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Estimation of Residual Stresses in Rail section using FEM

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***Abstract*— Stresses analysis plays important role in product design. Prior estimation of stresses in the structure helps in load carrying capacity of the members without fail. Metal forming is an important process in the product life cycle. During metal forming operations, the structure is heated and formed to the required shape. But due to higher heating cooling, certain residual stresses will form in the structure and are the potential source of cracks. So special care need to be considered to avoid the residual stress formation in the structures during forming process. Present work is carried out to find the different cooling times required based on the type of cooling film coefficients. The result shows drastic temperature loss in the beginning of the cooling cycle and slower in the later process. Even stresses are almost linear relation to cooling rates. Maximum stresses are generated at the web flange interface for rail section .**

***Keywords*— Residual stresses, Rail section, FEM.**

I. INTRODUCTION

1.1 General

Thermal simulations play an important role in the design of many engineering applications, including internal combustion engines, turbines, heat exchangers, piping systems, and electronic components. In many cases, engineers follow a thermal analysis with a stress analysis to calculate thermal stresses (that is, stresses caused by thermal expansions or contractions).

The study of thermal stress is important aspect in design as they may results in mechanical failure of components. Thermal stresses are developed in body whenever any part is prevented from assuming the size and shape that it would freely assume under a change in temperature or two materials with differing thermal coefficients of expansion are used in design.

1.2 Structural Thermal Analysis

Structural thermal analysis in the past were performed using analytical methods, which required a number of assumptions and simplifications. In general, structural thermal analysis are multidisciplinary, including calculations related to the both temperature distribution and thermal stresses.

As computers have become more and more powerful, people have tended to use numerical approaches to develop theoretical models to predict the effect of whatever is studied. This has improved structural thermal analysis and computer simulations. Numerical methods can potentially provide more accurate solutions since they normally require much less restrictive assumptions. The model and the solution methods, however, must be chosen carefully and validated to ensure that the results are accurate and that the computational time is reasonable.

II.METHOD AND METHODOLOGY

The Finite Element Analysis is carried out by using ANSYS tool for calculating the temperature distributions and thermal stresses on a flanged pipe joint. Concepts of heat transfer are summarized first, followed by a discussion thermal loads and boundary conditions.

This work is primarily concerned with thermal stress analysis. Temperature and temperature gradients are important causes of stress. Accordingly, for our purpose, “thermal analysis” means primarily the calculation of temperatures with in a solid body. A byproduct of temperature calculation is information about the magnitude and direction of heat flow in the body. The resulting temperatures from thermal analysis are used in structural analysis to calculate thermal stresses. Thus it is important to understand different methods of engineering analysis and their capabilities.

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III.FINITE ELEMENT MODEL DEVELOPMENT

A.Geometrical Model Specification:

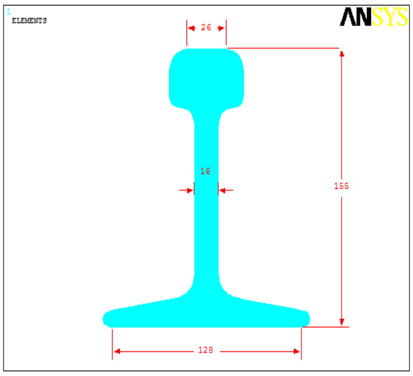

Fig3.1: Standard rail section

The figure 3.1 represents the rail section with dimensions. The above section is taken from the standard rail sections available from the standard sections. The dimensions are shown in the figure. The geometry is built in the Ansys software using mixed approach. Initially key points are built and lines are used to build the geometry. By joining the lines, geometrical area is built.

B. Material Properties:

TableMaterial properties

Material : Steel	Properties
Thermal Conductivity	42 w/m ^{0}c
Specific heat	465
Density	7804kg/m^{3}
Young's Modulus	200GPa
Poison's ratio	0.3
Thermal expansion coefficient	11.7

C. Meshed Plot

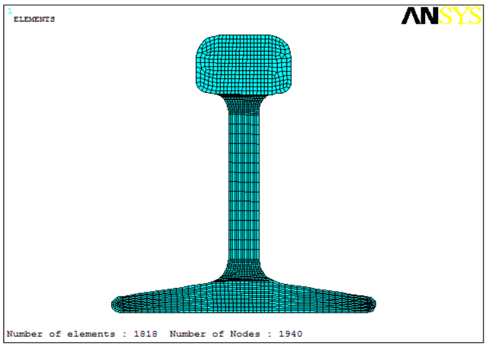

Fig 3.2: Meshed Plot of the problem

The meshed plot is shown in the above picture. The 4 noded elements are used for meshing the problem. Initially the geometry is split into 4 sided areas to ease quad meshing as the quad mesh gives better accuracy compared to the triangular mesh. From the basic definition of element derivation, triangular elements are more stiffer compared to the quad elements due to which accuracy is less.

C. Boundary Conditions:

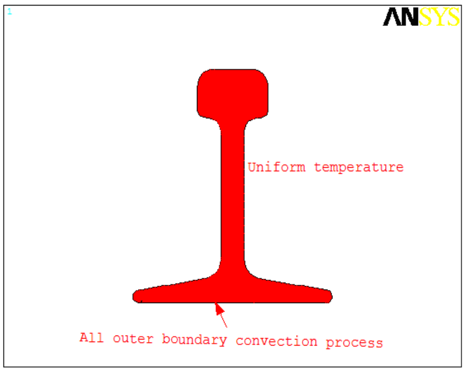

Fig 3.3 Thermal boundary conditions of the problem

The figure shows boundary conditions of the problem. The structure is initially subjected to a uniform temperature of 1200 ^{0}c. The structure is subjected to convective cooling on the outer surface. The loading is considered from the end of forming process. The problem is studied for effect of convective heat transfer on the residual stress formation in the structure.

IV RESULT ANALYSIS

WITH SLOW COOLING RATES

Case 1: With convection film coefficient: 10 w/m^{0}c

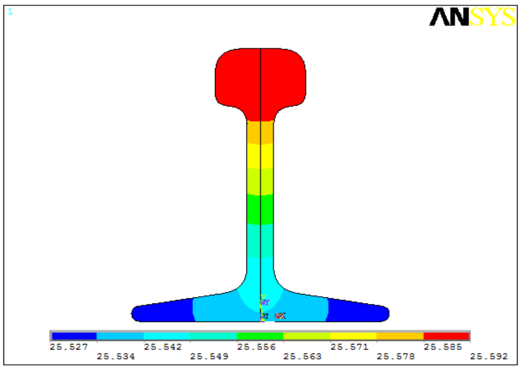

Fig 7.1: Temperature distribution after 25000 secs(~7 hours)

The figure shows temperature distribution after 25000 secs cooling. The temperature is almost at room temperature of 25 ^{0}c. Almost uniform temperature can be observed in the structure.

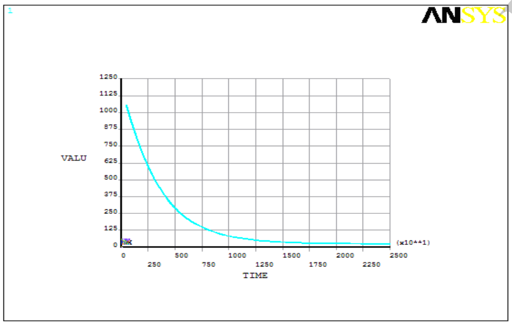

Fig 4.2: Transient heat cooling for 25000 secs.

The figure shows temperature drop in the problem along with the time. Intial drop of temperature is more compared to the end stage. This can be attributed to higher drop of temperature with increased difference between surrounding and object temperatures.

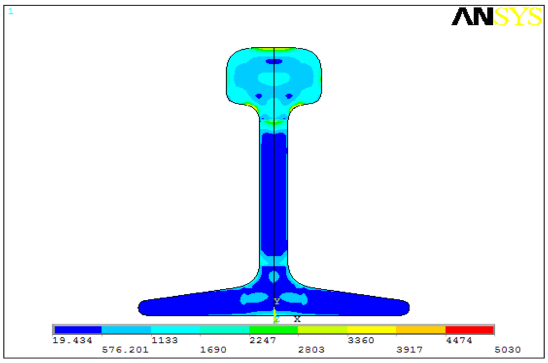

Fig 4.3: Residual stress formation in the structure.

The figure shows very little residual stress with longer cooling cycle. The stress is 0.005030 N/m^2(Almost negligible stress). The stress is minimum in the bottom region and slightly high at higher geometrical variation regions. In the middle section almost negligible stress can be observed.

Case 2: Convection film coefficient: 40 w/m^{0}c

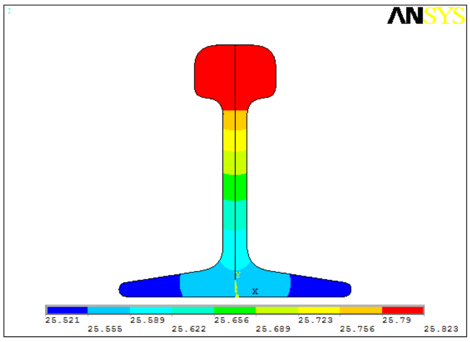

Fig 4.4: Temperature distribution after 7500 secs(~2 hours)

The figure shows temperature distribution after 7500 seconds of cooling. The temperature is almost at room temperature of 25 ^{0}c. Higher temperature can be observed at the top compared to the bottom. This can be attributed to the higher cross section compared to the bottom region which takes more time for cooling. Slightly more temperature also can be observed in the web region.

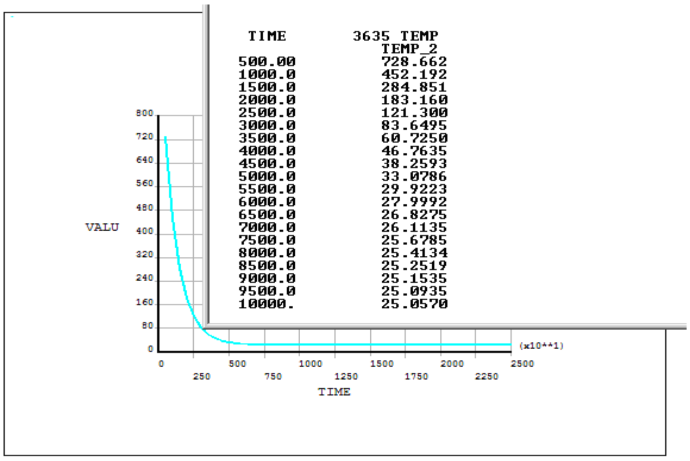

Fig 4.5: Temperature drop for 7500 Secs.

The figure shows temperature drop in the problem along with the time. Listing of the temperatures with time is represented .The values shows dropping temperature with time. The temperature is almost 25. 6785 ^{0}c after 7500 secs which is room temperature applied in the problem. In all the pictures, it can be observed that after 500 secs, the drop is almost negligible.

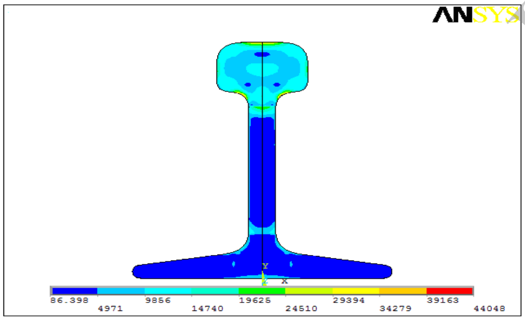

Fig 4.6: Residual stress formation in the structure.

The figure shows very little residual stress with longer cooling cycle. The stress is 0.044048 N/m^2 (Almost negligible stress). The stress is minimum in the bottom region and slightly high at higher geometrical variation regions. In the middle section almost negligible stress can be observed.

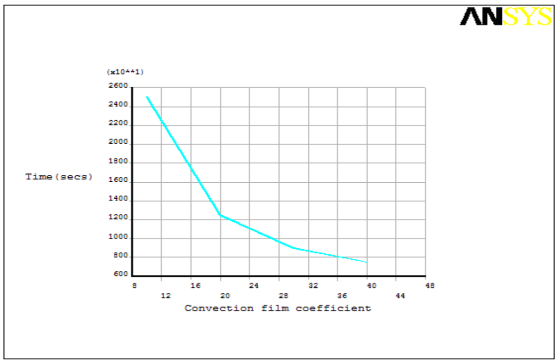

Fig 4.7: Graphical representation of convection film coefficient to Time

The graph shows reduced to cooling time with increased convection film coefficient. This higher convection film coefficient can be obtained by forced circulation of air etc.

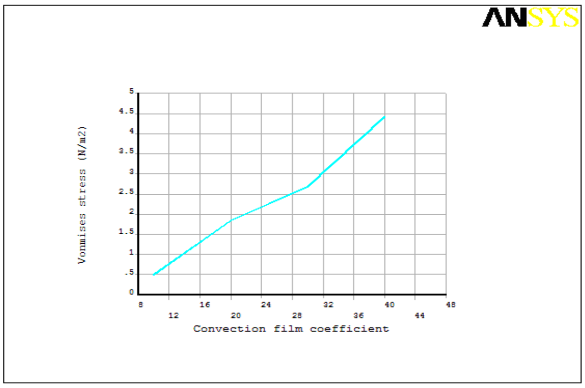

Fig 4.8: Stress variation with convection film coefficient

The figure shows stress increase with higher convection film coefficient. The stress increase is almost linear.

WITH FAST COOLING RATES

DRASTIC QUINCHING RATES:

Case 3: Convection film coefficient: 1000 w/m^{0}c

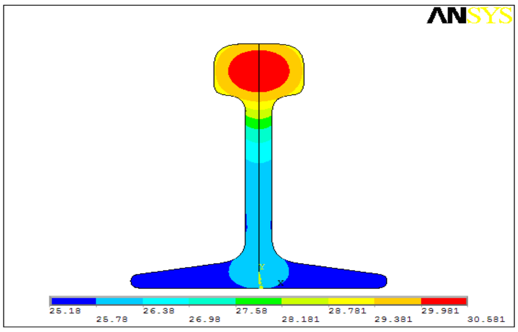

Fig 4.9: Temperature distribution after 258 secs

The figure shows temperature distribution after 258 seconds of cooling. The temperature is almost at room temperature nearing 25 to 30.1^{0}c. Higher temperature can be observed at the top center compared to the bottom. This can be attributed to the higher cross section compared to the bottom region which takes more time for cooling. Temperature drop can be observed from the top of web to lower web.

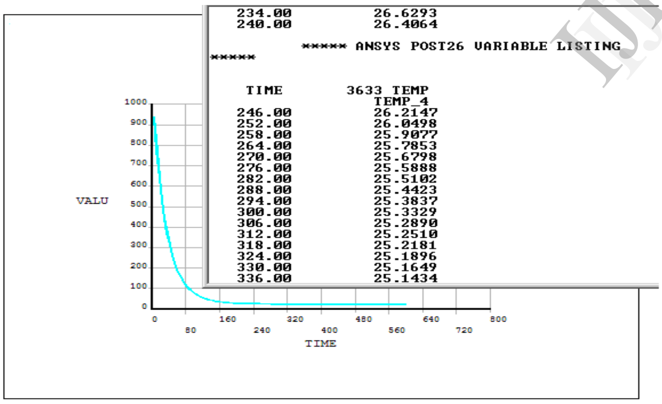

Fig4.9: Temperature drop for 258 Secs.

The figure shows temperature drop in the problem along with the time. Listing of the temperatures with time is represented. The values shows dropping temperature with time. The temperature is almost 25.9 ^{0}c after 258 secs which is room temperature applied in the problem. Also from the graph it can be observed that steeper temperature drop can be observed upto 160 seconds and later slope is very less indicating slow process of heat transfer.

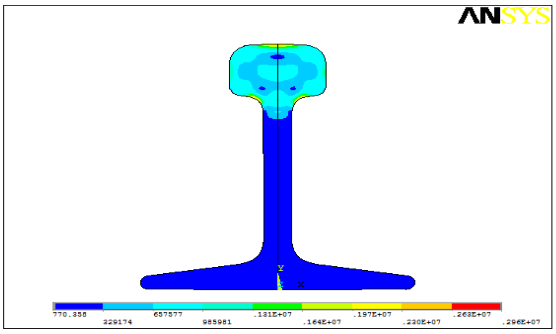

Fig 4.10: Residual stress formation in the structure.

The figure shows residual stress with shorter cooling cycle. The stress is 2.96Mpa at the web and flange interface. The stress is minimum in the bottom region and higher at the top region. This can be attributed non availability of time for heat transfer from the central regions of the thicker flange section.

Case4: Convection film coefficient: 4000 w/m^{0}c.

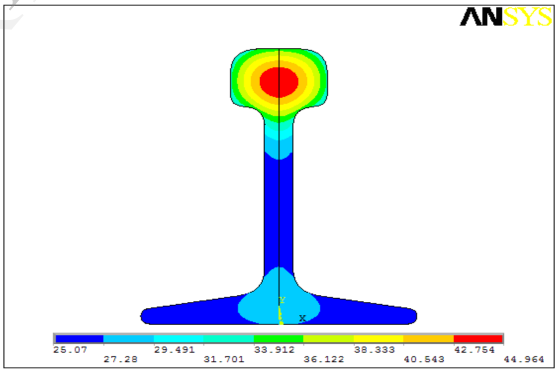

Fig 4.11: Temperature distribution after 84 secs

The figure shows temperature distribution after 84 seconds of cooling. The results indicates the temperature inside the body at higher cross section is more cooling slower whereas outer parts cooled fast and temperature drop is more. Due to the difference of temperature inside and outside boundary, residual stresses are forming the structure.

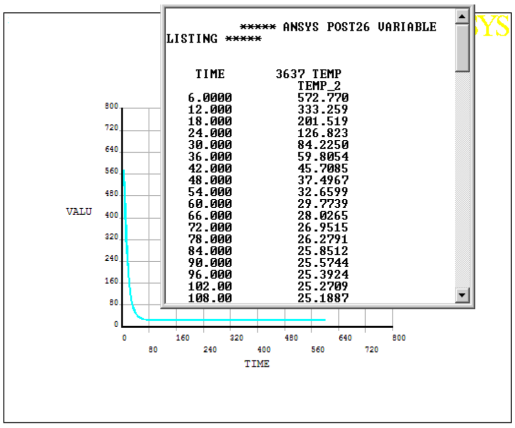

Fig 4.12: Temperature drop for 84 Secs.

The figure shows temperature drop in the problem along with the time. Listing of the temperatures with time is represented. The values shows dropping temperature with time. The temperature is almost 25. 85 ^{0}c after 84 secs which is room temperature applied in the problem. In all the pictures , it can be observed that after 50 secs, the drop is almost negligible.

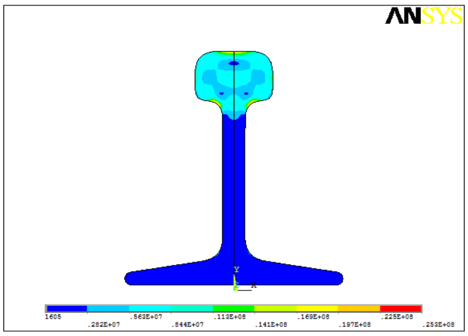

Fig 4.13: Residual stress formation in the structure.

The figure above shows higher residual stress formation in the structure. Maximum stress of 25.3Mpa is taking place at the interface web and flange. This can be attributed to overlap of stress flow lines across sharp geometrical variation regions and due to retained deformation at the inner side of the geometry.

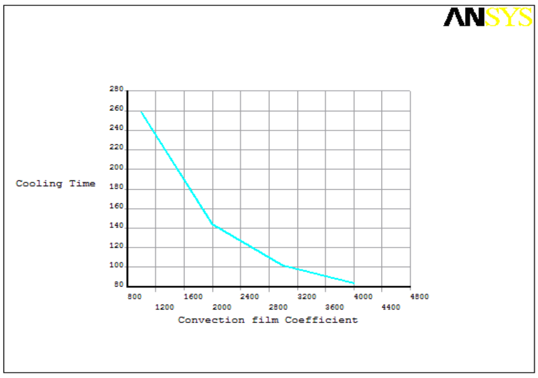

Fig 4.14: Cooling rate with reference to Convection film coefficient

The cooling time reduction with higher convection film coefficient can be observed from the graph. A continuous drop of cooling times can be observed in the graph.

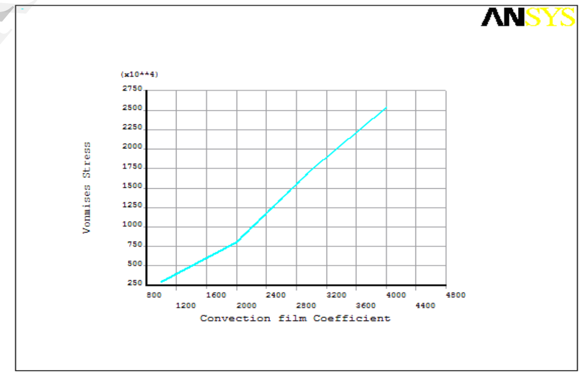

Fig4.15: Convection film coefficient with Vonmises stress

A linear relation can be observed. With higher convection film coefficients, stress increase can be observed.

COMBINED GRAPHS

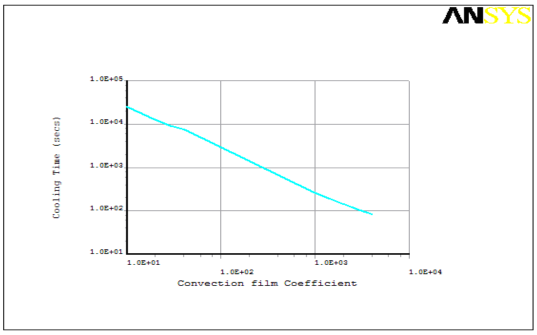

Fig 4.16: Log graph for convection film coefficient and cooling time

The graph shows a linear relation between the cooling rates and the cycle time. There is a continuous drop can be observed in the graph.

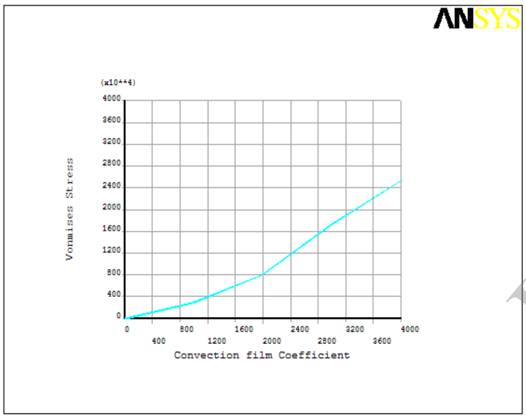

Fig 4.17: Convection film coefficient Vs vonmises stress

The figure shows relation between cooling rate and stress. Almost there is a gradual increase of stress throughout the cooling cycle.

V.RESULT DISCUSSION:

A standard Rail section is modeled and analyzed for residual stress conditions. Cooling rate is an important parameter influencing the residual stress formation in the structure. Any residual stress is the source for crack propagation and eventual failure of the structures under fatigue loads .So present work is checked for different cooling rates and resulting stress condition and zones of stress concentration. Initially the member is placed at 1200^0c initial condition. The convection loads are applied on the periphery of the geometry. The quad meshed model with plane55 element is used for analysis. Initially the structure is checked with low convection coefficients and later checked with drastic quenching conditions. The results shows the uniformity and drop of cooling time with higher convection film coefficients. The convection film coefficient with 10 w/m^0c shows 25000 seconds cooling time and gradual increase from 10 to 40 shows dropping cooling time levels of 12500, 9000 and 7500seconds. But the stresses are increasing from 0.005N/m^2 to 0.018,0.0268,0.044N/m^2. But the cooling curve shows a drastic drop of temperature and later very slow cooling rates. This can be attributed to higher temperature values in the beginning. Further analysis has been carried out with higher cooling rates. The results are similar to the initial trends but the development of considerable residual stresses in the structure, with stress reaching upto 25.3Mpa .So higher rate of cooling is the region of crack formation in the forming members. Also the stress concentration can be mainly observed near the web flange interface where sharp geometrical variation can be observed.

VI.CONCLUSION

The Finite Element Model and solution procedures are developed for Transient Thermal / Thermal – Structural Analysis. Finite Element Analysis is performed using ANSYS package. The analysis summary is follows.

A standard rail section is considered for analysis. The rail section is analyzed for residual stresses formation with different cooling rates. Initially the meshed structure is applied with lower cooling rates or with lower convection film coefficients. But with the lesser convection film coefficient values, residual stress generation is very small and can be neglected. But with higher cooling rates, the residual stress formations are high and considerable. The results shows with higher convection film coefficient a stress generation of 25.3Mpa can be observed. This value is very high as any further addition of stresses due to normal structural loads, results into a weaker zone and source for crack formation or location for failure. So this anlaysis helps in predicting the cooling time and cooling rate requirements for given allowable stresses. Also stresses can be estimated with different cooling members during forming process.

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