Knowledgeable Research (KR) 2026, Vol., (5):03
ISSN: 2583-6633, CODEN: KRABAU
International open-access peer-reviewed refereed monthly journal
https://knowledgeableresearch.com/index.php/1

Thermal conductivity enhancement of asbestos reinforced phenolic resin frictional composites by Abaqus-Python

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Abstract

The main problem of using organic frictional materials as brake lining materials is to solve the problem of stability of friction coefficient and wear rate; to prevent the dramatic temperature rise during braking and thermal decomposition of the resin matrix. To solve this problem, it is common to add materials with good thermal conductivity such as graphite, but at the same time there is disadvantage of low friction coefficient. Thus, to maintain a constant friction coefficient and also to improve the thermal conductivity of the material sufficiently, it is necessary to determine not only the optimum composition of the other fillers but also the binder and reinforcement components of the friction composite. Recently, the wide application of various engineering analysis programs and optimization algorithms has attracted considerable attention in increasing the speed and accuracy of material design and saving much cost. In this paper, a method for predicting the thermal conductivity of asbestos frictional composites with Abaqus-Python is proposed and the optimum composition is determined using PSO algorithm. We have manufactured composite specimens of the corresponding composition and tested for friction coefficient, wear rate and thermal conductivity measurements, and the simulated result goes will with experimental result.

Keywords: *Random particle reinforced composite, Thermal Conductivity, RVE, ABAQUS.*

Received: 10/02/2026
Accepted: 23/03/2026
Published: 31/03/2026

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INTRODUCTION

Today, various kinds of organic frictional materials have been developed and applied actively in the field of vehicles. Among them, asbestos reinforced phenolic resin matrix composites are used as brake lining materials for heavy trucks [1, 2].

The ideal binder to make such composites is phenol-formaldehyde resin.

This is because it is cheap, good moldable and has good heat resistance.

In addition, asbestos is used as a reinforcement material in composites because of its high heat resistance and wear resistance, high mechanical strength and good bonding properties with plastics.

The brake lining material is subjected to friction during braking, which causes a very rapid rise in surface temperature when the thermal decomposition temperature of the resin exceeds, causes the friction coefficient to become unstable and the wear rate increases rapidly [2].

Therefore, in the material design, the thermal conductivity of the friction material must be improved by adding materials with high thermal conductivity.

Several factors such as particle type, volume fraction, and particle size have effects on the thermal conductivity of the PPCs [3, 4].

The prediction model of the thermal conductivity of the PPCs includes thermodynamic models such as the Turner and Kerner models and the Hasselman-Johnson model that simultaneously predicts the thermal expansion and thermal conductivity of the PPCs [5].

Researchers have proposed a mathematical model to calculate the thermal conductivity of the materials when the spherical particles are randomly distributed in a continuous medium and there is no contact between particles. [6, 7]

The Hasselman-Johnson model was employed to analyze the experimental results, and the prediction model get closer to the obtained experimental data. [8]

However, these methods are used to study dual-phase composites, and the application is difficult for reinforcements with a genus of more than two, especially there is disadvantage that particle size is not considered.

Thus, the friction composite we are interested in contains the reinforcing material such as asbestos, barite, vermiculite, graphite in the interior, making it difficult to evaluate the thermal conductivity of the material using the proposed mathematical models.

Recently, an approach has been proposed to generate Representative Volume Element (RVE) model of composites with different reinforcement structures using engineering analysis softwares such as ABAQUS Software and to predict properties such as elastic modulus and limit of strength [9, 10].

This gives the possibility to predict more easily and accurately the properties of composite with random distribution of reinforcements with different particle sizes and fractions.

In particular, the use of Abaqus-Python can improve the speed of material design by enabling programmable implementation of all operations from modeling to simulation analysis and results processing.

The important problem in increasing the accuracy of the simulation results is to generate the RVE model which is similar to the real composite.

Many algorithms have been developed to generate RVE models in which the reinforcements are randomly distributed.

In [9] the hard-core random distribution algorithm (HCRDA) [9] was established, and in [10, 11] algorithms such as the agitation model and the random sequential evolution algorithm were developed.

In order to increase volume fraction, a nearest neighbor algorithm (NNA) was developed by Vaughan and McCarthy [13].

The principal drawback of the aforementioned algorithms is low effective or not to generate RVE model with non-uniform dispersions and volume fractions.

A vigorous method for generating model with high volume fraction in any condition is to use molecular dynamics simulations (MDS) [14].

In order to improve the computational efficiency, the RVE model with high volume fraction was generated by means of effective way based on event-driven molecular dynamics (EDMD). [14].

In this way, several optimization methods must be used to determine the optimum composition based on the RVE model and the thermal conductivity prediction.

Currently, particle swarm optimization (PSO) and its different variants are widely used in the field of material design to solve various optimization problems.

PSO algorithm is introduced to design concrete structures to solve the constrained optimization problem easily [15].

A. Paknahad determined the optimum structural dimensions by optimizing using PSO algorithm in the design of a complex pressure vessel [16].

In this paper, an RVE model of randomly distributed particle reinforced composite was established by implementing EDMD algorithm with Abaqus-Python, a methodology was established to predict the thermal conductivity from simulation results, and the PSO algorithm was used to determine the optimum composition of asbestos friction composite

The specimens with particles of corresponding size and fraction were manufactured to verify the simulation results.

2. Materials and Simulation Method

The properties of the materials used in this paper are listed in Table 1.

Table 1. *Properties of materials*

Properties / Material	Mean Particle size, mm	Density, g/cm^3	Thermal Conductivity, W/(m·K)	Specific Heat, J/(Kg·K)
Novolac resin	-	1.25	0.12	1600
Asbestos	0.8	2.5	0.15	880
Vermiculite	1.2	2.2	0.07	700
Graphite	0.2	2.25	120	712

Barite	0.2	4.3	2.5	436
Alumina	0.02	3.9	17	432

In Figure 1 and 2, an algorithm for random distributing of spherical particles of different sizes within a finite cube with respect to periodic boundary conditions [17] and the resulting RVE model are presented.

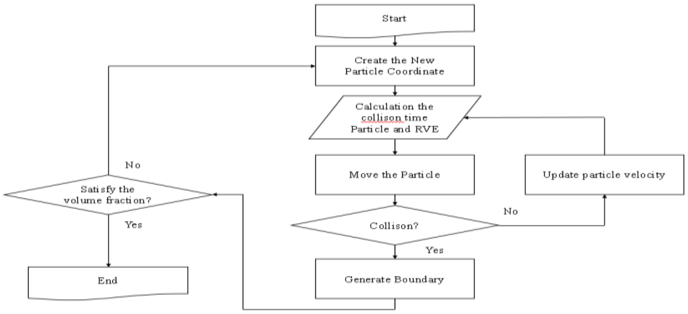
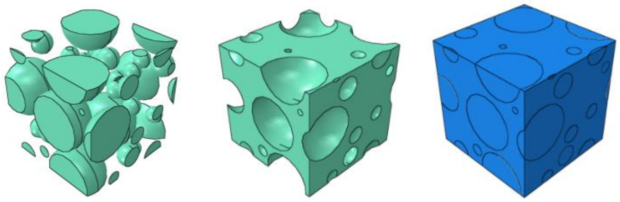


Figure 1. *EDMD algorithm*


(a) (b) (c)

(a)-Reinforcement, (b)-Matrix, (c)-Micro-scale RVE

Figure 2. *Generated RVE model*

Then, using Python Script, the surfaces that are in contact with each other between the reinforced and the matrix model are programmed to provide the complete constraint boundary conditions.

To simulate the thermal conductivity, the initial temperature boundary condition of 293K was applied on one side of the RVE model, 1 W/m^2 heat flux condition on the opposite side, and symmetrical boundary condition was applied on the other sides.

From the simulation results, the average temperature between both sides was calculated and the average thermal conductivity of the material was calculated using the following equation (1):

$$\lambda = \frac{q\delta}{S(T_1 - T_2)} \quad (1)$$

Where

λ—Thermal conductivity of composite, $W/(m \cdot K)$

S— Area of the RVE model under heat flux conditions, m^2

q— Heat flux on one side of the RVE model, W/m^2

δ — Distance between the surface and the opposite surface to which heat flux is applied, m

T_1, T_2—Temperature at the surface opposite to the surface that gives heat flux, K

In this way, based on the prediction of the thermal conductivity of the composite with arbitrary particle size and volume fraction, the following PSO algorithm was used to determine the optimum composition.

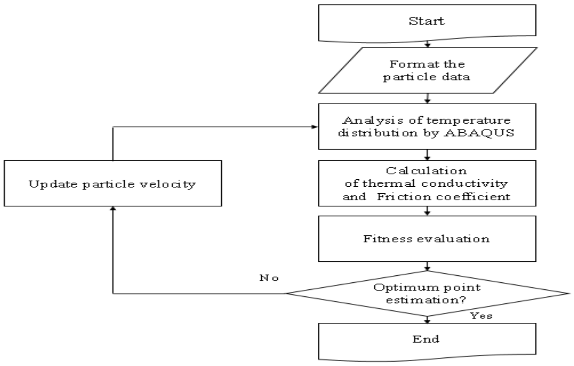


Figure 3. *PSO Algorithm*

The volume fraction of the novolac resin varies from 23 to 28%, the graphite varies from 3 to 8%, the fraction of asbestos varies from 40 to 60%, and the fraction of expanded vermiculite varies from 10 to 15%.

At this time, in PSO algorithm the number of particles is 10, and the initial velocity of all particles are zero.

The friction coefficient of the material was also predicted by Abaqus.

The simulation was carried out by applying the tangential displacement condition on one side of the RVE model and the friction coefficient was calculated using the following equation (2), (3) and (4):

$$\mathrm{w} = \int p(x)dx \quad (2)$$

$$F = \int \tau dx \quad (3)$$

$$\mu = \frac{F}{w} \quad (4)$$

$p(x)$—stress distribution along location, MPa

τ — Shear stress, MPa

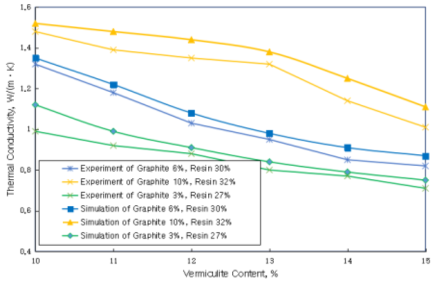
μ — Friction coefficient

To measure the thermal conductivity of the composite material by experimental method, QTM-500 was used.

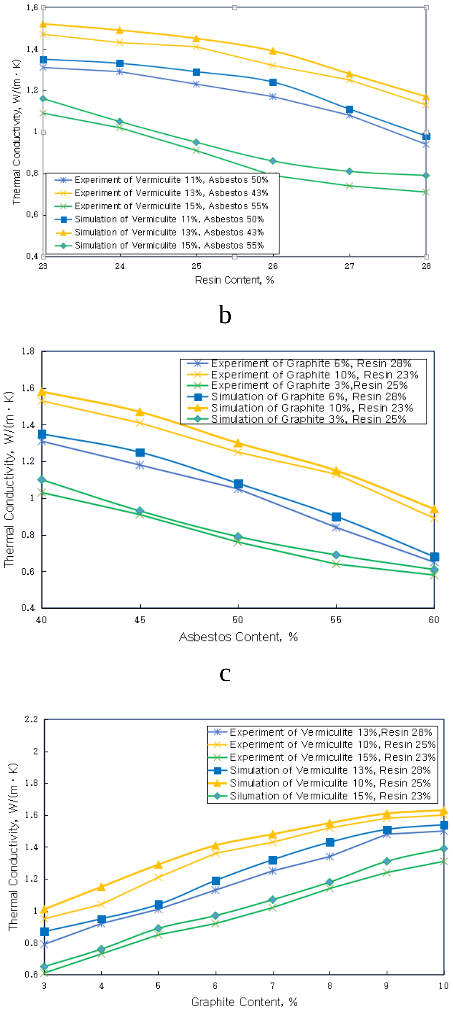
3. Result and Discussion

3.1 Comparison simulation data and experimental data

Figure 4 shows comparison the thermal conductivity predicted using Abaqus with the thermal conductivity obtained through the experimental method.



a



b

c

d

a) Thermal conductivity according to vermiculite volume fraction

b) Thermal conductivity according to resin volume fraction

c) Thermal conductivity according to asbestos volume fraction

d) Thermal conductivity according to graphite volume fraction

Figure 4. *Thermal conductivity with different volume fraction*

As shown in figure 4, Although there is a certain error between experimental result and simulation result, simulation result is relatively correct.

The reason for this error is that the ABAQUS-PYTHON method was not considered micro-pores.

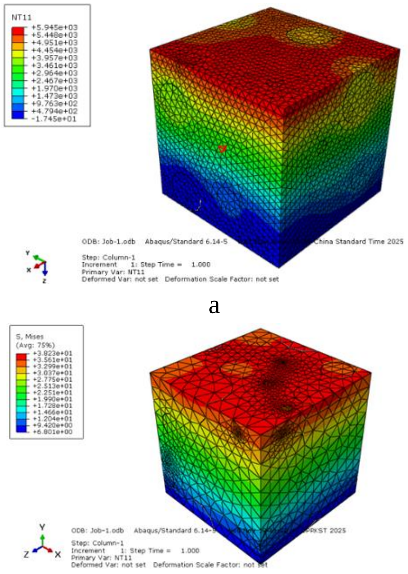
It is also assumed that all the reinforcing particles are perfectly spherical, but the real reinforcing particles have irregular shapes and sharp edges.

From results, the RVE model is acceptable in predicting the thermal conductivity of randomly distributed particle reinforced composites with different particle sizes and volume fractions, since it has some errors but is less than 5%.

3.2 Determination the optimum composition

The search using PSO algorithm resulted in four optimal compositions (with a particle population size of 10).

The Abaqus simulation results for predicting thermal conductivity and friction coefficient for the highest fitness object are shown in Figure 5.



a

b

a) Simulation results for Thermal conductivity calculation

b) Simulation results for friction coefficient calculation

Figure 5. *Simulation results for thermal conductivity and friction coefficient calculation*

To verify the simulation results and determine the more appropriate composition, the specimens corresponding to the four objects obtained were prepared and compared to analyze the friction coefficient, wear rate and thermal conductivity. (Table 2)

Table 2. *Experimental result*

No	**Friction coefficient**	**Wear rate, cm^3/kg·m**	**Thermal conductivity, W/(m·K)**	**No**	**Friction coefficient**	**Wear rate, cm^3/kg·m**	**Thermal conductivity, W/(m·K)**
1	0.31	6.7	1.398	6	0.36	6.1	1.356
2	0.34	5.9	1.295	7	0.35	5.8	1.342
3	0.38	5.3	1.587	8	0.33	5.5	1.568
4	0.33	6.1	1.493	9	0.37	6.4	1.467
5	0.35	5.7	1.523	10	0.32	6.5	1.505

From experimental results, the optimum composition of the third sample with the minimum wear rate, while satisfying the requirements of friction coefficient and thermal conductivity, was chosen.

Its composition is shown in Table 3.

Table 3. *Composition of brake friction material*

Material	**Novolac resin**	**Asbestos**	**Vermiculite**	**Graphite**	**Barite**	**Alumina**
Fraction, %	24	40	11	8	15	2

Conclusion

In this paper, a thermal conductivity prediction by Abaqus-Python and optimization method using PSO algorithm to stabilize the friction coefficient of asbestos friction composite were proposed to determine the optimum material composition.

To verify the accuracy of the simulation method and results, composite specimens with the corresponding composition were prepared and compared with the simulation results by measuring the friction coefficient and thermal conductivity.

As a result, although there are some errors in the experimental results, it can be seen that the proposed method is relatively accurate.

In the proposed simulation method, the shape of the reinforcing particles is assumed to be spherical.

Further research is necessary to further improve the reliability of the simulation results by considering the case of ellipsoidal, cylindrical, or any other shape of the particle.

References

1. D. Aleksendric, P. Carlone. (2015). Applications in brake friction and thermoset matrix composites. *Soft Computing in the Design and Manufacturing of Composite Materials*, 97~105. doi: 10.1016/j.compstruct.2013.10.039
2. W. Osterle, C. Prietzel. (2016). Influence of thermal conductivity and thermal stability on the fade and recovery characteristics of non-asbestos semi metallic disc brake pad, *J. Braz. Soc. Mech. Sci. Eng*. doi: 10.1016/j.compstruct.2017.01.035
3. Wu XJ, Zhang H, Zhang Y, Li J. (2012). Effect of copper fraction on the thermal conductivity and thermal expansion of Al–Cu/diamond composites. *Materials Design* 39

4. Fathy A, El-Kady O. (2013). Effect of SiC particle size on the physical and mechanical properties of extruded al matrix nanocomposites. *Materials Design* 54:348–35 3
5. Xue C, Yu JK, Zhu XM. (2011). Thermal properties of diamond/SiC/Al composites with high volume fractions. *Materials Design* 32:4225–4228

A. Khazaei, A. Shojaei. (2015). Modeling and optimization of friction materials based on genetic programming and experimental frictional data. *J. R. P. C*. 2015.

6. doi: 10.1016/j.icheatmasstransfer.2015.01.005
7. M. Kristkova, Z. Weiss. (2015). 3D FE model of friction heating and wear with a mutual influence of the sliding velocity and temperature in a disc brake. *International Communications in Heat and Mass Transfer*.
8. Hassan Sharifi. (2017). Effect of SiC particles on thermal conductivity of Al-4%SiC composites, *Heat Mass Transfer*. doi: 10.1016/j.icheatmasstransfer.2015.01.005
9. Wenzhi Wang, Yonghui Dai, Chao Zhang. (2016). Micromechanical Modeling of Fiber-Reinforced Composites with Statistically Equivalent Random Fiber Distribution. *Materials*. doi: 10.3390/ma9080624
10. Jiaying Gao, Modesar Shakoor. (2020). Predictive multiscale modeling for Unidirectional Carbon Fiber Reinforced Polymers. *Composite Science Technology*. doi: 10.1016/ j. compscitech.2019.107922
11. Romanov V, Lomov SV, Swolfs Y, Orlova S, Gorbatikh L, Verpoest I. (2013). Statistical analysis of real and simulated fibre arrangements in unidirectional composites. *Composite Science Technology*.
12. Wing Kam Liu, Cahal McVeigh. (2013) Predictive multiscale theory for design of heterogeneous material. *Composite Science Technology*. doi: 10.1007/s00466-007-0176-8
13. Vaughan TJ, McCarthy CT. (2010) A combined experimental-numerical approach for generating statistically equivalent fibre distributions for high strength laminated composite materials. *Composite Science Technology*. doi: 10.1016/j.compscitech.2009.10.020
14. Aram Bahmani. (2018). Three-dimensional microscopic assessment of randomly distributed representative volume elements for high fiber volume fraction unidirectional composites. *Composite Structures*. doi: 10.1016/j.compstruct.2018.02.075
15. Zhishuo Yang, Mingxia Chen, Feixin Chen. (2023). Application of ABAQUS by Using Python in Concrete-Filled Steel Tube. *Advances in Frontier Research on Engineering Structures*.
16. A.Paknahad. (2016). Optimum head design of filament wound composite pressure vessels using a hybrid model of FE analysis and inertia weight PSO algorithm. *International Journal of Material Forming*. doi: 10.1007/s12289-014-1199-2