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Structural Analysis of Turbine Blade Disc Fir-Tree Root Using ANSYS

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Abstract: ***In the present work, the analysis is carried out to find the stress nature in the fir-tree attachment of bladed disc configuration. The joint is critical for safety of the functioning of the turbine. So a three dimensional model is built and contacts are created between blade and disc fir-tree region. Using Solid Edge V19 a three dimensional model is prepared for different skew angles. The models are analysed using ANSY 14.0. The result shows that the skew angle has an effect on performance of the turbine disc assembly. It was found that the 40^0 skew angle is best suited for fir-tree joint, which gives minimal deformation and stress at higher temperature and Ti6242S is also the best material for turbine fir-tree disc attachment.***

Keywords: FEA, ANSYS, Turbine Blade, Fir-tree Joint, Turbine Disc

1. Introduction

The rotating discs are highly stressed components in aircraft engines. It is used to develop power to drive compressor and other accessories. Turbine disc has to sustain various kinds of loads such as inertia, pressure, thermal loads. etc. The gas turbine engines safety has always been the main concern of aircraft maintenance. Different methods are adopted in fastening turbine blades to disc. These are: pin joint, dovetail and fir-tree but Fir-tree fasteners are commonly implemented in turbine because they provide multiple areas of contact over which large thermal and centrifugal stresses can be accommodated. G. D. Singh and S. Rawtani discussed the effect of different parameters individually on deformation pattern of the blade root. They studied Fir Tree root individually for stiffness characteristics at the top and bottom neck for normal step load, tangential friction load due to contact between the blades. Deformations of the root for different values of applied load were determined based on finite element model. [1] Rajasekaran et al. have shown that by employing a penalty formulation, the state of partial slip can be predicted incorrectly as full sliding whereas a Lagrange formulation predicts the correct slip-stick behaviour and it is found that the Lagrange multiplier approach predictions match the analytical results well, but prediction by the penalty formulation is sensitive to slip tolerance selected [2]. Wenbin Song et al. has carried out automation and optimization of the design of a turbine blade fir-tree root by incorporating knowledge based intelligent computer-aided design system (ICAD) and finite element analysis. The fir-tree joint is a critical component which is subject to high mechanical loads and used to transfer loads from blade to disk. The loading on the root is mainly due to centrifugal load which is dependent on the mass of the whole blade. They have carried out fir-tree root optimization using a two-stage hybrid strategy combining gradient-based methods [3]. JianfuHou et al. have used non linear finite element method to determine the stress and dynamic characteristics of turbine blade. They imposed an appropriate displacement constraint to maintain cyclic symmetric boundary condition for the disc. Interaction between the blade fir-trees and disc fir-trees were represented using general surface to surface contact centrifugal forces which are generated by rotation of disc. The peak stress occurs at trailing corner of top fir-tree and not at the leading edge where failure occurred [4].

2. Materials

Material selection in any designing process or mechanical study plays an important role in understanding the adaptability and feasibility of the design to carry out its intended function efficiently and effectively. The material selection in our study is mainly based on the following factors. They are corrosion resistance, resistance to high thermal stress, impact strength, and fatigue strength and with the above parameters light weight is most important. In this study the following materials are selected and they are shown in Table 1, [5] which satisfies the above material selection criteria.

Table 1: Material Properties

Materials	Mechanical			Physic-al	Thermal	
	Y(Gpa)	G(Gpa)	υ	ρ (g/cc)	T(^{0}C)	CTE
Ti6242	120	45.5	0.32	4.54	20	7.7
Ti6242S	118	44.5	0.32	4.54	00-100	7.7
Alloy832	120	45.8	0.31	4.55	20-200	10.6
Alloy 685	125	47.0	0.33	4.45	20-200	9.50

3. Method

A fir-tree three dimensional CAD models are generated using Solid Edge V19 which is shown in Fig. 1. These models are prepared for different skew angles. Further the models are imported in ANSYS 14.0 and meshing is carried out as shown in Fig.2.

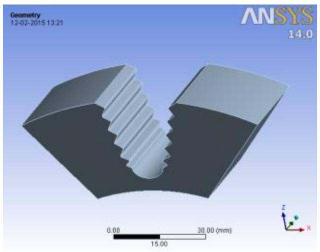


Figure 1: Fir-Tree CAD model

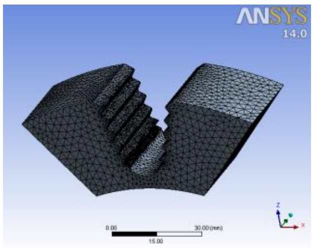
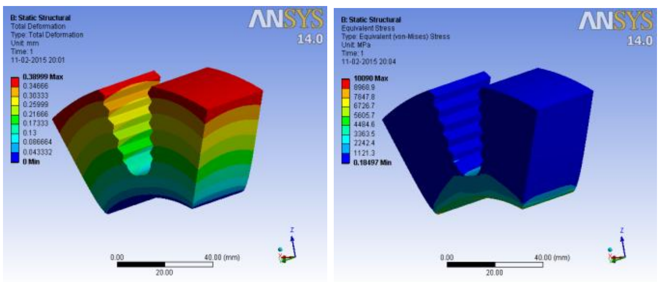


Figure 2: Meshed Model

Meshing of the model is performed using SOLID 186 elements (since the element supports creep, stress stiffening, large deflection, and strain capabilities). The bottom curvature is fixed and a pressure load of 3 MPa is taken as boundary conditions along with varying temperatures (1000^0C and 2000^0C) for different Titanium alloys and different skew angles of fir-tree joint.

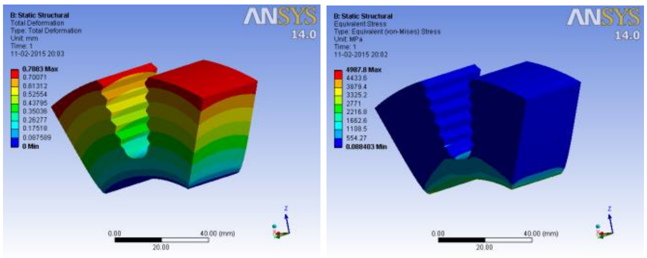
4. Result and Discussion

Static structural analyses are performed along with Steady state thermal analysis of the fir tree joint and the following results were obtained. The Fig. 3-8 shows the variation of stresses and total deformation for 1000^0C and 2000^0C for (30^0 to 50^0 (increment of 5^0)) different skew angles.



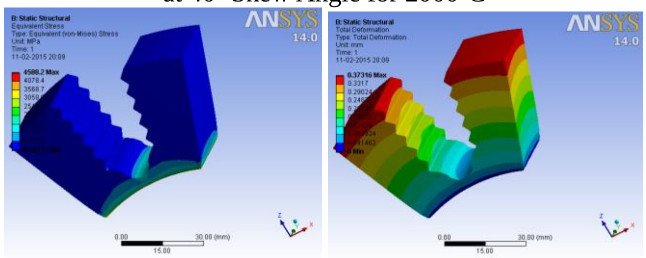
3(a) 3(b)

Figure 3: Total Deformation 3(a) and von- Mises stress 3(b) at 40^0 Skew Angle for 1000^0C



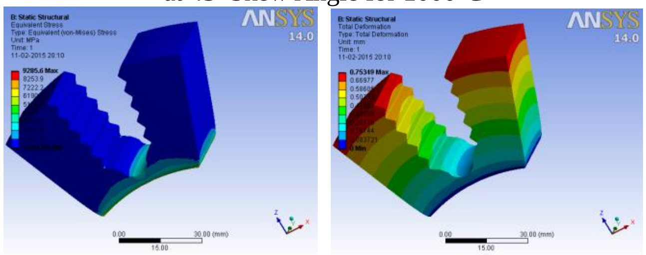
4(a) 4(b)

Figure 4: Total Deformation 4(a) and von- Mises stress 4(b) at 40^0 Skew Angle for 2000^0C



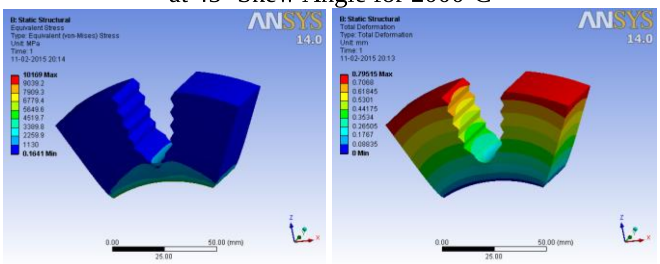
5(a) 5(b)

Figure 5: Total Deformation 5(a) and von- Mises stress 5(b) at 45^0 Skew Angle for 1000^0C



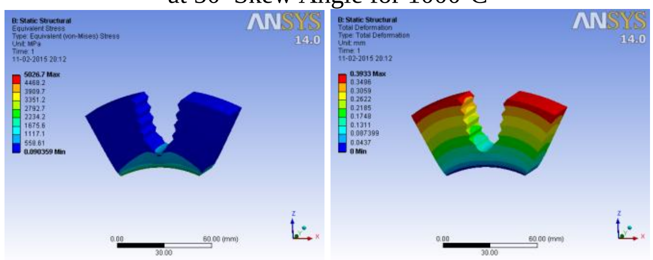
6(a) 6(b)

Figure 6: Total Deformation 6(a) and von- Mises stress 6(b) at 45^0 Skew Angle for 2000^0C



7(a) 7(b)

Figure 7: Total Deformation 7(a) and von- Mises stress 7(b) at 50^0 Skew Angle for 1000^0C



8(a) 8(b)

Figure 8: Total Deformation 8(a) and von- Mises stress 8(b) at 50^0 Skew Angle for 2000^0C

The results for 1000^0C different material and skew angles are shown in Table 2-3, the results are compared. The Fig 9 and 10 shows the total deformation and von- Mises stress vs. materials for different skew angles at 1000^0C. 30^0, 35^0, 45^o and $50^o$are displayed minimum deformation for Ti6242S material as compared to any other materials. Whereas 40^0

skew angle exhibits least total deformation as compared to the same skew angles for the same materials.

For von-Mises stress 35^0 skew angle exhibits more stress value whereas 45^0 skew angle exhibits a constant stress variation but 40^0 and 50^0 skew angles exhibits displays a least stress variation for Ti6242 and Ti6242S as compared to other materials.

Table 2: Results for Total Deformation at 1000^0C

Materials	Different Skew angle				
	30°	35°	40°	45°	50°
Alloy 685	0.12	0.19	0.23	0.22	0.26
Alloy 832	0.24	0.21	0.26	0.26	0.26
Ti6242	0.12	0.19	0.19	0.22	0.23
Ti6242S	0.17	0.16	0.19	0.18	0.19

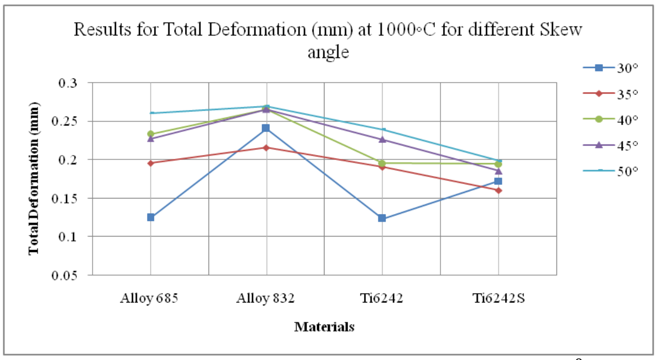


Figure 9: Results for Total Deformation at 1000^0C

Table 3: Results for von-Mises Stress at 1000^0C

Materials	Different Skew angle				
	30°	35°	40°	45°	50°
Alloy 685	0.12	0.32	0.11	0.16	0.11
Alloy 832	0.23	0.35	0.12	0.15	0.13
Ti6242	0.11	0.28	0.088	0.15	0.11
Ti6242S	0.09	0.24	0.08	0.16	0.09

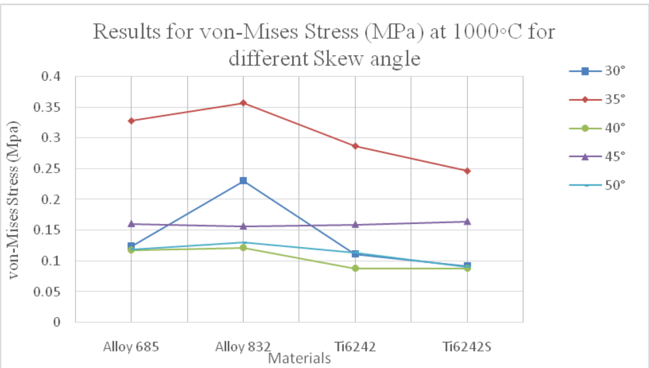


Figure 10: Results for von-Mises Stress at 1000^0C

Table 4: Results for Total Deformation at 2000^0C

Materials	Different Skew angle				
	30°	35°	40°	45°	50°
Alloy 685	0.48	0.43	0.53	0.51	0.43
Alloy 832	0.54	0.49	0.60	0.45	0.48
Ti6242	0.48	0.43	0.35	0.40	0.430
Ti6242S	0.39	0.35	0.35	0.41	0.35

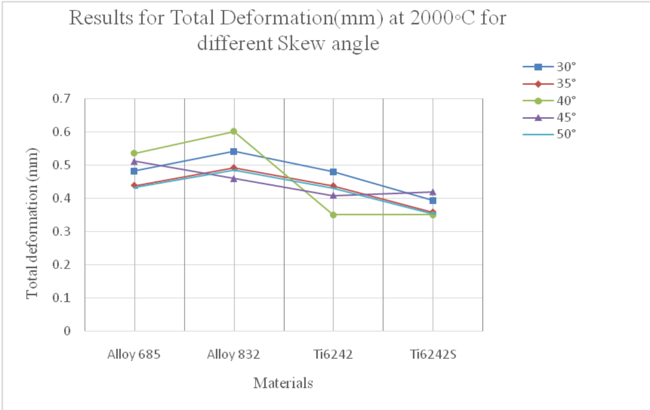


Figure 11: Results for Total Deformation at 2000^0C

Table 5: Results for von-Mises Stress at 2000^0C

Materials	Different Skew angle				
	30°	35°	40°	45°	50°
Alloy 685	0.25	0.51	0.24	0.13	0.17
Alloy 832	0.45	0.56	0.25	0.11	0.18
Ti6242	0.22	0.59	0.18	0.13	0.17
Ti6242S	0.18	0.47	0.18	0.09	0.16

Table 4 and 5 shows the tabulated results for different materials, different skew angles at 2000^0C. From these results it is found that 40^0 and 45^0 skew angles exhibits minimum deformation for Ti6242S whereas 45^0 skew angle exhibits least stress value as compared to skew angles for Ti6242S material and these results are shown in fig 10-12.

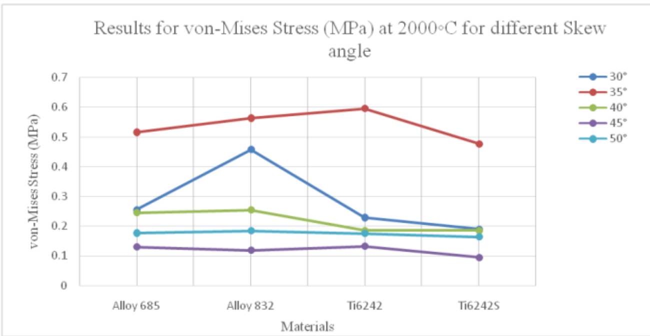


Figure 12: Results for von-Mises Stress at 2000^0C

5. Conclusion

The blade disc fir tree has been analyzed using both static structural and static thermal analysis. It is found that a Ti6242S material is best suited at high temperatures and different skew angles for the blade disc fir tree attachment. The results which were obtained in this study showed a least stress variations for skew angle 40^0. Whereas the deformations which are the major factor contributing to the life of a turbine disc fir tree attachment was also found minimal for 40^0 skew angle. This study can be extended further on non-linear analyses along with optimization techniques for the fir tree attachment, which in turn minimizes the wear and failure rate.

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