

Effect of Temperature on Thermal Conductivity of Metals

Prof. A Maurya

Assistant Professor, Department of Mechanical Engineering, Padm. Dr. V. B. Kolte College of Engineering, Malkapur, Maharashtra-443101, India.

DOI: 10.5281/zenodo.19381969

ABSTRACT

Thermal conductivity is a critical thermophysical property of metals that significantly influences their performance in heat transfer applications. The thermal conductivity of metals is strongly dependent on temperature due to changes in electron and lattice interactions. This paper investigates the effect of temperature on the thermal conductivity of metals, explains the underlying physical mechanisms, and discusses trends observed in common engineering metals such as copper, aluminum, and steel. Understanding this temperature dependence is essential for the accurate design of thermal systems operating under variable thermal conditions.

Keywords:- Thermal conductivity, metals, temperature effect, heat conduction, electron transport.

1. INTRODUCTION

Metals are widely used in engineering systems due to their high thermal conductivity, which makes them ideal for applications such as heat exchangers, electronic cooling, power plants, and manufacturing processes. Thermal conductivity determines how efficiently a material can conduct heat under a temperature gradient. In many real-world applications, metals operate over a wide temperature range. Therefore, assuming constant thermal conductivity may lead to inaccurate thermal analysis. This paper focuses on examining how temperature affects the thermal conductivity of metals and the physical principles governing this behavior.

2. HEAT CONDUCTION IN METALS

Heat conduction in metals occurs primarily through the movement of **free electrons**, with lattice vibrations (phonons) contributing to a lesser extent. This distinguishes metals from non-metals, where heat transfer is mainly phonon-driven.

The total thermal conductivity k of a metal can be expressed as:

$$K = k_e + k_p$$

Where:

k_e = electronic thermal conductivity.

k_p = phonon (lattice) thermal conductivity In metals, k_e is the dominant term.

3. EFFECT OF TEMPERATURE ON THERMAL CONDUCTIVITY

3.1 Low Temperature Range

At low temperatures, thermal conductivity of metals generally **increases with increasing temperature**. This occurs because: The number of free electrons contributing to heat transport increases, Electron scattering is relatively low

3.2 Intermediate Temperature Range

At moderate temperatures (including room temperature), thermal conductivity reaches a **maximum or plateau**. In this range: Electron population remains high, Increased lattice vibrations begin to cause electron scattering

3.3 High Temperature Range

At high temperatures, thermal conductivity of metals **decreases with increasing temperature** due to: Increased electron-phonon scattering, Reduced mean free path of electrons
Thus, thermal conductivity and temperature exhibit an **inverse relationship** at elevated temperatures.

4. WIEDEMANN-FRANZ LAW

The temperature dependence of thermal conductivity in metals is closely related to electrical conductivity through the **Wiedemann-Franz Law**:

$$K/\sigma T = L$$

Where:

k = thermal conductivity. σ = electrical conductivity T = absolute temperature L = Lorenz number
As temperature increases, electrical resistivity increases, causing a corresponding decrease in thermal conductivity.

5. THERMAL CONDUCTIVITY TRENDS IN COMMON METALS

Metal	Thermal Conductivity at 25°C (W/m·K)	Trend with Temperature
Copper	~400	Decreases significantly
Aluminum	~205	Decreases moderately
Steel	~50	Slight decrease
Nickel	~90	Decreases
Iron	~80	Decreases

High-purity metals exhibit a stronger temperature dependence compared to alloys due to fewer impurity scattering effects.

6. EFFECT OF ALLOYING

Alloys generally show: Lower thermal conductivity than pure metals, Weaker temperature dependence. This is due to increased electron scattering caused by impurities and lattice distortions. As a result, alloys are often preferred in high-temperature applications where stable thermal properties are required.

7. ENGINEERING APPLICATIONS

Understanding temperature-dependent thermal conductivity is crucial in:

Heat exchanger design, electronic device cooling, nuclear reactors, Thermal barrier systems, Metal casting and welding processes

Accurate modeling ensures thermal safety, efficiency, and reliability.

8. EXPERIMENTAL METHODS FOR MEASURING THERMAL CONDUCTIVITY

Common experimental techniques include:

Steady-state longitudinal heat flow method, Transient plane source (TPS) method, Laser flash analysis (LFA).

These methods allow determination of thermal conductivity over a wide temperature range.

9. LIMITATIONS AND CHALLENGES

Challenges in analyzing temperature effects include: non-linearity of thermal properties, Measurement errors at extreme temperatures, Oxidation and phase changes in metals, Advanced numerical models are often required to overcome these limitations.

10. CONCLUSION

The thermal conductivity of metals is strongly influenced by temperature due to electron–phonon interactions. While conductivity increases at low temperatures, it decreases at higher temperatures as scattering mechanisms intensify. Pure metals exhibit higher thermal conductivity and stronger temperature dependence compared to alloys. Considering temperature-dependent thermal conductivity is essential for accurate thermal analysis and efficient engineering design.

11. REFERENCES

- [1] Incropera, F. P., et al., Fundamentals of Heat and Mass Transfer, Wiley
- [2] Callister, W. D., Materials Science and Engineering, Wiley
- [3] Holman, J. P., Heat Transfer, McGraw-Hill
- [4] Kittel, C., Introduction to Solid State Physics, Wiley
- [5] Bidwell, C. C. (1940). Thermal conductivity of metals. Physical Review, 58, 561.
- [6] Agazhanov, A. S., Samoshkin, D. A., & Stankus, S. V. (2023). Thermal conductivity and thermal diffusivity of iron in the temperature range of 300–1700 K. Physics of Metals and Metallography, 124(12), 1149–1158.
- [7] Thermal conductivity of metals at low temperatures (Vol. 12). (1961). Solid State Physics.
- [8] Tong, Z., Li, S., Ruan, X., & Bao, H. (2019). A comprehensive first-principles analysis... arXiv.
- [9] The temperature dependence of thermal conductivity of some chemical elements. (1991). Experimental Thermal and Fluid Science, 4(3).
- [10] Thermal conductivity and resistivity. (n.d.). In Wikipedia.

- [11] Wiedemann–Franz law. (n.d.). In Wikipedia.
- [12] Bloch–Grüneisen law. (n.d.). In Wikipedia.
- [13] Thermal conductivity of W–Cu composites at various temperatures. (2001). Materials Letters.
- [14] Effect of heat treatment on metal thermal conductivity. (2023). Atlantis Press.
- [15] Temperature and Conductivity Relation Explained (SinoAnalyzer), This article explains how temperature affects both electrical and thermal conductivity in metals — particularly that conductivity decreases with increasing temperature due to electron scattering.
- [16] Review Section on Thermal Conductivity & Temperature (RSC Publishing), In this research review, the section on effect of temperature specifically discusses how thermal conductivity of metals varies with temperature.
- [17] NASA Technical Reports Server — Thermal Conductivity of Metals (NTRS), A NASA educational report on thermal conductivity, including discussion of conduction and temperature effects in metals (useful for background & conceptual explanation).
- [18] Thermal Conductivity of W–Cu Composites at Various Temperatures (ScienceDirect) Research article discussing how thermal conductivity changes with temperature in tungsten–copper composites, including direct metal conductivity trends.
- [19] Effect of Heat Treatment on Metal Thermal Conductivity (Atlantis Press), A conference article that includes experimental data showing how temperature affects metal thermal conductivity, especially after heat treatment.