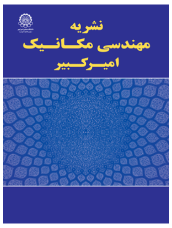

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Impact of Flow around Annular Fins on their Thermal Stresses and Strains

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ABSTRACT: This study considers the impact of transient flow around an annular fin on the development of thermal stresses and strains. The fin thermal stress results were solved for two general cases with and without flow around the fin. The investigations are shown that the thermal stresses developing in the fin are initially similar in the two cases (with no flow and with the external flow). Furthermore, the results show that the maximum tangential stress takes place at the same location in the two cases but those are different. In addition, the tangential is not symmetrical in the case with the flow and the maximum stress, although at the base of the fin, is located in the flow front. Moreover, in the case with the flow, the two-dimensional temperature distribution results in a considerable asymmetrical thermal strain and consequently, asymmetrical thermal stress none of which are observed in the case without flow. Therefore, according to the results, the analysis of the flow around annular fins is essential for calculating thermal stresses.

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1- Introduction

Fins are suitable engineering tool for increasing and reducing heat transfer from the surface, which are used in various industries. The research on annular fins can be divided into two general categories. The first category is researches done with the presence of the fluid flow and the second category is performed without the presence of the flow. First, some of the researches in the field of annular fins will be reviewed that have been done without the presence of fluid flow. Among these researches Chiu and Chen's [1] study of temperature distribution and thermal stresses in an isotropic annular fin can be noted. Also Ghorbanpoor Arani et al. [2] investigated the thermal stresses in intelligent materials. Some of the studies that consider the fluid flow around fins in heat transfer calculations as well as thermal stresses will be referred now. Erfan and Chapman [3] investigated the thermal stresses caused by the distribution of the ambient, axial and radial temperature in the radiation tubes. Marion Cruz et al. [4] also solved their problem considering heat transfer and thermal stresses in a thin-walled circular tube, assuming a non-uniform heat flux in the wall of the tube and the presence of turbulent flow inside the tube. According to the stated researches, it was found that up until now the effect of the fluid flow on thermal stresses created in the fins has not been investigated. In this paper, the transient effects of flow on the distribution of temperature, thermal stresses and thermal strains are investigated and the need to study the flow around the fins in order to properly understand the worst points created by thermal stresses is analyzed. First, the results of temperature distribution and thermal stresses inside annular fins with and without the presence of free flow are compared. In the second section, we analyze the results of temperature distribution and thermal stresses inside an annular fin within a set of fins.

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2- Problem Description

In this paper, 3 geometries are studied and the following is a description of each geometry: (a) fin in no-flow state (b) fin in free flow state (external flow) (c) fin in a state of flow within a set of fins (internal flow). Also, in all three conditions, the fin has the $E = 7.1\times10^{10}\,\mathrm{Pa}, \nu = 0.33, \rho = 2700\,\mathrm{kg/m^3}$ that are Modulus of elasticity, Poisson coefficient and density respectively. Also, $C_p = 925\,\mathrm{J/kgK}$ is heat capacity. Geometric dimensions of the fin in all three conditions are shown in Fig1 .(a). At the inner edge of the fin, we have a constant temperature condition of 600 Kelvin in all cases. At the initial moment fluid's and the fin's surface temperature is 300 Kelvin. Fig. 1 shows three cases that are considered in this paper.

3- Governing Equations and Boundary Conditions

Eq. (1) to (3) show continuity, momentum and energy equations for fluid zone, respectively.

Inlet and outlet boundary conditions: There is a periodic

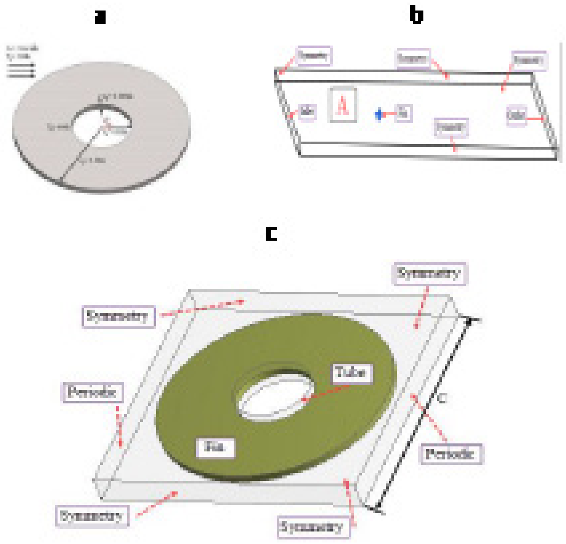

Fig. 1. (a) Fin geometry and boundary conditions in non-flow state (b) annular fin in free flow state (c) . the annular fin in external flow

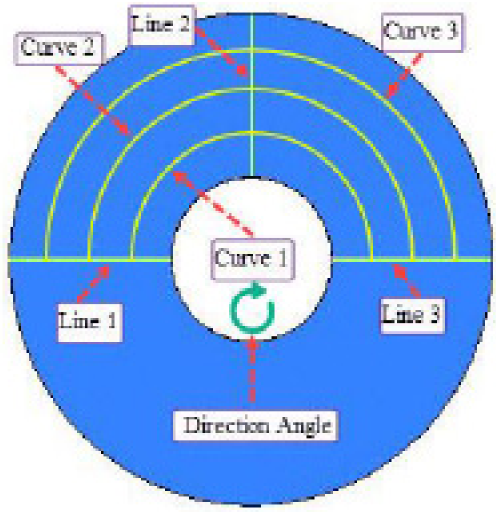

Fig. 2. Lines and curves

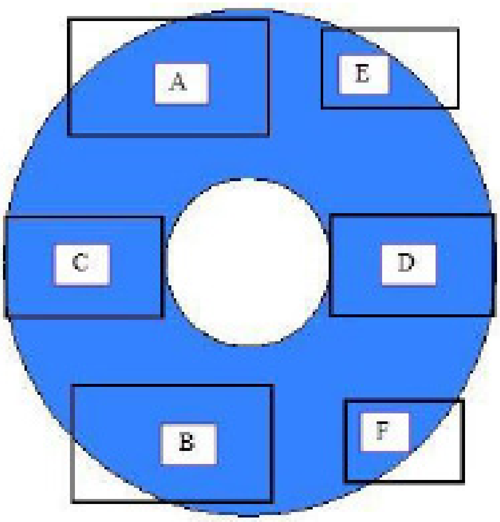

Fig. 3. The regions

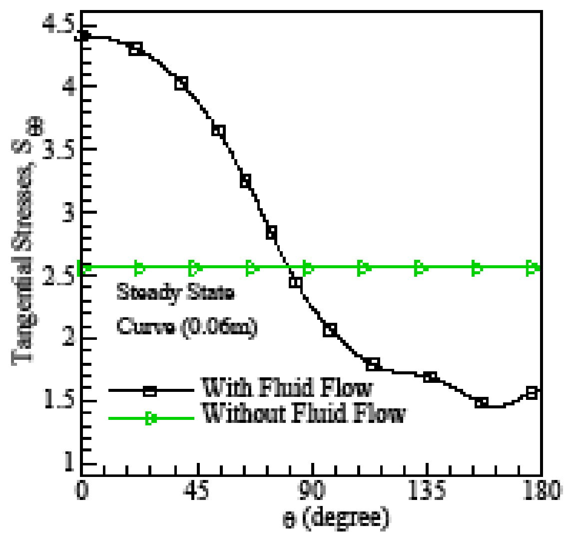

Fig. 4. Tangential stress in tip of the fin for two states

boundary condition at the Inlet and the outlet as shown in Figs. 1(b) and 1(c) the boundary conditions at the upper and lower surfaces of the fin, as well as the right and left surfaces are assumed to be symmetry boundary condition.

$$\frac{\partial \rho^f}{\partial t}+\vec{\nabla}.(\rho^f \vec{V}^f)=0 \qquad (1)$$

$$\frac{\partial \vec{V}^f}{\partial t}+(\vec{V}^f.\vec{\nabla})\vec{V}^f=-\frac{1}{\rho^f}\vec{\nabla}p^f+\nu^f\vec{\nabla}^2\vec{V}^f \qquad (2)$$

$$\frac{\partial T^f}{\partial t}+(\vec{V}^f.\vec{\nabla})T^f=\alpha^f\vec{\nabla}^2T^f \qquad (3)$$

Eq. (4) show energy equation for solid domain:

$$k^s\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T^s}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 T^s}{\partial \theta^2}+\frac{\partial^2 T^s}{\partial z^2}\right)=\rho^s c_p^s\left(\frac{\partial T^s}{\partial t}\right) \qquad (4)$$

$$T^s(r,\theta,z,t)=T^s(r,\theta+2\pi,z,t),\ \frac{\partial T^s(r,\theta,z,t)}{r\partial\theta}=\frac{\partial T^s(r,\theta+2\pi,z,t)}{r\partial\theta},$$
$$T^s(r_i,\theta,z,t)=[illegible],\ k^s\frac{\partial T^s(r_i,\theta,z,t)}{\partial r}=k^f\frac{\partial T^f(r_i,\theta,z,t)}{\partial r}, \qquad (5)$$
$$k^s\frac{\partial T^s(r,\theta,0,t)}{\partial z}=k^f\frac{\partial T^f(r,\theta,0,t)}{\partial z},\ k^s\frac{\partial T^s(r,\theta,0.0004,t)}{\partial z}=k^f\frac{\partial T^f(r,\theta,0.0004,t)}{\partial z}$$

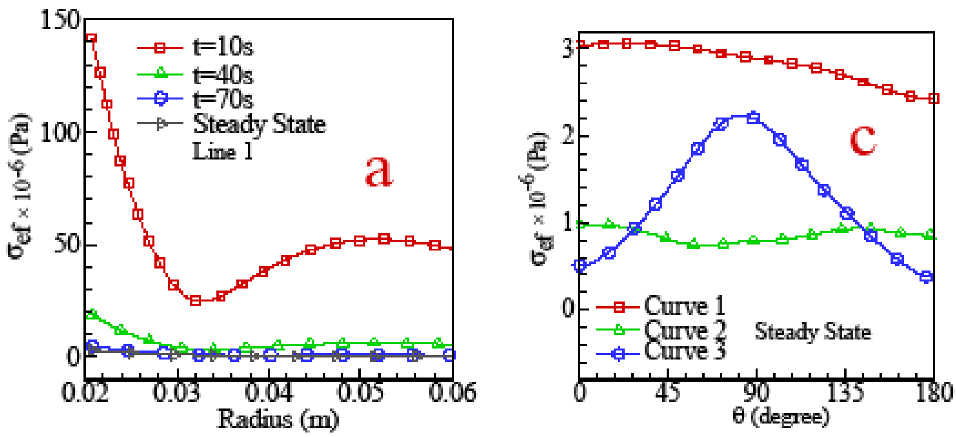

Fig. 4. (a) effective stresses in Line1 for various times (c) effective stresses in various curves in steady state

The boundary conditions are as Eq. (5) and initial condition is 300K. The boundary condition of the fluid and fin intersection is as follows. (Coupled boundary condition at fluid and solid contact boundary)

$$k^s \frac{\partial T^s}{\partial n} = k^f \frac{\partial T^f}{\partial n} \quad (6)$$

The equilibrium and structural equations in solid for calculation of thermal stresses and strains are as Eqs. (7) and (8) respectively.

$$\frac{\partial \sigma_r}{\partial r} + \frac{1}{r}\frac{\partial \tau_{r\theta}}{\partial \theta} + \frac{(\sigma_r - \sigma_\theta)}{r} = 0$$
$$\frac{\partial \tau_{r\theta}}{\partial r} + \frac{1}{r}\frac{\partial \sigma_\theta}{\partial \theta} + \frac{2\tau_{r\theta}}{r} = 0 \quad (7)$$

$$\sigma_r = \frac{E}{1-\nu'^2}\left[\varepsilon_r + \nu'\varepsilon_\theta - (1+\nu')\alpha'\Delta T\right]$$
$$\sigma_\theta = \frac{E}{1-\nu'^2}\left[\varepsilon_\theta + \nu'\varepsilon_r - (1+\nu')\alpha'\Delta T\right] \quad (8)$$
$$\tau_{r\theta} = \frac{E}{1+\nu'}\varepsilon_{r\theta}$$

Radial normal stresses in inner and outer radius of fin are zero. Also, displacements of the fin in axial and radial directions are zero.

4- Results

By comparing a and b states, as it can be seen, in Fig. 3 asymmetric tangential thermal stresses is existed. as shown in In Fig. 4, the c state, effective stress diagrams have been drawn. At 10 seconds since radial, tangential and shear stresses have the highest value, the greatest amount of effective stress is developed and over time, due to the decrease in stresses, effective stress has also decreased. On the other hand, in effective stress diagrams it is observed that the highest effective stress is developed in the base of the fin. This is because, in terms of absolute value, tangential stress has greater value at the base of the fin. It is also observed that regions A and B at the tip of the fin have the most effective stress. The reason for this is the greater tangential stress in these areas but in general, the greatest amount of stress lies at the base of the fin, where the tangential stress is highest.

5- Conclusion

1.Temperature distribution inside fins is asymmetric and two-dimensional. **2**.The temperature and tangential stress contours were similar, indicating the predominance of tangential stress in the fin. **3**.The highest effective stress in the base of the fin is in area A **4**.The maximum absolute magnitude of the shear strain and stress is approximately in the region E and F and at the edge of the fin. **5.**These values represent, respectively, the largest change in the angle of the element at this angle and the highest cut in this area.

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