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# Possible Magneto-Caloric materials - NiF2 reinforced composite and Boron reinforced composite

**Sonali Rai, Shivangi Singh, Er. Vivek Agnihotri**

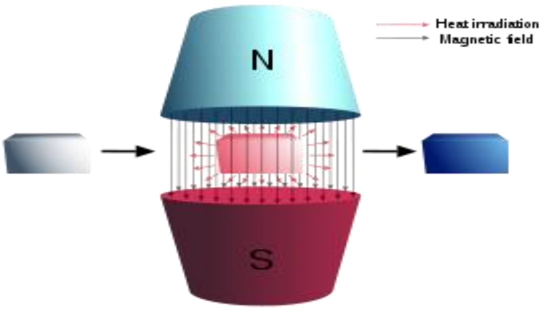
Shri Ramswaroop Memorial College for Engineering and Management, Lucknow

**ABSTRACT**: Nowadays, Material engineering has progressed by far into various super materials or advanced materials. MCE materials are one such example. These materials are those which exhibit temperature change properties when magnetic field applied onto them. Also known as adiabatic demagnetisation, this field is being worked upon by many material scientists to find a better way to refrigeration. In this paper, we have proposed two composite materials which may show Magneto-Caloric effect after fabrication. Since we didn't had a reliable way to confirm their magneto-caloric effect by software analysis, we have done some calculations based on mechanical properties and compared them with Rare earth metals – Gadolinium and Germanium

**Keywords:** Magneto-Caloric Effect (MCE), Magneto-Caloric materials, Magnetic Cooling, MCE Composites, Rare earth metals, Magneto-Caloric composite materials.

## 1. INTRODUCTION

Magneto-Caloric Effect was first discovered by the German physicist, E. Warburg in 1881. MCE, also known as diabatic demagnetization shows temperature variation (cooling or heating effect) of a material when subjected to magnetic field. When a MCE material is applied with magnetic field, it heats up. And as soon as the magnetic field is removed, the material losses its heat to the surrounding, cooling down to a temperature lower than that of when it was first introduced into the field. This phenomenon produces cooling effect. These MCE materials can be used to attain lower temperature such as room temperature, zero-degree temperature and much lower temperature like 10-50 Kelvin.
Many material scientists studying these materials have pointed out their scope in the refrigeration sector.




**Concept of Magneto-Caloric Refrigeration.**

### 1.1 Measuring the MAGNETOCALORIC EFFECT

Direct measurement of MCE is done with rapidly changing of magnetic field.
It can be done by two ways:
1) By changing the magnetic field on an immobilised sample (1 to 40 Tesla Range).
2) By moving the sample in and out of a constant magnetic field (0.1-10 T range).
Also a differential scanning calorimeter (DSC) operating under applied magnetic field can be used for the measuring purpose. The DSC measures the enthalpy of transformation (i.e. latent heat ) when temperature transition occurs due to the field Latent heat then gives the entropy change.

### 1.2 Examples of Rare Earth Metals and their MCE tendencies

Terbium, Holmium, Gadolium, Lanthanide alloys, Gadolium and Germanium alloys, etc.

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### 1.3 Example of Magneto-Caloric Composite Materials

Pb-Bi-Cd alloy bonded $LaFe_{11.6}Si_{1.4}H_{1.4}$ composite materials, $Pr_{0.5}Sr_{0.5}MnO_3$, $LaFe_{11.2}Si_{1.8}$/Ta magneto-caloric composites

## 2. DESIGN OF THE COMPOSITES

For the design of the composites, three separate blocks were designed with following dimensions- 63.5mm and 50.8mm for the length and breadth and the thickness as 6.35 mm for block 1, 2.54 mm for block 2 and 3.81 mm for block 3 using Solid works. And then all the three blocks were joined together into a solid.

### 2.1 Material Overview:

**A. NiF2 reinforced Magneto-Caloric composite:**

1. Matrix - Epoxy resin/ FR-4 Epoxy.
2. Reinforcements - Boron.
3. Metal filler - Nickel II Fluoride [$NiF_2$].

**B. Carbon fibre Magneto-Caloric composite:**

1. Matrix - Epoxy resin/ FR-4 Epoxy.
2. Reinforcements - Carbon fibre.
3. Metal filler - Boron.

## 3. ANALYSIS OF THE COMPOSITES

### 3.1 RESULTS FOR THE BORON REINFORCED COMPOSITE:

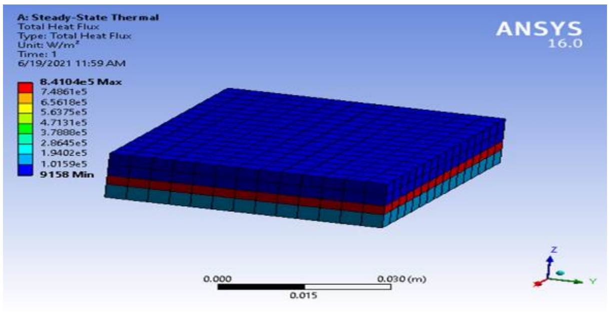


**Fig. Heat flux analysis result of the $NiF_2$ reinforced composite.**

**Table1: Heat Flux value ($NiF_2$):**

| Time [s] | Minimum [W/m²] | Maximum [W/m²] |
|---|---|---|
| 1. | 2175.8 | 2.0048e+005 |

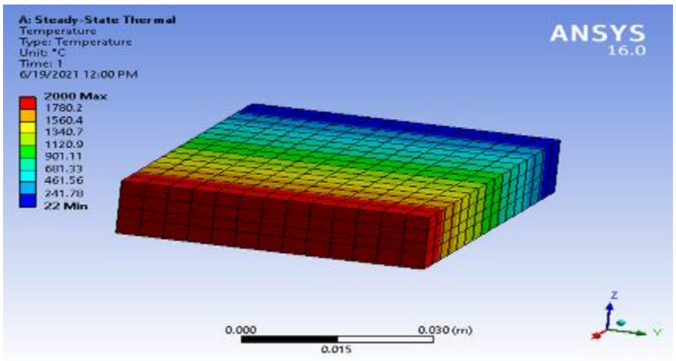


**Fig. Temperature analysis of $NiF_2$ reinforced composite**

  

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**Table2: Temperature Value ($NiF_2$)**

| Time [s] | Minimum [°C] | Maximum [°C] |
|---|---|---|
| 1. | 181.8 | 1000 |

### 3.2 RESULTS FOR CARBON FIBER COMPOSITE:

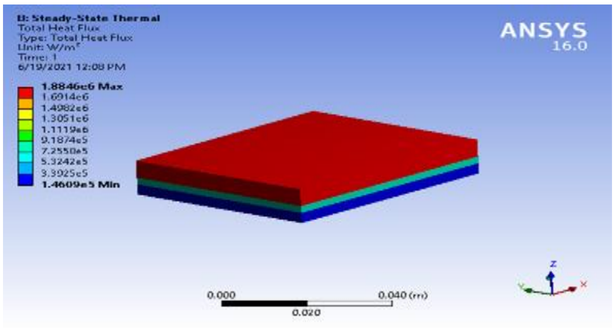


**Fig.: Heat flux diagram for carbon fibre composite.**

**Table3: Heat flux value (Carbon Fibre composite)**

| Time [s] | Minimum [W/m²] | Maximum [W/m²] |
|---|---|---|
| 1. | 1752.1 | 2.2238e+005 |

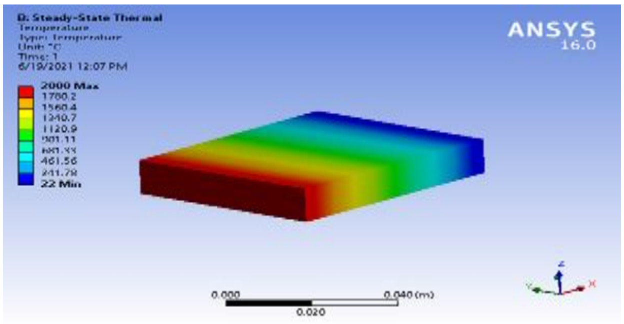


**Fig: Temperature diagram for carbon fibre composite.**

**Table4: Temperature value (Carbon fibre Composite)**

| Time [s] | Minimum [°C] | Maximum [°C] |
|---|---|---|
| 1. | 201.78 | 1000 |

## 4. MATHEMATICAL CALCULATIONS OF PROPERTIES OF COMPOSITES

### 4.1 $NiF_2$ REINFORCED COMPOSITE:

**Table No.5. Mechanical values $NiF_2$ reinforced composite**

| Material | Tensile Strength (GPa) | Tensile Modulus (GPa) | Shear Modulus (GPa) | Poisson's Ratio |
|---|---|---|---|---|
| FR-4 Epoxy | 0.32 | 24 | 22 | 0.136 |
| Boron | 2.8 | 400 | 3.4 | 0.13 |
| $NiF_2$ | 0.15 | 109 | 40 | 0.36 |

**Calculation:**
Taking volume fraction as follows:
$V_{FR} = 0.5$ ; FR-4 Epoxy - 50%
$V_B = 0.3$ ; Boron – 30%
$V_N = 0.2$ ; $NiF_2$ – 20%

(A) Tensile Strength:
$\sigma_c = (0.32*0.5) + (2.8*0.3) + (0.15*0.2)$
$= 1.03$ GPa

(B) Tensile Modulus:
$E = (24*0.5) + (400*0.3) + (109*0.2)$
$= 153.8$ GPa

(C) Poisson's Ratio:
$V = (0.136*0.5) + (0.13*0.3) + (0.36*0.2)$
$= 0.179$

(D) Shear Modulus:
$1/G_{LT} = (0.5/22) + (0.3/3.4) + (0.2/40)$
$= 0.1159$ GPa
$G_{LT} = 8.6236$ GPa

### 4.2 CARBON FIBRE REINFORCED COMPOSITE

**Table No.6. Mechanical values of carbon fibre reinforced composite**

| Material | Tensile Strength (GPa) | Tensile Modulus (GPa) | Shear Modulus (GPa) | Poisson's Ratio |
|---|---|---|---|---|
| FR-4 Epoxy | 0.32 | 24 | 22 | 0.136 |
| Boron | 2.8 | 400 | 3.4 | 0.13 |
| Carbon Fibre | 5.6 | 295 | 15 | 0.24 |

**Calculation:**
Taking volume fraction as follows:
$V_{FR} = 0.5$ ; FR-4 Epoxy - 50%
$V_B = 0.3$ ; Boron – 30%
$V_{CF} = 0.2$ ; Carbon Fibre – 20%

(A) Tensile Strength:
$\sigma_c = (0.32*0.5) + (2.8*0.3) + (5.6*0.2)$
$= 2.12$ GPa

(B) Tensile Modulus:
$E = (24*0.5) + (400*0.3) + (295*0.2)$
$= 427.2$ GPa

(C) Poisson's Ratio:
$V = (0.136*0.5) + (0.13*0.3) + (0.24*0.2)$
$= 0.155$

(D) Shear Modulus:
$1/G_{LT} = (0.5/22) + (0.3/3.4) + (0.2/15)$
$= 0.1242$ GPa
$G_{LT} = 8.045$ GPa

[**Note:** The values for the theoretical calculations were taken from the Wikipedia and the book –'Material Science' by K.M Gupta.]

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## 5. PROPERTY COMPARISON TABLE:

**Table No.7. Property Comparison**

| PROPERTY | $NiF_2$ REINFORCED COMPOSITE | CARBON FIBER COMPOSITE | GERMANIUM | GADOLINIUM |
|---|---|---|---|---|
| YOUNGS MODULOUS (GPa) | 153.8 | 427.2 | 103 | 54.8 |
| TENSILE STRENGTH (GPa) | 1.03 | 0.143 | 2.12 | 0.173 |
| SHEAR MODULOUS (GPa) | 8.6236 | 8.045 | 41 | 21.8 |
| POISSONS RATIO | 0.179 | 0.155 | 0.28 | 0.259 |
| MAXIMUM SERVICE TEMPERATURE (KELVIN) | 391 K-1273 K | 474.78K-1273K | 360K-460 K | 470K-580K |

## 6. COST ANALYSIS:

Since the main objective of the project was to design a Magneto-Caloric composite that is economical and made up of easily available materials.

Therefore, here we will be giving the cost of the materials used to make the composite and the total cost of composite that will sum up if fabricated in work laboratory.

Cost of materials used in the project to make the composites:

**Table No.8. Cost analysis 1**

| S NO. | MATERIAL | QUANTITY | PRICE IN INR |
|---|---|---|---|
| 1 | NICKEL FLUORIDE | 10 Gram | 10,911.30 |
| 2 | BORON (Crystalline, 1 cm, 99.7% trace metals basis) | 5 Gram | 11,372.90 |
| 3 | CARBON FIBRE | 5 meter | 10,000 |
| 4 | FR-4 EPOXY/ EPOXY RESIN (D.E.R. 332) | 250 Gram | 5,150.40 |

Cost of rare earth metals:

**Table No.9. Cost analysis 2**

| S NO. | MATERIAL | QUANTITY | PRICE IN INR |
|---|---|---|---|
| 1 | GADOLINIUM (powder, 500 max. part. size (micron), weight 10 g, purity 99.9%) | 1 EA | 56,330 |

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| | | | |
|---|---|---|---|
| 2 | GERMANIUM<br>(rod, 2.0 mm diameter, length 50 mm, purity 99.999%) | 1 EA | 64,480 |

As we can see in the above tables, the cost of the individual materials differs a lot. The price of gadolinium for 10 gram quantity is average 25,000 INR and the cost of a 500 Gram Gd sphere would be around 125,00,000 INR. On cost analysis of the composites made for the project, the Boron reinforced composite would cost around 27,000 INR for a 1square inch piece and carbon fibre composite would cost 25,000 INR.

## 7. CONCLUSION

Now, with all data presented here we conclude that the composites we have made are economical in the context of pricing as they can be fabricated in between the cost range of 25,000 to 30,000 INR, which in comparison to the Gd sphere used as refrigerant in the first MCE refrigerator would cost much lower.

As for the working of the composites, both composites have steady state working temperature closer to the curie temp of Gd (20 °C).
The composites have material constitution of NiF2 and Boron, both of which are magnetic materials and we are expecting them to show MCE properties while being part of the composites too.

Since, the MCE analysis can only be done in laboratory therefore we are concluding our project based on the theoretical calculations of mechanical quality and thermal service ranges of designed composites being compared to Gd and Ge.

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