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Original Research Article

# Numerical calculations of displacements in aluminum alloy 356.0, copper alloy C93200 and grade G4000 discs depending on temperature

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**ABSTRACT:** The behavior of temperatures is very important from the point of view of materials science. Each material has its own unique identity, and the resistance they show to temperature is different. They may vary depending on the areas of use on disks. In this study, the displacements occurring in disks consisting of three different materials were calculated by means of a mathematical program. Aluminum alloy A356.0-T6 and 356.0 area are composed of 7% Si, 0.2 Fe (max), 0.10 Zn (max), and 0.3% Mg alloy. Copper alloy C93200 (bearing bronze) consists of 85% to 8% Pb and Sn 6.5% and other materials. Grade G4000 is composed of iron (Fe) 94.5%, carbon 3.3%, silicon 1.7%, and other materials. The obtained stresses were compared among themselves and decoupled by means of graphs. In this study, the effect of temperature on displacement was investigated. At the end of the study: Displacements occurring on the disk generally occurred most often on the disk with aluminum alloy 356.0 material. In turn, it is thought that the result can already be expressed as grade G4000 and copper alloy C93200 (bearing bronze) towards the minimum.

***KEYWORDS*:** aluminum alloy 356.0; grade G4000; mathematical formulation; stress analysis

## 1. Introduction

The stresses that occur on the discs can determine the resistance of the efficiency of the machines to temperature. It is very important in the displacements that occur in machine parts. For example, the radial displacement of a disk can cause a static imbalance if the disk is displaced in the vertical plane. As a result, the wheel can exert an up-down impact force. When such a wheel rotates, a torque is created on the axle that changes direction, which can lead to irreversible problems with the suspension, tires, and steering mechanism. When the temperature concept is involved in this situation, the damage caused may increase. In this study, the displacements of aluminum alloy 356.0, copper alloy C93200 (bearing bronze), and grade G4000 material discs were examined at 40 ℃, 50 ℃, 60 ℃, 70 ℃, and 80 ℃ temperatures. The results obtained were compared with other studies obtained in the literature. When the different studies conducted on this subject are examined, precise analytical and numerical solutions for rotating a circular disk of variable thickness are presented in a different study. The stress function, displacement, stresses, and distributions of stresses are presented[1]. In a different study, the stresses that occur at the end of the pressure force applied to discs of varying thickness were studied[2]. In a similar study, the stresses occurring on discs of varying thickness exposed to elastic and viscoelastic stress were again examined. The results obtained have been shared with the literature[3]. In different studies, the stresses occurring in the discs under the conditions of Poisson distribution have been investigated[4]. Again, in a different study about discs, based on Mindlin's theory, the stresses occurring in thermoelastic rotating discs were studied[5]. In different studies, tangential and radial stresses occurring in disks of different materials were considered[6,7].

## 2. Material and method

In this study, the displacements (displacements) occurring in disks subjected to linear decreasing temperature distribution were considered numerically. In the modeling: Numerical analysis was performed for the temperature values of 40 °C, 50 °C, 60 °C, 70 °C, and 80 °C. **Figure 1** shows the disk subjected to radial displacement. The disc is fixed, and its dimensions are referenced as *a* = 20 mm, *b* = 60 mm.

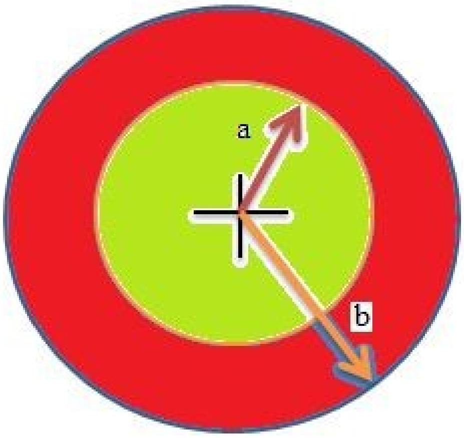


**Figure 1.** A disk subject to displacement.

The mechanical properties of the disc material are given in **Table 1** below.

**Table 1.** Mechanical properties of discs[8–11].

| Disc No. | Disc materials | *E* (MPa) | $\alpha$ (1/°C) | $\upsilon$ |
|---|---|---|---|---|
| 1 | Aluminum alloy 356.0 | 80,000 | $21.5 \times 10^{-6}$ | 0.33 |
| 2 | Copper alloy C93200 (bearing bronze) | 100,000 | $17.3 \times 10^{-6}$ | 0.35 |
| 3 | Grade G4000 | 180,000 | $11.4 \times 10^{-6}$ | 0.29 |

### Analytical formulation

The general equilibrium equation $\sigma_z = 0$ for a thin disk is as follows[12].

$$\frac{r(d\sigma_r)_i}{dr} + (\sigma_r)_i - (\sigma_\theta)_i = 0, (i = 1) \tag{1}$$

$$\varepsilon_{ri} = \frac{1}{E_i}(\sigma_{ri} - \upsilon_i\sigma_{\theta i}) + \alpha_i T_r \tag{2}$$

$$\varepsilon_{\theta i} = \frac{1}{E_i}(\sigma_{\theta i} - \upsilon_i\sigma_{ri}) + \alpha_i T_r \tag{3}$$

$$\sigma_{ri} = \frac{F}{r} \tag{4}$$

$$\sigma_{\theta i} = \frac{\mathrm{d}F}{\mathrm{d}r} \tag{5}$$

If Equations (6) and (7) are applied in Equations (4) and (5):

$$\varepsilon_{ri} = \frac{1}{E_i}(\frac{F}{r} - \upsilon_i \frac{\mathrm{d}F}{\mathrm{d}r}) + \alpha_i T_r \tag{6}$$

$$\varepsilon_{\theta i} = \frac{1}{E_i}\left(\frac{\mathrm{d}F}{\mathrm{d}r} - \upsilon_i \frac{F}{r}\right) + \alpha_i T_r \tag{7}$$

The fitness equation for elongation:

$$r\frac{\mathrm{d}\varepsilon_{\theta i}}{\mathrm{d}r} + \varepsilon_{\theta i} - \varepsilon_{ri} = 0 \tag{8}$$

It is obtained. The equilibrium equation where the stress function can be defined as $F$ and equations between Equations (1)–(8) are used to obtain the general Equation (9).

$$r^2\frac{\mathrm{d}^2F}{\mathrm{d}r^2} + r\frac{\mathrm{d}F}{\mathrm{d}r} - F = -r^2\alpha_i E_i T_r' \tag{9}$$

Since the discs are different from each other, $i$ = 1 for each disk. $T_0$ is the first temperature value, $\mathrm{T}_\mathrm{r}^{'}$ is the temperature value of any point in the radial direction. If $T_r'$ is substituted in Equation (10) for stress analysis:

$$r^2\frac{\mathrm{d}^2F}{\mathrm{d}r^2} + r\frac{\mathrm{d}F}{\mathrm{d}r} - F = -r^2 E_i\alpha_i \frac{T_0}{(b-a)} \tag{10}$$

$$F = C_1 r^1 + C_2 r^{-1} + A_i r^2 \tag{11}$$

It is obtained. Radial and tangential stresses,

$$\sigma_r = C_1 + C_2 r^{-2} + A_i r = \frac{F}{r} \tag{12}$$

$$\sigma_\theta = C_1 - C_2 r^{-2} + 2A_i r = \frac{\mathrm{d}F}{\mathrm{d}r} \tag{13}$$

Radial and tangential stresses are written as above. Using the boundary conditions $r = a$ for case $r = a$ durumunda $\sigma_r = 0, r = b$ for case $\sigma_r = 0$ the integration constants, $C_1$, $C_2$ and the final term $A_i$ are determined as follows:

$$A_i = \frac{E_i\alpha_i T_0}{3(b-a)} \tag{14}$$

$$C_1 = -A_i(a^2 + ab + b^2)/(b + c) \tag{15}$$

$$C_2 = A_i(a^2b^2)/(a + b) \tag{16}$$

$u$: radial displacement is obtained as in Equation (17) below:

$$(U_r)_i = \left(\frac{C_1 r(1-\upsilon_i)}{E_i} - \frac{C_2(1-\upsilon_i)}{rE_i} + \frac{A_i r^3(3-\upsilon_i)}{E_i} + \alpha_i rT\right)i \tag{17}$$

## 3. Findings and discussion

In this study, an environment in which the modulus of elasticity does not change with temperature was assumed: aluminum alloy 356.0, copper alloy C93200 (bearing bronze), and grade G4000 for three different disks made of materials. Radial displacements were investigated by assuming that the temperature increases parabolically from the inner face of the disks to the outside. The dimensions of the modeled disk are taken as $a$ = 20 mm, $b$ = 60 mm. The solutions were obtained by using different temperature values such as 40 °C, 50 °C, 60 °C, 70 °C, and 80 °C. The material properties of the disc are given in **Table 1** as follows. The result of the analysis was obtained by assuming that the modulus of elasticity does not change with temperature (remains constant).

The stresses occurring on the disk modeled from different materials have been created by the development of a mathematical program. In the program, the result was created by replacing the material properties, radius, and stress formulas of the disk. In addition, the disk model created with the ANSYS 2024 program is given in **Figure 2** below.

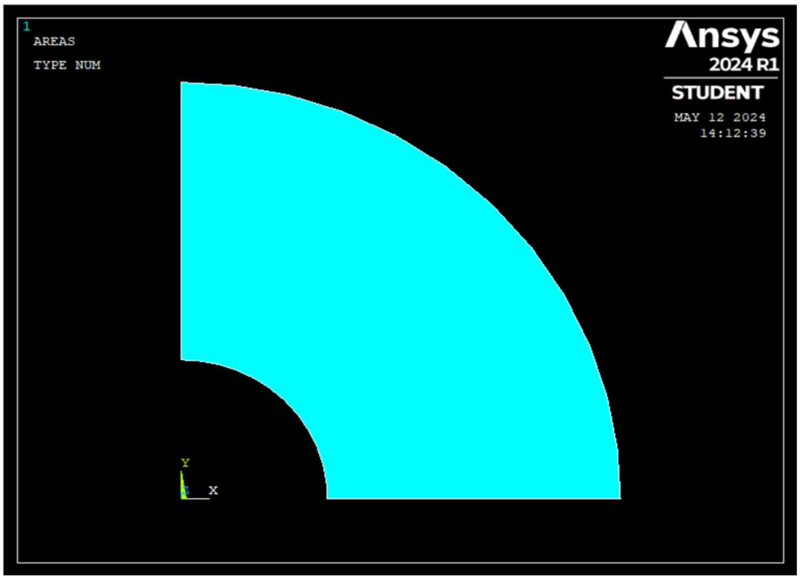


**Figure 2.** Modeling of a disk with different materials.

In **Table 2**, the calculated displacements on disks consisting of three different materials are given.

**Table 2.** Radial displacements occurring in disks.

| Material | *r* | 40 °C | 50 °C | 60 °C | 70 °C | 80 °C |
|---|---|---|---|---|---|---|
| Copper alloy C93200 (bearing bronze) | *r* = 20 | 0.0038 | 0.0042 | 0.0051 | 0.0060 | 0.0068 |
| | *r* = 60 | 0.1165 | 0.1401 | 0.1632 | 0.1868 | 0.2100 |
| Grade G4000 | *r* = 20 | 0.0021 | 0.0023 | 0.0028 | 0.0033 | 0.0038 |
| | *r* = 60 | 0.0647 | 0.0778 | 0.0907 | 0.1038 | 0.1166 |
| Aluminum alloy 356.0 | *r* = 20 | 0.0017 | 0.0019 | 0.0022 | 0.0026 | 0.0030 |
| | *r* = 60 | 0.05181 | 0.0622 | 0.0725 | 0.0830 | 0.0933 |

**Figure 3** shows the linear increase of the temperature from the inner region to the outer part of the disc.

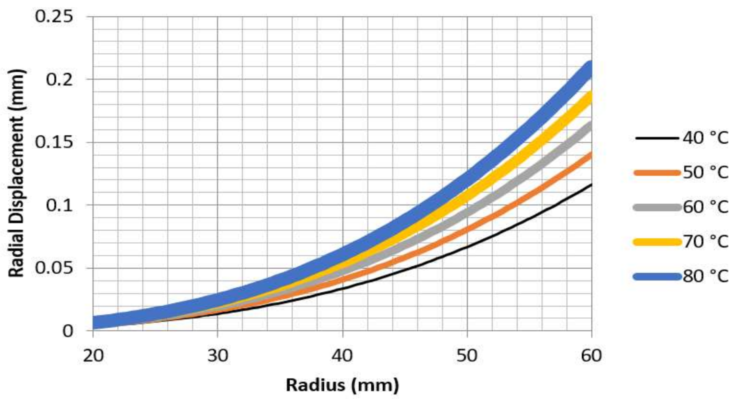


**Figure 3.** The radial displacements of the copper alloy C93200 (bearing bronze) disc.

The radial displacements occurring in the disc with grade G4000 material are given in **Figure 4**. **Figure 5** shows the radial stress on the aluminum alloy 356.0 disc.

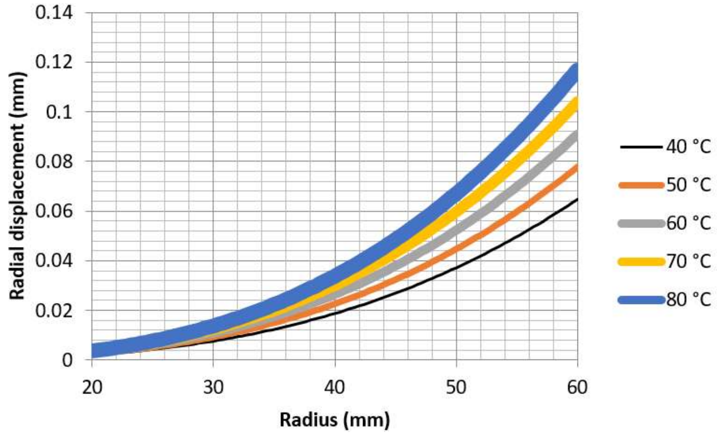


**Figure 4.** The radial displacements of the grade G4000 disc.

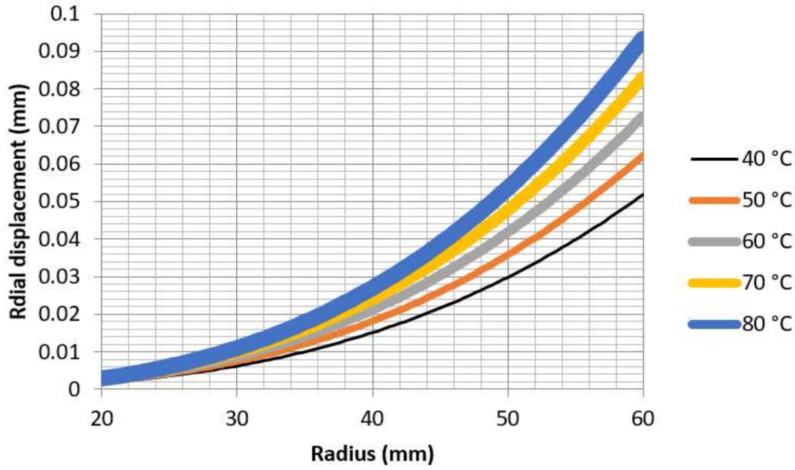


**Figure 5.** Radial displacements in the aluminum alloy 356.0 disc.

In this study, it was assumed that the modulus of elasticity does not change with temperature. Computer software is designed this way. In general, as the temperature increases, the atoms or molecules of a substance usually start vibrating more. This vibration alters the interactions between the particles inside the substance and can cause changes in the properties of the material decently. In this study, the disk materials are also different from each other.

Radial displacements due to the temperature effect of disks can usually be caused by changes in the internal structure of the material with a temperature change. This may be due to the ductility of the material in particular. However, as the temperature increases, there may be changes in the flexibility of the material. Part of the increase in the radial displacements of the discs as the temperature increases may be due to changes in their ductility properties. As the temperature increases, the disk may become flexible, which may lead to increased radial displacements. With the molecules inside the disks moving more and displacing each other more, the change of the disks in the radial direction may increase.

## 4. Conclusion

The discs are made of three different materials. The mechanical properties of the materials that make up the disks are different from each other, so the radial displacements that occur on each disk at the end of operation are different from each other.

As the temperature increases, the radial displacements increase. 80 °C: It has been determined that the displacement value of the copper alloy C93200 (carrier bronze) disc in the innermost and outermost parts is about 80% higher than that of the disc with G4000 class material. 80 °C: It has been determined that the displacement value occurring in the outermost part of the G4000 quality material disc is 24% higher than that of the aluminum alloy 356.0 material disc.

When the displacements occurring inside and outside the materials are examined, the displacements occurring on the disc based on copper alloy C93200 (carrier bronze) material may be preferred in the designs as it is considered that the displacements occurring on the other G4000 class and aluminum alloy 356.0 material discs are less displacement. Displacements usually occurred on most copper alloy C93200 (bearing bronze) material discs. For this reason, it is estimated that the displacements occurring on the aluminum alloy 356.0 material disk are low, and it can be used in the design.

## Conflict of interest

The author declares no conflict of interest.

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