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Simulation and analysis of disc brake temperature field

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Abstract: Aiming at the thermo-mechanical coupling phenomenon in the braking process, the finite element software is used to analyze the temperature field of the coupling contact surface between the brake disc and the friction disc. A simplified model of brake disc is established, and then a finite element model is established for analysis. According to the set running state of the vehicle, the overall temperature field characteristics of the brake disc are analyzed. The variation rules of the element nodes temperature in radial, circumferential and axial directions are analyzed. The research lays a foundation for the structural modification of the brake.

Keywords: Disc brake, Thermo-mechanical coupling, Finite element analysis, Friction disc

1. Introduction

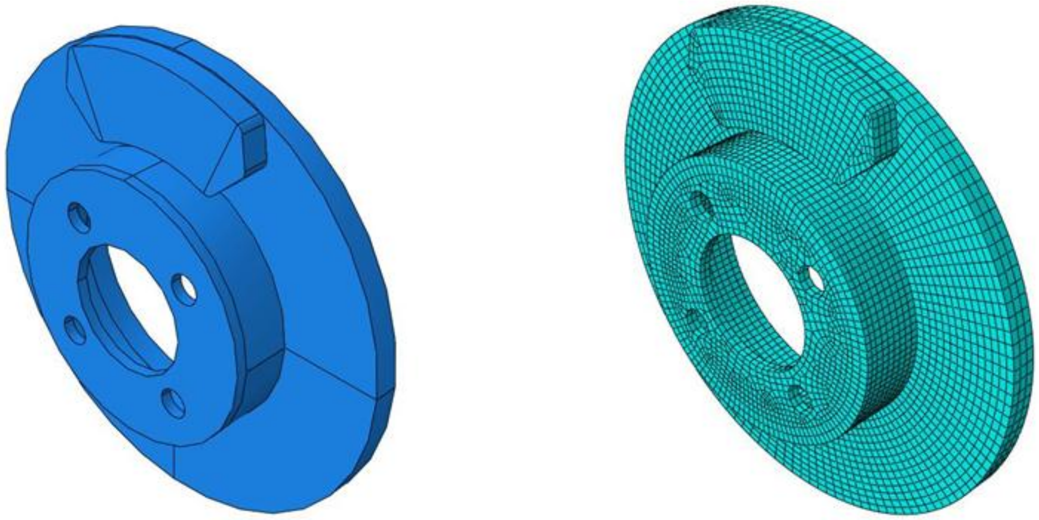
Brake is the key parts of the car, and the traffic accidents caused by brake faults account for the majority of the year. Therefore, the brake performance is related to the ride comfort and ride safety of the passengers. The brake disc is the main component of the brake. The temperature field on the surface of the brake disc is a multidisciplinary problem, which is the hotspot and difficult of the research [1-7]. When a car is braking, it will generate braking heat, which is the instantaneous high temperature on the surface of the brake disc due to high-speed friction of the friction disc. The high temperature changes the thermal characteristic parameter of the brake disc and friction disc, reduces the friction coefficient of the contact surface and leads to the decline of the friction torque, causes the thermal recession of the brake disc [8-10]. The thermal stress caused by high temperature will break the brake disc and affect the safety of braking. The thermo-mechanical coupling phenomenon during braking is studied, which has important theoretical and practical significance for the brake safety and the brake stability. Simulation can not only shorten the research period, but also save a lot of money. Therefore, the paper conducts simulation analysis on brake disc, studies the influence of thermo-mechanical coupling on brake, and studies the distribution characteristics of temperature field in all directions of brake.

2. Network Structure

When the brake is in emergency braking, the friction only occurs in the coupling surface, and heat generated is almost completely absorbed by the brake disc and the friction material. Therefore, in the analysis of thermo-mechanical coupling, the brake backplate and some unnecessary chamfering and circular holes are removed. Thermo-mechanical coupling analysis is a complicated nonlinear problem with lots of calculations and longtime consumption. Meanwhile, the brake disc is symmetric in the thickness direction. Therefore, in order to save calculation time, the model adopts symmetric structure to analyze only one side friction disc.

After the model simplification is completed, it is necessary to import ABAQUS to mesh divide the hexahedral mesh, and the mesh size is 4.5mm. After dividing the mesh, the brake disc has 9,734 units and 14,060 nodes, and the friction material has 1,368 units and 1,905 nodes.

The element types of brake disc and friction disc are C3D8RT, C is the solid element, 3D is the three dimensional, 8 is the number of nodes in the element, R is reduction integral, and T is temperature. Figure 1 shows the simplified model and finite element model of the thermo-mechanical coupling.



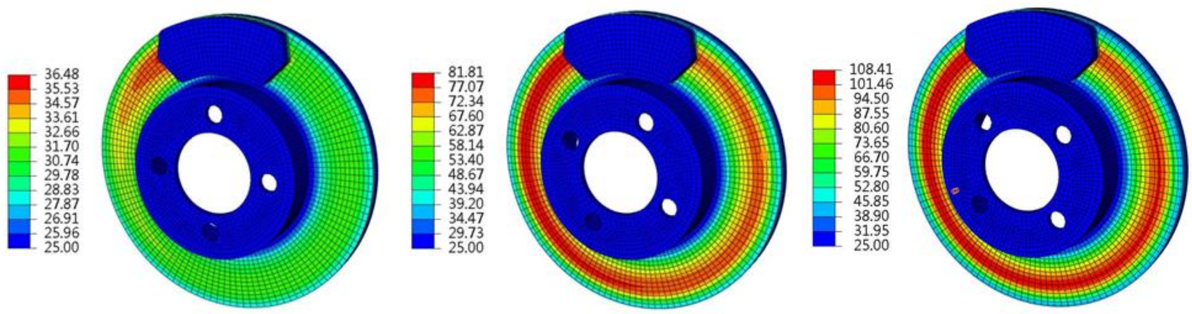
a) Simplified model b) Finite element model

Figure 1: Simplified and finite element models for thermo-mechanical coupling analysis

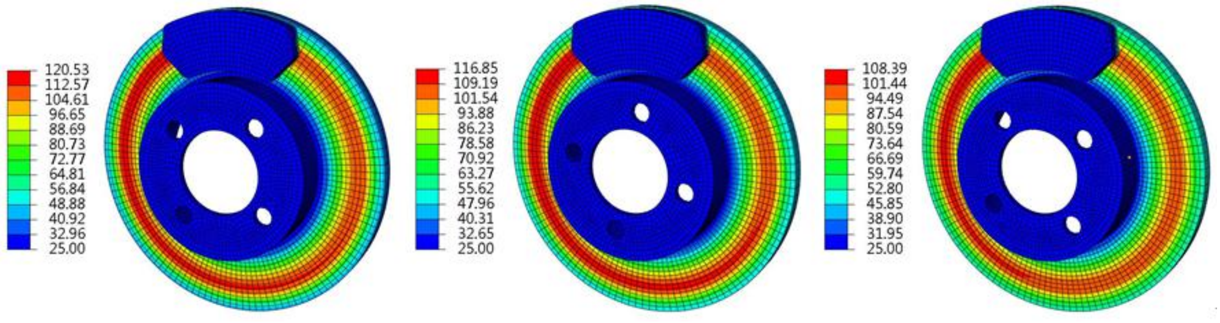
3. Experimental Dataset

In ABAQUS, the emergency brake with the initial speed of 100 km/h and braking time of 3.472s is simulated. Since thermal-mechanical coupling is a highly nonlinear problem, the entire simulation process takes 13 hours to complete the calculation.

According to the working principle of disc brake, by applying the braking pressure on the friction disc, the friction disc and the brake disc squeeze each other, making the brake disc slow down to stop. The large amount of heat generated by friction is absorbed by brake disc and friction disc, which increases the surface temperature of brake disc. Therefore, the temperature field of the whole model is analyzed Figure 2 shows the temperature field distribution of the model overall mesh element at different moments, and the unit is ℃.



a) 0.1s b) 0.8s c) 1.5s

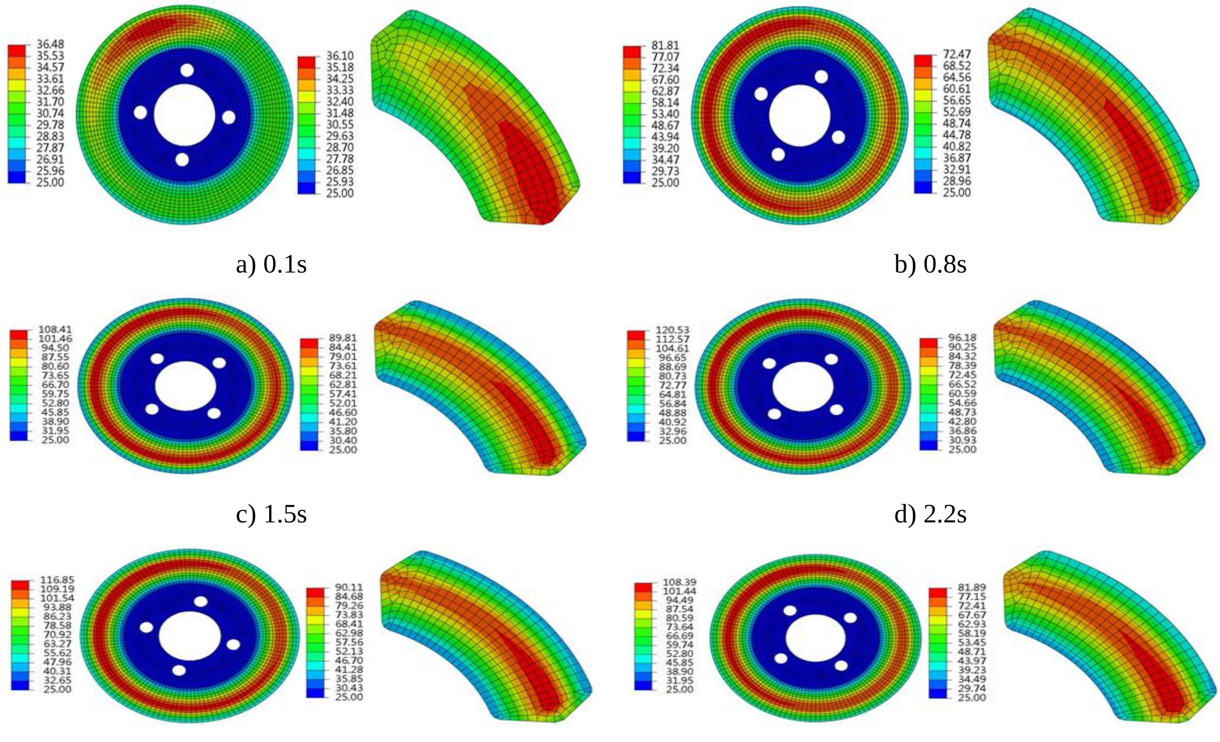


d) 2.2s e) 2.9s f) 3.4s

Figure 2: Global temperature field distribution of model

According to Figure 2, the overall temperature of the model first increases and then decreases, because the friction heat generation rate at the beginning is much higher than the convective heat transfer on the brake disc surface. As the speed decreases, the frictional heat decreases. At this time, the convective heat transfer and heat conduction on the brake disc surface play a leading role, leading to the temperature on the brake disc surface begins to decrease. The high temperature part of the model always appears in the middle of the friction contact area, and the temperature near the brake disc cap is always the lowest.

The friction disc thermal conductivity is low, heat is difficult to transfer to the friction disc external surface, so the external surface temperature is the same as the initial temperature value and does not change. Since the disc cap is far away from the friction contact surface, it is difficult to conduct heat, so the temperature is the same as the initial setting. In order to know the temperature field changes of brake disc and friction disc in more detail, the temperature field changes of brake disc and friction disc at 6 moments are taken as shown in Figure 3, and the unit is ℃.



a) 0.1s b) 0.8s

c) 1.5s d) 2.2s

e) 2.9s f) 3.4s

Figure 3: Temperature distribution of brake disc and friction disc

According to Figure 3, the temperature field of brake disc and friction disc is analyzed, and the following conclusions can be drawn:

(1) At the same time, the maximum temperature on the brake disc surface is always higher than that in the friction disc contact area, and heat generated by friction is mainly absorbed by the brake disc; the surface temperature of the brake disc changes little at the maximum radius and near the cap. The high temperature of the brake disc mainly focuses on the middle part of the contact area, so the radial temperature gradient changes greatly, while the circumferential temperature gradient changes little.

(2) The temperature of the brake disc surface element also increases gradually first and then decreases gradually as the braking time changes. The maximum temperature difference of the brake disc surface element reaches 45.33℃ between 0.1~0.8s, and 26.6℃ between 0.8~1.5s. After that, the maximum temperature difference rate gradually decreases, which is mainly due to the different leading roles of the friction heating and convection heat transfer in different time periods.

(3) The temperature at which the friction disc contacts the surface also increases first and then decreases with time. However, because there is no convection heat transfer at the contact surface of the friction disc, heat transfer is the main factor of temperature change.

(4) At 0.1s, the surface temperature of the friction disc shows a low inlet temperature and a high outlet temperature. With the extension of braking time, the high temperature gradually spreads to the inlet, and finally forms a uniform band and focuses in the middle of the friction contact area. The stiffness of the friction disc is lower than that of the brake disc, so the middle part is fully contacted and the temperature of the middle part is higher.

The circumferential and radial temperatures of brake disc surface have been roughly studied. In order to further understand the changes of the brake disc surface temperature, the temperature of brake disc surface node in radial, axial and circumferential directions will be analyzed respectively.

2.1 Radial temperature distribution characteristics of brake disc

Figure 4 shows eight nodes on the radial direction of the brake disc friction surface, which is used to study the variation rule of the brake disc temperature on the radial direction. In ABAQUS post-processing, the temperature of 8 nodes is extracted and plotted. The curve of node temperature changing with time is shown in Figure 5. From Figures 4 and 5, the following conclusions can be drawn:

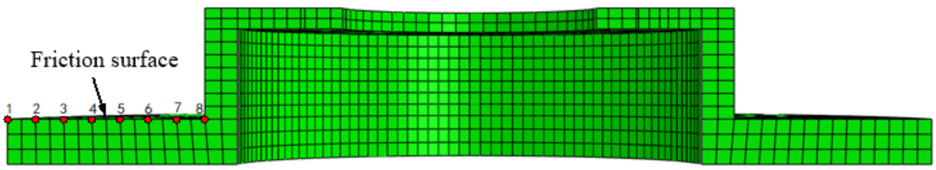


Figure 4: Radial node number of brake disc

(1) The temperature rise is highest at the middle nodes (3, 4 and 5) in the friction area, and the temperature curve rises gradually with the time change in a zigzag shape. At the beginning of braking, the zigzag interval is relatively small, and then the zigzag interval increases, because when the node is in the friction area, the friction heat generation is higher than heat conduction and convective heat transfer on the surface playing a leading role; when the node is far away from the friction area, there is no input of friction heat source, and the friction-generated heat decreases as the speed of the brake disc decreases. At this time, heat conduction and surface convective heat transfer play a major role, which leads to the increase of zigzag interval.

(2) The temperature curve of the nodes (2 and 6) located at the friction area edge changes in a zigzag pattern with the increase of braking time. The main reason is the periodic influence of the friction heat source and convection heat transfer, but the overall temperature rise is lower than that of the nodes in the friction area.

(3) Since the nodes (1, 7 and 8) located outside the friction area are far away from the friction area, the temperature change of the nodes is smaller than the other nodes. Since the temperature in the friction area is always higher than that in the non-friction area, heat is continuously input into the non-friction area from the friction area, so the three nodes temperature increases with the increase of braking time. Due to the node 7 is closer to the friction area, the temperature also changes in a zigzag at the beginning.

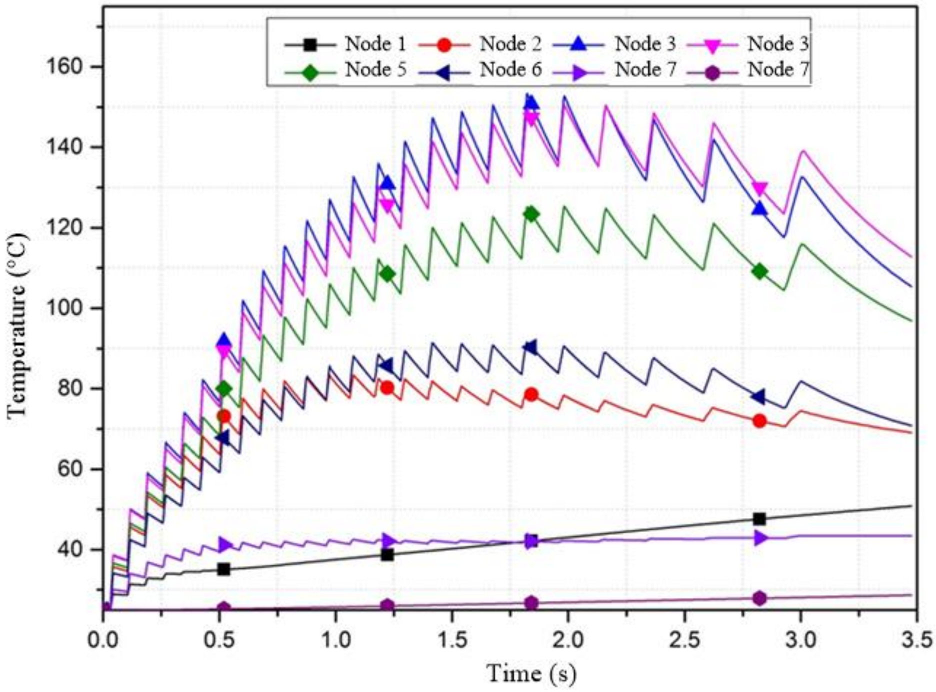
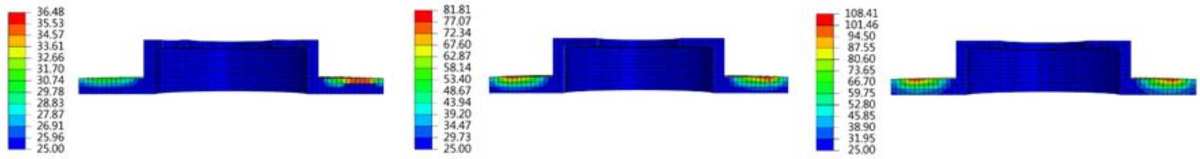


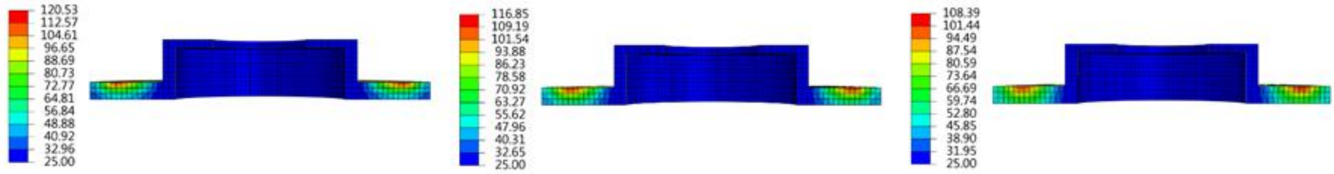
Figure 5: Radial node temperature curve of brake disc

2.2 Axial temperature distribution characteristics of brake disc

Due to the low thermal conductivity of the friction disc, the external surface temperature of the whole friction disc is always the same as the initial set temperature. The thermal conductivity of the brake disc is higher than that of the friction disc, so it is necessary to analyze the axial temperature change of the brake disc. Figure 6 shows the axial temperature change of the brake disc unit, and the unit is ℃.



a) 0.1s b) 0.8s c) 1.5s



d) 2.2s e) 2.9s f) 3.4s

Figure 6: Radial temperature distribution of brake disc

According to Figure 6, the high-speed rotation of the brake disc generates heat at 0.1s, and the surface temperature in the friction area increases rapidly. After that, it can be clearly seen that with the continuous input of friction heat source, heat is continuously diffused in the axial direction of the brake disc. In order to better understand the change of axial node temperature, 4 nodes in the axial are selected for investigation, the axial node number of brake disc is shown in Figure 7.

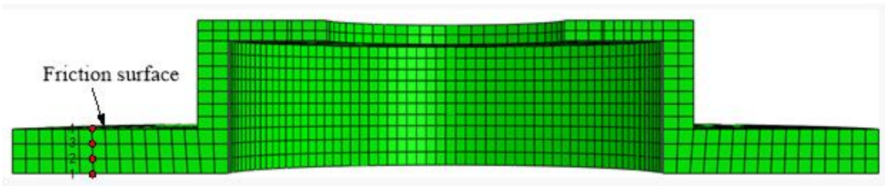


Figure 7: Axial node number of brake disc

In ABAQUS post-processing, four nodes temperatures in the axial are extracted and plotted, and the axial node temperature curve is shown in Figure 8.

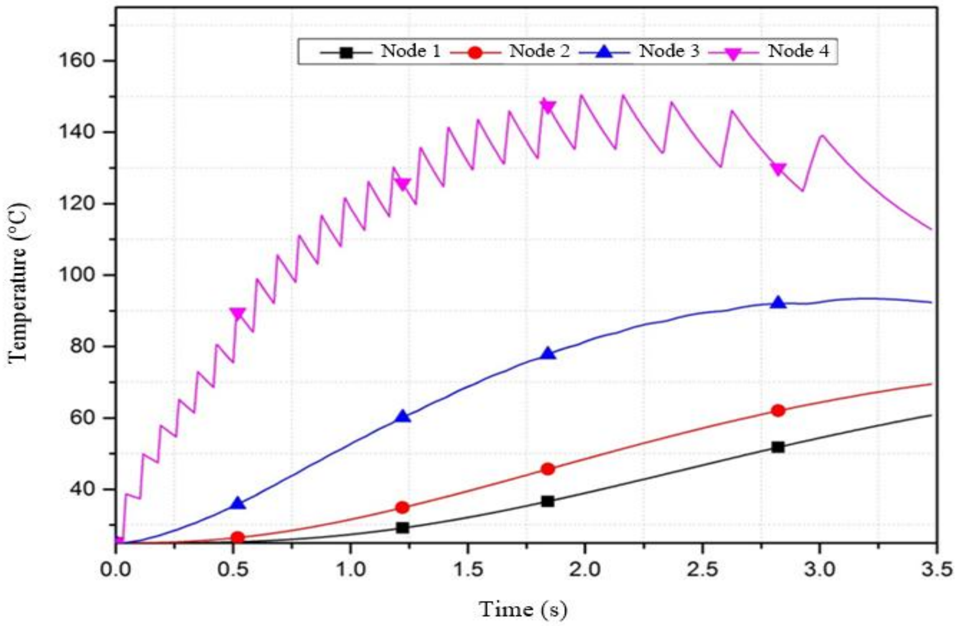


Figure 8: Axial node temperature curve of brake Disc

The following conclusions can be drawn from Figures 6, 7, and 8:

(1) The external node 4 is located on the friction contact surface. Due to the alternating effects of friction heat and convection heat transfer, the node 4 temperature changes in a zigzag shape. Node 4 is located on the friction contact surface, and the temperature is always higher than that of the other three nodes, because the friction heat rate on the surface of the brake disc is much higher than the internal heat conduction rate, and the temperature difference between node 4 and node 1 reaches 90℃.

(2) The internal nodes (1, 2 and 3) is located inside the brake disc and does not contact with air, so it is only affected by heat conduction but not convection heat transfer. The change of internal node temperature is only related to the surface friction heat. During the whole braking process, the surface temperature is always higher than the internal temperature, so the internal node temperature increases with the input of the heat source and changes linearly.

2.3 Circumferential temperature distribution characteristics of brake disc

As can be seen from Figure 2, the temperature distribution of the brake disc in the circumferential direction is not particularly average, so it is very necessary to analyze the brake disc temperature in the circumferential direction. Figure 9 shows the number of the brake disc circumferential node. The four nodes are located at the same radius of the brake disc, and the difference between the two nodes is 90°

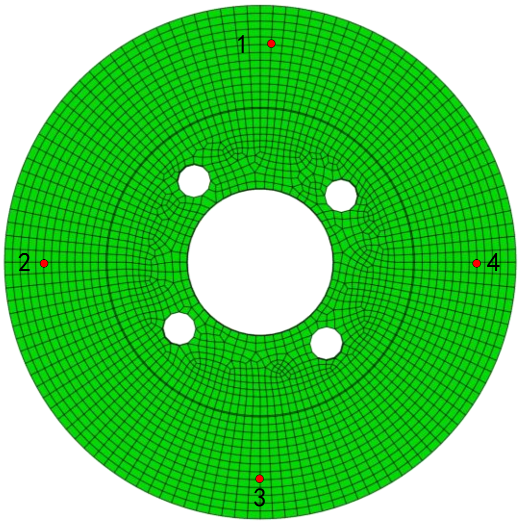


Figure 9: Circumferential nodal number of brake disc

In ABAQUS post-processing, the four circumferential node temperatures are extracted and plotted. The circumferential node temperature curve changing with time is shown in Figure 10. It can be seen from Figure 10 that the four circumferential nodes temperature in the middle position of friction contact increases first and then decreases, and they all change in a zigzag shape. However, due to the time out of sync, there is a certain temperature difference between the points, but the overall difference in temperature is not big.

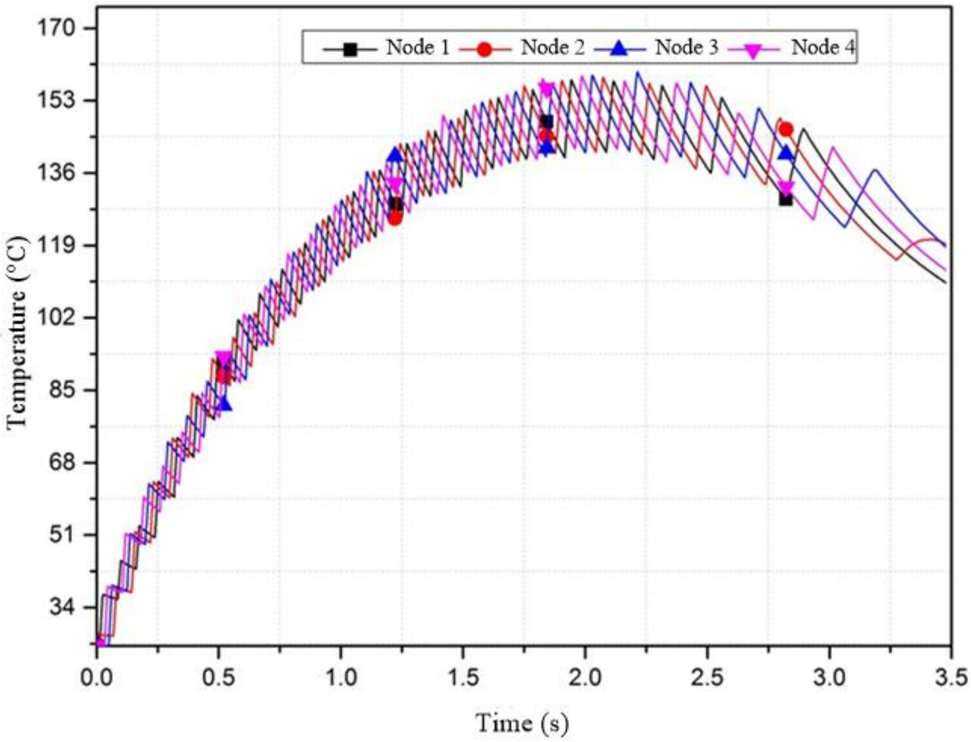


Figure 10: Circumferential node temperature curve of brake disc

4. Conclusion

The simplified 3D model and finite element model of the brake disc are constructed, which can save computing time and improve mesh quality. By analyzing the radial, axial and circumferential node temperatures of the brake disc, it is found that the temperature rise of the node in the friction contact area is the largest, and the surface temperature rose in a zigzag pattern due to the influence of the convective heat transfer and friction heat. This study provides a theoretical basis for the structural improvement of brake disc in the future.

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