CAME 56

COMPARSION OF THERMOELASTIC RESULTS IN TWO TYPES OF FUNCTIONALLY GRADED BRAKE DISKS

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ABSTRACT *Thermoelastic simulation of functionally graded (FG) brake disk using finite element (FE) ANSYS software is performed. The material properties of two types of FG brake disks are assumed to vary in radial and thickness direction according to a power law distribution. The brake disks are in contact with one hollow pure pad disk. Dry contact friction is considered as the heat source. The proper thicknesses of pad disks are found to have full-contact status. The behavior of thermoelastic results for thickness and radial FG brake disks are compared. The results show that the behavior of temperature and vertical displacement in these two types of FG brake disks are the same. On the other hand, the variations of radial displacements for different grading indices n are not the same. The behaviors of other results are quite the same. It can be concluded that the variation direction of material properties in FG brake disk can affect the results.* ***Keywords:*** *functionally graded material, finite element method, brake disk, thermoelastic.*

INTRODUCTION

Functionally Graded Materials (FGMs) are materials in which the volume fraction of two or more constituents materials varied smoothly and continuously as a function of position along certain dimension(s) of the structure from one point to the other [1, 2]. Some works have been done using finite element method to obtain the thermomechanical response. Shahzamanian et.al [3-4] simulated FG brake disk to investigate the contact status and thermoelastic analysis. The steps of simulation of FG brake disk are described and the results are obtained for different values of contact stiffness factors and gradation indices. Yong, H. J and Ahn, S.H. [5] analyzed the instability in FG brake disk with variation of material properties in thickness direction. The results are presented in different times. Gao, C.H and Lin, X.Z. [6] obtained the temperature distribution in a three-dimensional brake disk by using FEM at different time. Pure pad disk is considered as a sector. In the present study, a FG hollow rotating brake disk with inner radius r_i, outer radius r_o, thickness, h and axisymmetric with respect to z-axis subjected to contact with one homogenous material hollow disk is analyzed. The material properties of the constituent components of two types of FG brake disks are assumed to be represented by a power law distribution with the radius and thickness of disk. Friction is considered to be the heat source that causes the thermal stresses. The thermoelastic results of FG brake disks with variation of material properties in radial and thickness direction are compared.

GRADATION RELATION

In the present study, the property variation, P, of the material in the FG disk along the radial, r, and thickness, z, direction are assumed to be of the following forms in equations 1-2 respectively [7, 8]: ()(),nioiioirrPrPPPrr· · −=−+· · −· · iorrr<< (1) 22()1;0;2222nncmzhzhhhPzPPnzhh· · ++ · · · · =+−≥−≤≤· · · · · · · · · · · · · · · (2) where, P_c, P_m and n are pure ceramic properties, pure metal properties and grading index respectively.

FINITE ELEMENT METHOD (FEM)

Finite element ANSYS software is used to present the results. For thermomechanical loads, plane 13 element, is applied for the brake disk and pad disk. Targe 169 and Conta 171 element are used for brake and pad disks respectively to define the contact surfaces. The FG brake disk is divided into two hundred elements. . The mesh division for radial and thickness FG brake disk is presented in Figures 1-2 respectively. Increasing number of the elements generally will improve the accuracy of the results. ANSYS Parametric Design Language (APDL) is used

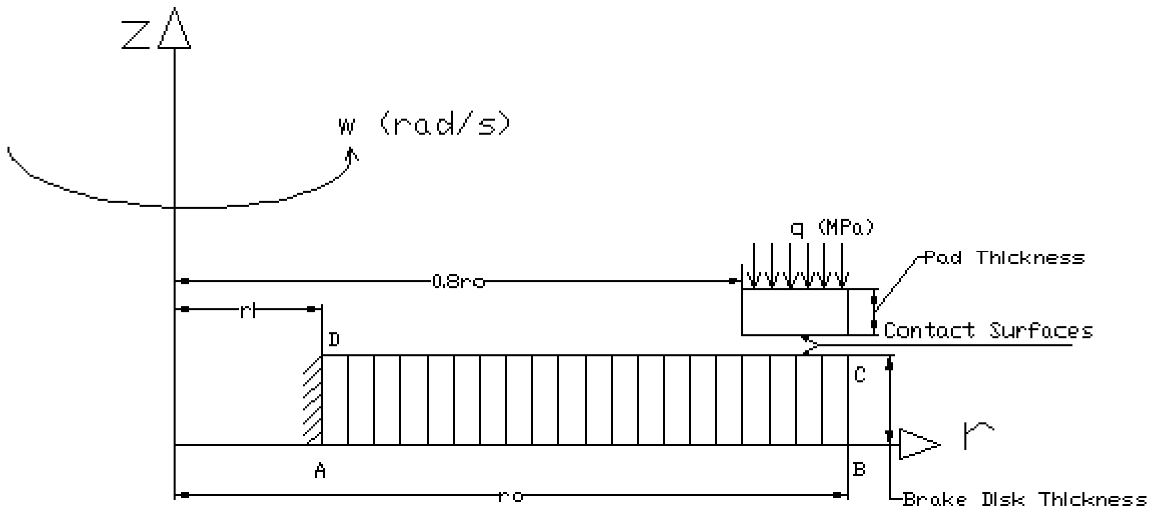

Figure 1: Mesh division for radial FG brake disk

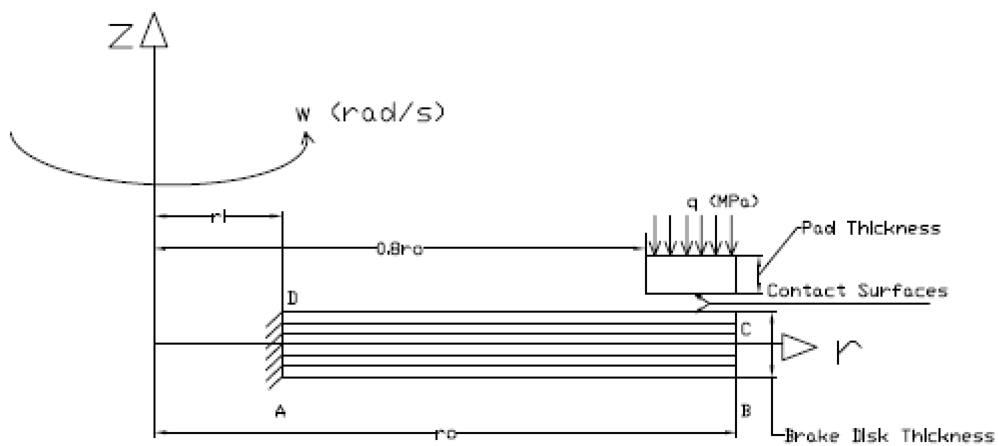

Figure 2: Mesh division for thickness FG brake disk

In the case of thermal and structural, the rate of frictional dissipation $_{T}Q$ is given by:

$_{Tf}QHqV\mu = \times\times\times$ (In this case $_{f}H = 1$) (3)

where $V$is the sliding rate, $_{f}H$is the frictional dissipated energy converted into heat, $\mu$is the friction coefficient and $q$is the contact pressure.

MECHANICAL BOUNDARY CONDITION FG brake disk is mounted onto a shaft at the inner surface. Hence, the boundary conditions are as follow: $u_r = 0$ at $r = r_i$ (4) $\sigma_r = 0$ at $r = r_o$ (5)

CONTACT STATUS CONSIDERATION To achieve a full-contact problem between the FG brake disk and pure pad disk, contact status of both radial and thickness FG brake disks are investigated for different gradation indices [3-4]. In this case, the pad thickness value of 0.65 make full-contact status in radial and thickness FG brake system for all of the values of gradation indices which are applied to present the thermomechanical results.

RESULTS AND DISCUSSION A FG brake disk with $R_o = 5 R_i$ and $h_{brake} = 10\,mm$ subjected to centrifugal force due to constant angular velocity $\omega = 1000.0\ rad/s$ and vertical pressure due to pad $q = 1000.0\ KPa$ is considered. The friction coefficient between pad and brake disk for radial FG brake is $0.75 \le \mu \le 1.4$. For the FG brake disk, the ceramic surface is in contact with pad disk. Thus, friction coefficient between the pad and disk is equal to $\mu = 0.75$. A pad disk with $R_{o,pad} = 1.25 R_{i,pad}$ is considered when $R_{o,pad} = R_o$. The material properties applied are shown in Table 1 [3-4].

Table 1: Material properties

Material property	$E\ (GPa)$	υ	$\rho\ (Kg/m^3)$	$\alpha\ (1/K)$	$K\ (W/mK)$	$c\ (J/kg.K)$	μ between pad and pure material disk
Partially Stabilized Zirconia (PSZ), Ceramic	151.0	0.3	5700	10×10^{-6}	2.0	400	0.75
Aluminum, Metal	70.0	0.3	2700	23×10^{-6}	209	900	1.4

In the following sections, the results are presented in non-dimensional form by Temperature, displacement, stress and strain are normalized by factors $T_{max}-T_{min}$, $\rho\omega^2 R_o^3/E_{cr}$, $\rho\omega^2 R_o^2$ and $\rho\omega^2 R_o^2/E_{cr}$ respectively. The non-dimensional temperature for radial and thickness FG brake disk at the first contact point $(R = 0.8 R_o)$ are demonstrated in Figures 3-4 respectively.

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 Non-dimensional Radius (R=r/ro) Non-dimensional Temperature n = 1.5 n = 1.0 n = 0.8 n = 0.5

Figure 3: Non-dimensional temperature for radial FG brake disks

Figure 4: Non-dimensional temperature for thickness FG brake disks

It can be seen from Figures 3-4 that the behavior of non-dimensional temperature at the first contact point is same. Non-dimensional vertical displacement in radial and thickness FG brake disk are shown in Figures 3-5. The results show that the variations of these displacements are similar to each other.

Figure 5: Non-dimensional vertical displacement in radial FG brake disks
0.790.80.850.90.951.00 0.20.40.60.8 1.0Non-dimensional Radius(R=r/ro)

Non-dimensional radial displacement for radial and thickness FG brake disk is presented in Figures 7-8 respectively.
Figure 6: Non-dimensional thickness displacement in radial FG brake disks
Figure 7: Non-dimensional radial displacement in radial FG brake disks
Figure 8: Non-dimensional radial displacement in thickness FG brake disks From Figure 7, it can be derived that by increasing the gradation indices, the non-dimensional radial displacement for radial FG brakes disk increases. But this observation on the thickness FG brake disk is different. It can be seen from Figure 8 that the radial displacement for thickness FG brake decreases with the increase of the grading index $n$up to certain value and after that, increasing the grading index resulted in the radial displacement increases up to full metal disk. Non-dimensional radial stress for radial and thickness FG brake are displayed in Figures 9-10 respectively.
0.20.30.40.50.60.70.80.91.0-0.038 -0.035-0.03 -0.025-0.02 -0.015-0.01 -0.0050.0 Non-dimensional Radius(R=r/ro)Non-dimensional Vertical Displacement

0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
Non-dimansional Radial Stress
Non-dimensional Radius (R=r/ro)
Full metal
Full ceramic
n = 0.5 n = 0.8
n = 1.0 n = 1.5
0.75 0.8 0.9 1
-1.8
-1.6
-1.4
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
Non-dimansional Radius (R=r/ro)
Non-dimansional Shear Stress of out-plane
Full ceramic
Full metal
n = 0.5
n = 0.8
n = 1.0
n =1.5
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
-0.75
0
0.877
1.754
2.63
3.51
4.39
4.65
Non-dimensional Radius(R=r/ro)
Non-dimensional Radial Stress
Full Metal
Full Ceramic
n = 1.5
n = 1.0
n = 0.8
n = 0.5
Figure 9: Non-dimensional radial stress in radial FG brake disks
Figure 10: Non-dimensional radial stress in thickness FG brake disks
It can be deduced from Figures 9-10 that non-dimensional radial stress after the first contact point $(0.8)_o RR>$in both radial and thickness FG brake disks for all of the gradation indices are equal to the values of that of full-metal and full-ceramic brake disk. It should be mentioned that before the first contact point $(0.8)_o RR<$for radial FG brake disk, the non-dimensional radial stress for all of the gradation indices are equal and less than that for full-metal and full-ceramic. The reverse is the case for thickness FG brake disk, the non-dimensional radial stress for all of the gradation indices are not equal and their values are bigger than for full-metal and full-ceramic. It is noted that by increasing the gradation indices, the non-dimensional radial stress increases.
The non-dimensional out-of-plane shear stresses are shown in Figures 11-12 for radial and thickness FG brake disks in contact surfaces.
Figure 11: Non-dimensional shear stress of out-of-plane in radial FG brake disks

0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
-0.02
-0.01
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
Non-dimensional Radius (R=r/ro)
Non-dimansional Total Radial Strain
Full metal
Full ceramic
n = 1.5
n = 1.0
n = 0.8
n = 0.5
0.75 0.8 0.85 0.9 0.95 1.0
-0.24
-0.12
0
0.035
Non-dimensional Radius(R=r/ro)
Non-dimensional Shear Stress In-plane Circumferential
Full Ceramic
Full Metal
n = 0.5 , 0.8 , 1.0 , 1.5

Figure 12: Non-dimensional shear stress of out-of-plane in thickness FG brake disks It is seen that for radial and thickness FG brake disks, the values of shear stresses of all gradation indices are equal. Before $R/R_o = 0.8$, the non-dimensional shear stresses in gradation indices for radial FG disks are lesser than those in full-metal and full-ceramic but, this subject for thickness FG disks is vice versa. At $R/R_o = 0.8$, the shear stresses for thickness FG disks are smaller than in full-metal disk and shear stresses in radial FG disks are bigger than in full-ceramic disks. After $R/R_o = 0.8$, the shear stresses of radial and thickness disks have one intersection with the shears of full-metal and full-ceramic disks. In radial FG disks at first the shear stresses of FG disks are greater than full-ceramic and full-metal disks but, this issue for thickness FG disks is different. The non-dimensional total radial stress for radial and thickness FG brake disks are presented in Figures 13-14 respectively.

Figure 13: Non-dimensional total radial strain in radial FG brake disks

0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
-0.1325
0
0.1325
0.265
0.398
0.53
0.66
Non-dimensional Radius(R=r/ro)
Non-dimensional Total Radial Strain
Full Ceramic
Full Metal
n = 1.5
n = 1.0
n = 0.8
n =0.5

Figure 14: Non-dimensional total radial strain in thickness FG brake disks

From Figure 13 and Figure 14, it is noted that the non-dimensional total radial strain for radial FG brake disks are closer to the non-dimensional total strain of full-metal. But, in thickness FG brake disks, the non-dimensional total radial strain is closer to the value of full-ceramic.

CONCLUSION

The thermoelastic analysis of two types of FG brake disks is studied. The material properties of radial FG brake disk vary in radial direction and for thickness FG brake disk the material properties vary in thickness direction. FG brake disk is in contact with pure pad disk. Dry friction is considered as heat source. At first, contact status of FG brake disk is investigated to have full-contact status between FG brake and pad disk. This analysis is done by ANSYS software. The results show that the behavior of non-dimensional temperature and vertical displacement are similar for radial and thickness FG brake disk. Non-dimensional radial displacement for radial and thickness FG brake disk are different. It is seen that non-dimensional radial stress, shear stress of out-plane and total radial strain are quite same.

Finally it can be concluded that the gradation of the constituent components is a significant factor in the thermomechanical responses of FG brake disks.

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