

Original Research Article

MATERIAL SELECTION FOR HEAT SINKS IN HPC

MICROCHIP-BASED CIRCUITRIES

ABSTRACT

Heat sinks are integral components of HPC microchips which are extensively used in modern electronics and power supply circuitries to provide the system with intelligence and effective control. They typically generate large amount of heat sufficient to damage the chip and other sensitive electronic components of the circuitry. Heat sinks are applied to accomplish a continuous cooling of the microchip by conducting thermal energy away from it and dissipating same into the environment. Suitable materials for the heat sink are therefore important for effective protection of the microchip. In this study, material selection for heat sinks applicable in microchip-based circuitries was carried out using the CES EduPack software. Over 3,000 candidate materials were first screened using design constraints after which shortlisted ones were ranked using design objectives. Appropriate trade-offs were applied to select the final material which was an alloy adjudged most suitable for the defined function, objectives and constraints.

Keywords: Heat sink, Microchip, Constraint, Material selection, CES EduPack, Objective

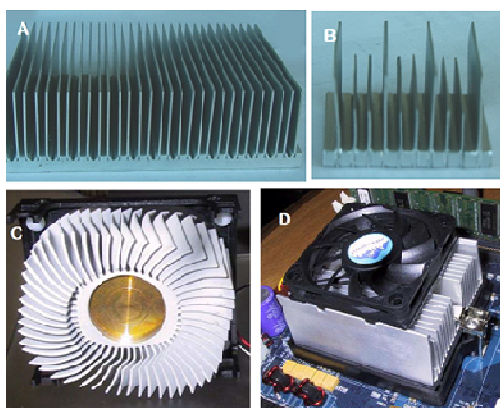
1. BACKGROUND

Electronic components used in modern day electronics are becoming smaller, thinner, faster, lighter and more powerful [1]. This is because high-powered integrated circuit packages (microchips) are produced by integrating larger number of transistors into a single unit [1, 2]. The hundreds of millions of transistors working together in a small confined space generate a lot of heat energy which put the system at risk of damage if not controlled [2].

Heat sinks have been designed and conventionally used to prevent overheating of the chips and to enhance their efficiency [3]. They are used for cooling the computer processing unit (CPU) in computer systems. They also find important application in high-powered semiconductor devices such as power transistors, lasers and light emitting diodes (LEDs) [4]. Several designs utilize light alloys such as aluminium alloy as sinks [5] but other materials could well be used. Sinks are categorised according to their shape (geometry) [6] Fig 1. Among the categories are

- i. *Extruded type* in which the heated metal is forced through a profile die. It has moderate performance, cost effective, limited dimension and best for most applications.
- ii. *Stamped type*- the metal is stamped to form a particular shape and best for low power. It is inexpensive but comes with low performance.
- iii. *Bonded type* has the fins bonded to a pre-grooved base with an epoxy usually for large applications but has moderate performance. They comes in large sizes and expensive.

- iv. *Folded fin type* has its fins pre-folded and soldered or brazed to the base plate as the case may be. They usually have a very high performance, best for ducted air, expensive and require high heat-flux density.
- v. *Skived type*- it has many applications with medium to high performance, usually with thick base, high weight and directional sensitive.
- vi. *Swaged type*- the individual fin of this type of sink are placed in a pre-grooved base and a roller swage the sides to the fins. It is applicable in high power areas and usually heavy and bulky.
- vii. *Forged type*- formed by compressing heated metal into a desired shape.
- viii. *Single fin assembly type*



A- Swaged type;
B- Single fin assembly type;
C- heat sink with copper core;
D- Extruded type

Fig. 1: Cross section of typical heat sinks.

It is applicable commonly in computer systems, cell phones, uninterrupted power supply (UPS), DVD players, Heat pipes, Stabilizers etc. An alternative to heat sink is heat pump as found in large scale applications.

Figs. (2) and (3) show a sketch of application of the heat sink and the model function respectively.

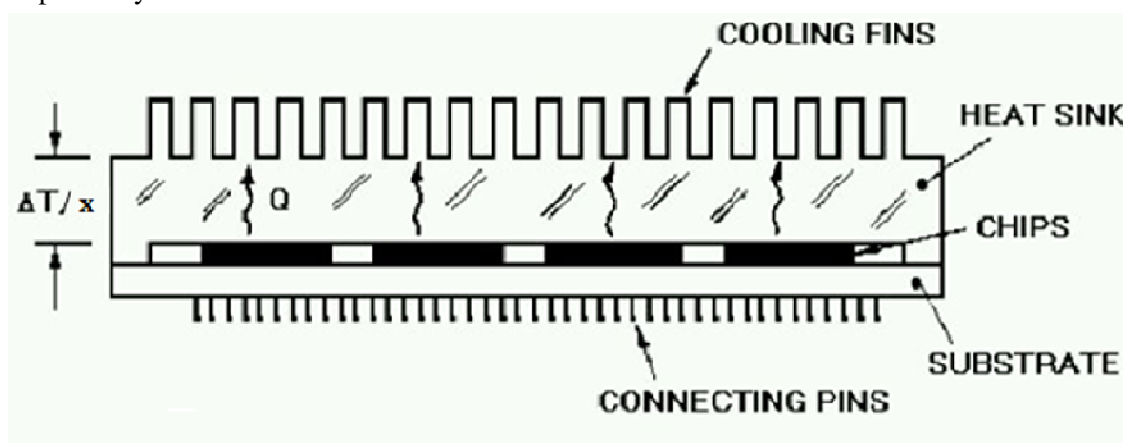


Fig. (2): Heat sink schematic.

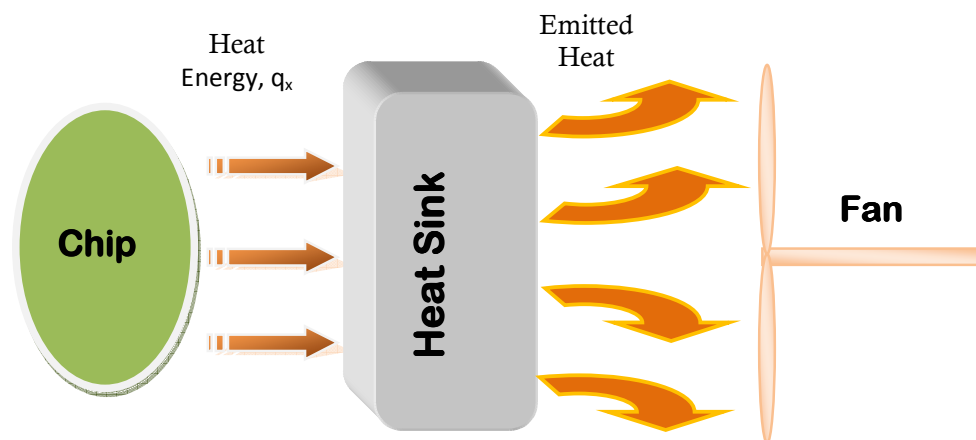


Fig. (3): Model of a heat sink in a circuit.

The limitation associated with heat sink include the fact that it takes up too much design space in the circuitry and sometimes requires a fan to blow-out the dissipated heat energy by convection.

Microchip is a manufactured component, based on integrated circuit (IC) technology and usually made from silicon material [7]; it is a single unit package with some level of intelligence for both application and control systems.

Major application of chips include: aerospace, medical and biomedical, manufacturing, home appliances, security, automotive, communication, design solutions etc. This is because of their simple, small, fast, light, efficient and cost effective nature [8].

Typical microchip-based systems include the computer system; chemical, biochemical and several other analysis systems; cell, clinical and other diagnosis systems; target validation systems; power supply systems, lighting system [9, 10, 11] and countless other systems.

The circuitry advantages associated with the use of microchips are the provision of intelligent system; controllability and processing of integrated circuits in the system; lower cost [12] and high performance. A typical microchip device is shown in Fig. (4).

Its related disadvantages in a circuitry include:

- (i) Not flexibility- each chip is produced for a specific purpose. Therefore, the possibility of upgrading the chip is limited which means as the functionality demand increases, a new system is eventually required.
- (ii) High power requirement- it requires significant power to operate. The demanding high currents and voltage by the integrated components results in heat generation thus requiring heat sink to keep it from burning-out.

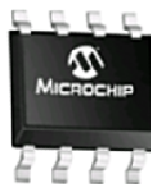


Fig. (4): Typical microchip

87 The present work reflects on the numerous applications of heat sinks in multifarious
88 microchip-based appliances and therefore applies GRANTA Design (CES EduPack) software
89 to conduct materials selection for it.

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91 2. METHODOLOGY

92 2.1 Function and Mathematical model

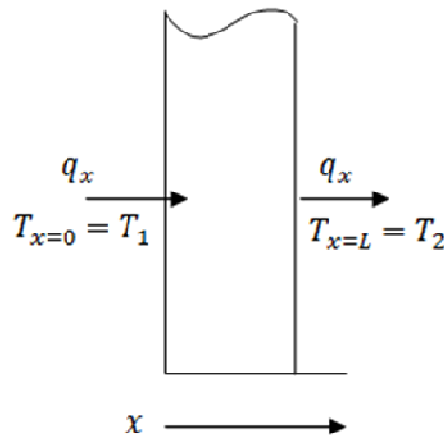
93 The specific function of a heat sink is to effectively absorb and dissipate heat away from a
94 chip device as quickly as possible. A typical heat sink must have a temperature higher than
95 the surrounding in order to transfer heat either by convection, conduction or radiation. This is
96 reflected by the principle of heat transfer- thermal energy is transferred from a region of
97 higher temperature to a region of lower temperature in a fluid medium [13, 14].

98 For steady heat transfer and constant temperature with time, the Laplace equation for the one-
99 dimensional heat-flow holds [14].

$$\frac{\partial^2 T}{\partial x^2} = 0 \quad (1)$$

100 The schematic diagram of steady state heat transfer across the one-dimensional conductor is
101 shown in Fig. (5).

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Fig. (5): Steady state 1-D heat conduction.

105 It is assumed that the chip operates continuously and thermal conductivity is constant. The
106 result of equation (1) gives the Fourier equation that was used to calculate the heat flow.

$$Q_x = -KA \frac{dT}{dx} = KA \frac{\Delta T}{L} \quad (2)$$

107 Where: Q_x = Rate of heat transfer by conduction in x – direction

108 K = Thermal conductivity of the sink

109 A = Area of contact between the chip and heat sink

110 ΔT = Temperature difference along the sink

111 $\frac{\Delta T}{L}$ = Temperature gradient in x – direction

112 L = Thickness of the sink

113 Since the rate of heat transfer is directly proportional to the area of contact therefore, a large
114 chip will require a large heat sink.

115 Assuming the total area of chip contact is

$$CA$$

116 Therefore, the mass of the sink is given as:

$$m = CA.L.\rho \dots\dots\dots (3)$$

117 Where: ρ = Density of material of which the sink is made

118 Combining equations (2) and (3) by division, the resulting equation gives the power drained
119 per unit weight of sink as:

$$\frac{Q_x}{m} = \frac{\Delta T}{CL^2} \left(\frac{K}{\rho} \right) \dots\dots\dots (4)$$

120 The thermal expansion limits the temperature difference (ΔT); a very high temperature will
121 cause differential strain between chip and sink which will damage the chip. The expansion
122 difference is given by:

$$\Delta \varepsilon = \Delta \alpha . \Delta T \dots\dots\dots (5)$$

123 Where: $\Delta \alpha$ = Difference in thermal coefficient between sink and chip

124 But the expansion difference must be kept below the critical value as expressed in eqn 6.

$$\Delta \varepsilon \leq \Delta \varepsilon^* \dots\dots\dots (6)$$

125 Combining equations (5) and (6) into equation (4), the temperature difference term is
126 eliminated:

$$\frac{Q_x}{m} = \frac{\Delta \varepsilon^*}{CL^2} \left(\frac{K}{\rho \Delta \alpha} \right) \dots\dots\dots (7)$$

127 Let the material index be given as M_1 .

$$\frac{Q_x}{m} = \frac{\Delta \varepsilon^*}{CL^2} \left(\frac{K}{\rho \Delta \alpha} \right) = \frac{\Delta \varepsilon^*}{CL^2} M_1$$

$$M_1 = \left(\frac{K}{\rho \Delta \alpha} \right) \dots\dots\dots (8)$$

128 2.2 Constraints and Objective

As in every problem of selection, objectives represent what the design is required to maximize, maintain or minimize while constraints represent essential non-negotiable conditions to be met in the design. The design objectives are high thermal conductivity, light weight (low density) and low thermal expansion coefficient. In a specialized high-tech design as a portable heat sink for a microchip in an integrated circuit, cost is not imposed as a constraint. The design will be constrained by a restriction in $\Delta\alpha$ ($\leq 1\text{e-}5$ strain/ $^{\circ}\text{C}$) and K/ρ ($\geq 1\text{e-}2$) being results of preliminary simulations for the design.¹ CES EduPack was applied to select the best material for the heat sink using the Function-Objectives-Constraints approach.

2.3 Screening and Ranking

The logarithmic form of the objective function in eqn 8 can be expressed in the standard equation of a straight line as

$$\log\left(\frac{K}{\rho}\right) = \log(\Delta\alpha) + \log M_1 \dots \dots \dots (9)$$

Fig 7 is a plot of eqn 9 in CES EduPack where M1 has a slope of 1. Figs 7 and 8 show screening using design constraints. Ranking was done in Figures 9, 10 and 11 to arrange materials that survived screening in a desired order for the purpose of selecting the best material.

3. DISCUSSION

Results obtained from this study are provided in Figs 6—11 and Table 1. Of the over 3,000 candidate materials in the material space (All Bulk Materials), which were originally considered, 97% were screened off—being materials which fall below the line graph of equation 9 (Fig 7). The screened volume may not be considered critical considering the important role of heat sinks. Further screening was done in Fig 8 by applying restrictions on thermal expansion coefficient to box out more materials as indicated by line-box M2. All materials which fall outside line-box M2 box were again screened off. All materials which eventually survived the screening process were ranked by Performance index in Fig 9 with diamond as the best followed by Al-60%C alloy. The performance of Al—60%C only drops below that of diamond by about 10%. Fig 10 reveals that Al—60%C excels other candidates in terms of thermal expansion coefficient. Table 1 therefore considers the strength of the various candidates and arrive at Al—60%C as the most suitable material as heat sink for microchip-based devices and circuitries.

In practice, the material constituents of sinks are generally aluminium alloy provided with fins [5]. The fins are designed to maximize the surface area in contact with the cooling medium surrounding it. Traditional heat sinks are composites of two materials where one provides good conductivity and the other limits thermal expansion. The conductivity and heat dissipation could also be enhanced by special structural designs.

¹ CES EduPack is a trademark of Granta Design Limited—the Software used to create the charts and property rankings used in this manuscript (The CES EduPack. Granta Design Ltd. Cambridge, UK; 2011. Available: www.grantadesign.com)

4. CONCLUSION

- 1) This study concludes that Al—60%C is the most suitable choice that satisfies the prescribed objectives and constraints for the selection project.
- 2) The design was not constrained by cost because it is a highly sensitive application that was intended—heat sinks for HPC integrated circuit microchips.
- 3) The general properties of aluminium alloys broadly agree with the final material choice in terms of weight, workability and thermal properties.
- 4) This study is important for applying property-based criteria in selecting high performance materials for designs with defined function, objectives and constraints.

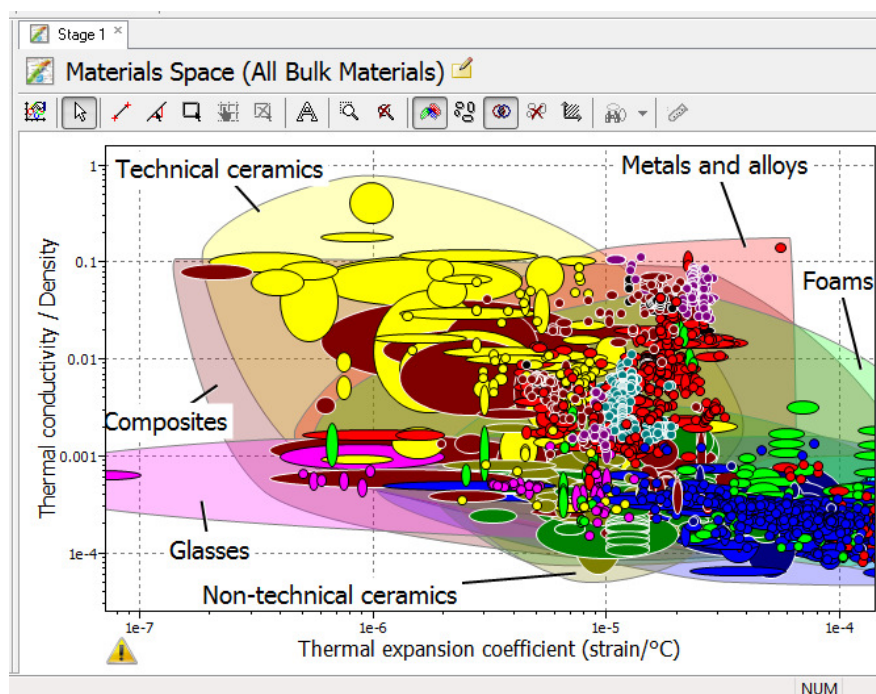


Fig 6: Over 3000 materials in the sample space (all bulk materials)

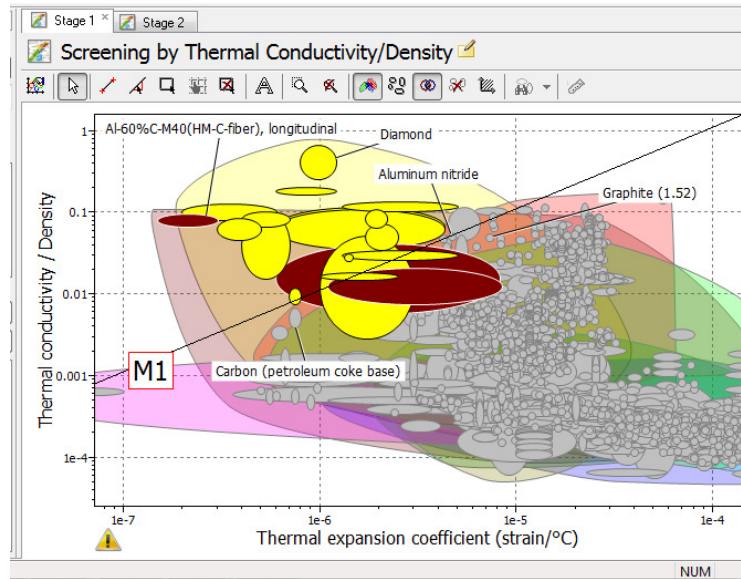


Fig 7: Screening by Thermal Conductivity/Density

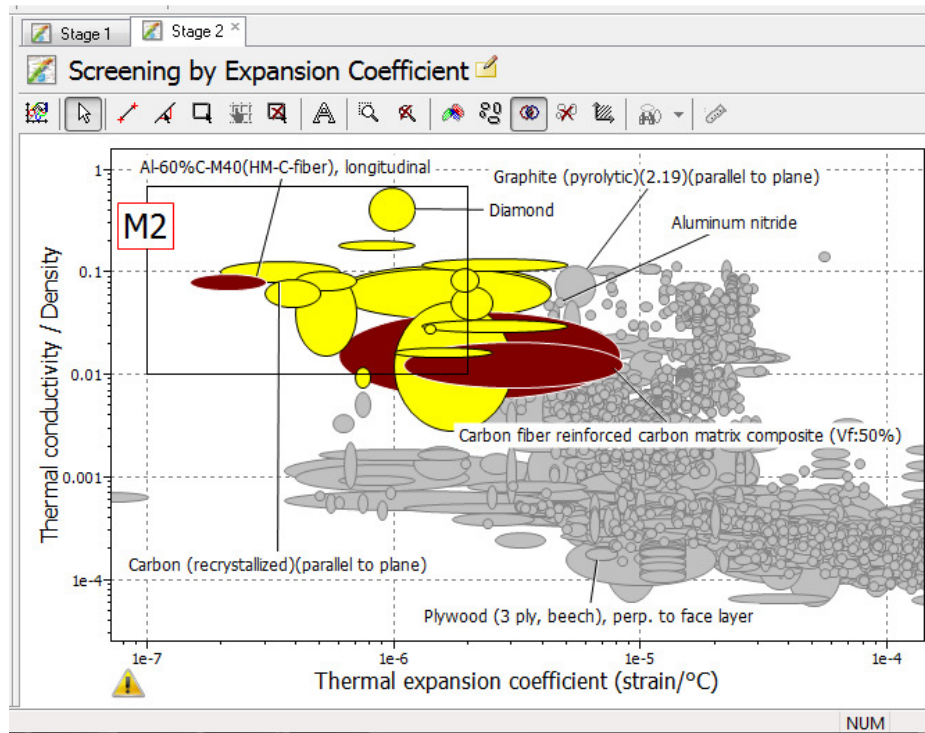


Fig 8: Screening by Expansion Coefficient

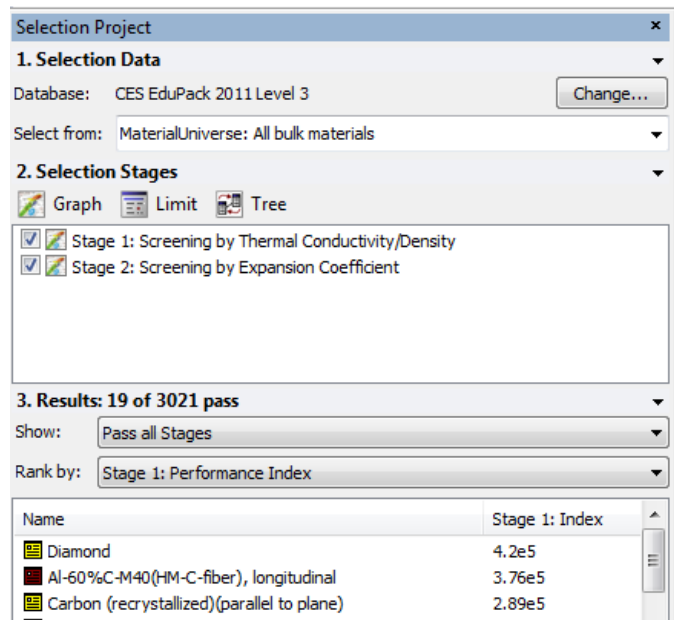


Fig 9: Ranking by performance index

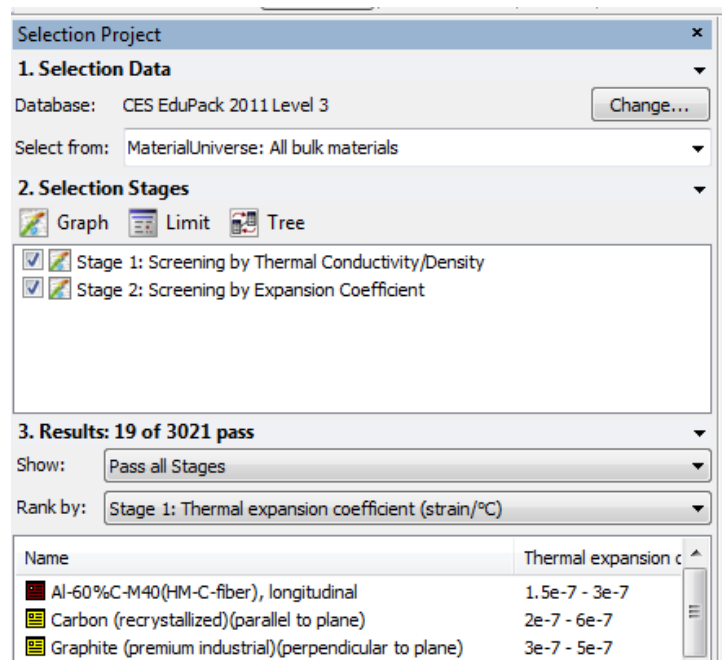


Fig 10: Ranking by Thermal Expansion Coefficient

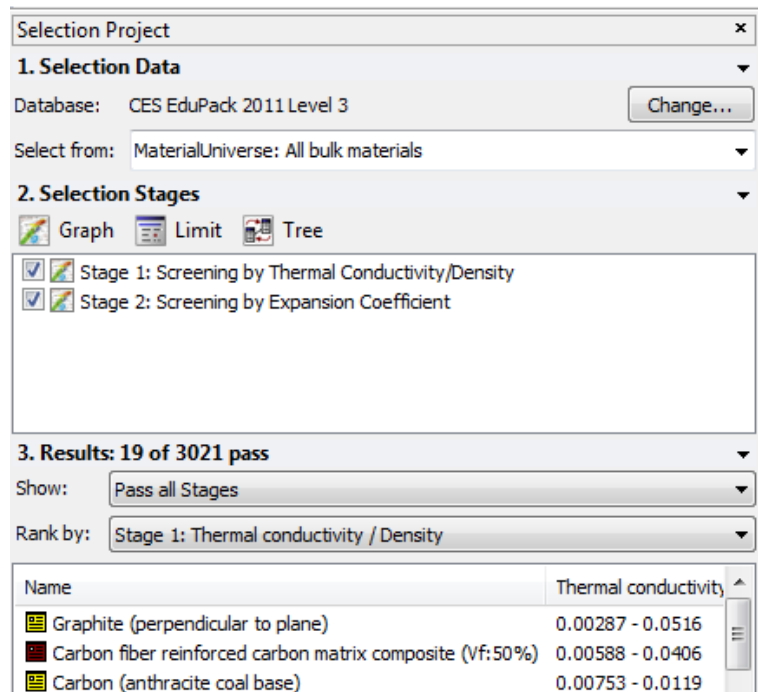


Fig 11: Ranking by Conductivity/Density

Table 1: Selection consideration for shortlisted material candidates

(Based on Figs 9, 10 & 11)

Material	Strength	Comment
Diamond	Highest performance index	Enormous hardness makes workability difficult
Al—60%C	Second highest performance index. Excellent workability. Lowest thermal expansion. Excellent thermal conductivity	Properties are most suitable among candidate materials
Carbon fiber	Moderate thermal conductivity	Workability not adequate
Graphite	Lowest thermal conductivity Moderate thermal expansion	Flaky, thermal conductivity inadequate

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