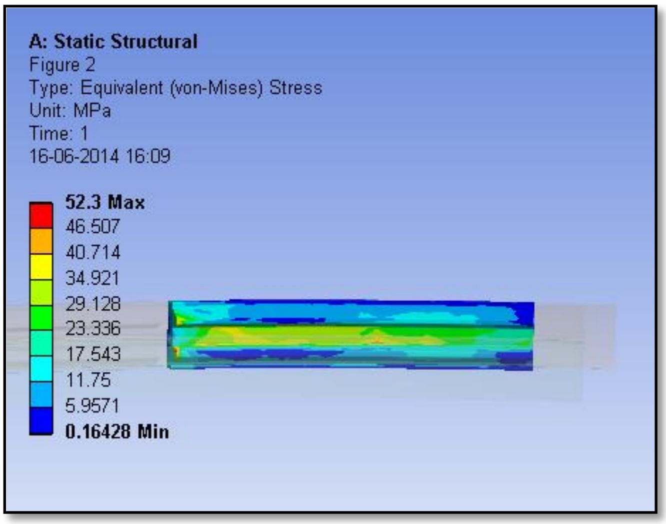

Fig.12, equivalent von-Mises stress generated in the clamp

Here we are analysing complete wedge block assembly and the result obtained foe single wedge block is shown below

During ground conditions the stresses acting on the two flange assembly is shown below. The equivalent von mises stress is calculated using ansys and it is shown below.

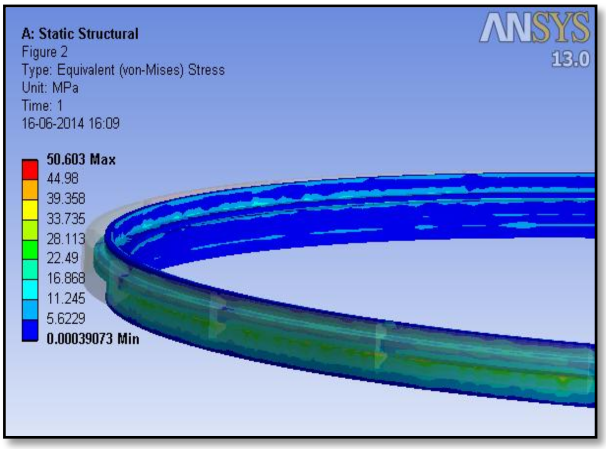

Fig.13, Equivalent von mises stress acting in the flanges

b. Case II.(With external load)

The stress in the flight condition is studied here using ANSYS. In this condition an external load is also acting on the joint .the effect of external load is analysed using FE analysis.

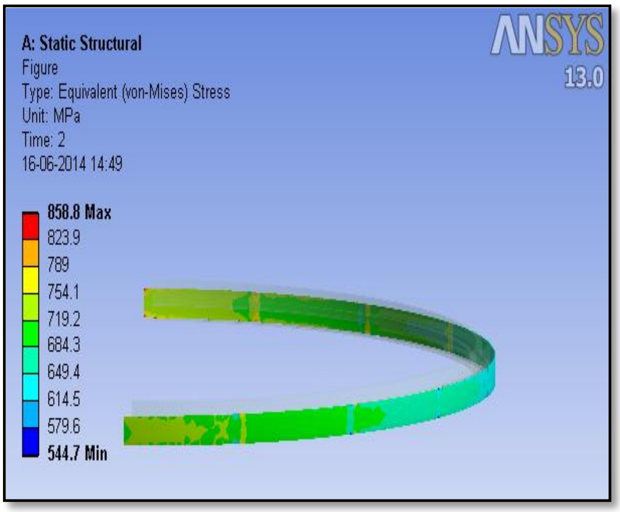

Fig .14, Von-mises stress in the band

The equivalent von mises stress is calculated using FE analysis for wedge block assembly is conducted and the result obtained for single wedge block is shown in figures below

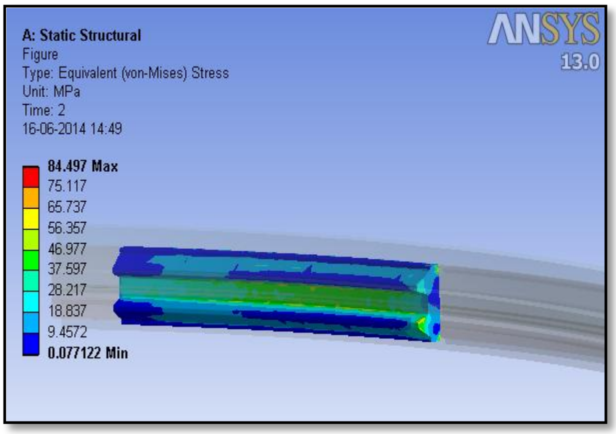

Fig.15,Equivalent von mises stress in single wedge block

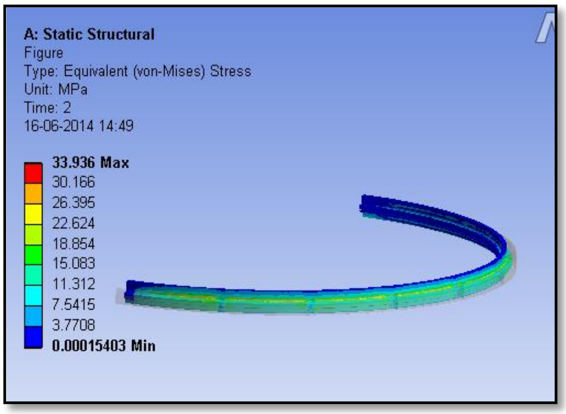

Fig .16, Equivalent von mises stress in the fanges

IV. RESULT

By analysing the3D model of the merman band joint we get different values of stress and strain for two loading condition the maximum deformation is occurred in the band due to the tensile load applied in it. the maximum value is 3.536mm .The stress generated in the different components is analysed and compare that values with the ultimate stress. Ultimate tensile stress for structural steel is between 400-500 Mpa and the ultimate stress for aluminium alloy is 483Mpa .The maximum von mises stress in the band is 833.95 Mpa the stress analysis gives values that are comparatively larger than the ultimate tensile stress in some areas so the chance of failure is maximum at that points ,in order to achieve safety we must change the loading conditions or make changes in the design to withstand higher loads. , Only a simplified model is considered here for analysis in the actual condition the structural capabilities of the joint are slightly different.

V. CONCLUSION

In this paper Finite Element analysis of merman band joint used for launch vehicles is carriedout the conclusions are summarised as follows.

- In this work the main intention is to study the joint characteristics by modelling and analysing with Pro-E and ANSYS software.
- For analysis part a simplified model of the typical merman band joint is used to avoid the convergence difficulties and the difficulties in analysis due to the non linearity of the system.
- The calculation is done in two step one is considering the external load (flaying sate) and without considering the external load ,only pretension load is considered (ground state)
- The deformation produced in the different parts at two different loading conditions is calculated using FE analysis.
- The stress produced in the different components in different loading conditions is calculated.
- The finite element analysis gives a complete picture of mechanical behaviour of the of clamp band joint, and design guidelines without costly experiments.

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