Study of Thermal Properties of Iron-Graphite Composites

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Abstract- *A therough study is carried out to understand the difference of properties between compacted Graphite Iron(CGI) & Gray Iron with different graphite(Carbon) compositions.In this present work effect of temperature and graphite contents on the micro structural and thermal properties of iron based powder metallurgy freeform was studied. The different graphite contents (0.5%, 1%, 1.5% and 5%) were mixed in iron powder and compact them in 665 MPa. These specimens were sintered at 1000^0 C in muffle furnace. Micro structural properties were evaluated using scanning electron microscopy. Experimental results were compared to determine to best combination of graphite and iron powder perform. Maximum density was found between the range 2% to 5% graphite contents and temperature at 1000^{0}C. As the graphite content in the iron increases, from 0% to 2% the thermal & electrical conductivity decreases whereas from 2% onwards, the thermal & electrical conductivity increases.*

Keywords- Sintering, Compaction, Thermal conductivity, Coefficient of thermal conductivity.

I. INTRODUCTION

Materials play a very crucial role in manufacturing of various machine and machine tools used in our day to day life. The properties they exhibit need to be studied and analysed very carefully. It is known that iron has a thermal conductivity of around 72w/mk. But as the carbon content in the iron goes on increasing, its thermal conductivity decreases upto about 2% of carbon (graphite) content i.e. till it is steel. But the thermal conductivity goes on increasing again after the carbon (graphite) content increases beyond 2% i.e. when the iron turns into cast iron. All this happens when the iron is melted and carbon is added separately that is by convectional method of casting. But the same content of carbon (graphite) when added to iron by producing powders of both iron and graphite i.e. through the process of powder metallurgy yields different results. Powders of iron and graphite are to be prepared. They need to be blend and properly mixed, compacted to form Compacted Graphite Iron (CGI). Our study deals with the difference of properties exhibited by the Gray Iron with different carbon composition prepared by convectional method and Compacted Graphite Iron (CGI).

It is necessary to keep the operating temperature of thermal stressed electronically components within specified limits. The ideal thermal management material therefore working as heat sink should have a low and tailorable coefficient of thermal expansion (CTE), mechanical stability, high mechanical damping, low production cost and a suitable machine ability. Carbon in the form of graphite (graphite flake, graphite fibre, expanded graphite or pyrolytic graphite) is a candidate for the use in thermal management materials. Commercial available aluminium/ graphite composites have a very high TC up to 750 W/ mK and a low CTE of 4 ppm/ K but have a too low strength. So in the wake of this, we need to try some other metal having sufficient strength like Iron and form Iron/Graphite composites and decrease the properties like TC, CTE. There are several Synthesis methods for creating nanoparticles like, Physical vapor deposition, Chemical vapor deposition, Sol-gel Method, RF Plasma Method, Pulsed Laser Method, Thermolysis and Solution Combustion Method. But these methods are Very costly, so comparatively cheaper method has to be developed. Synthesis of nanomaterials by a simple, low cost and in high yield has been a great challenge since the very early development of nanoscience. Various different processes have been developed for the commercial production of nanomaterials. Among all top down approaches, high energy ball milling, has been widely exploited for the synthesis of various nanomaterials. Various types of high-energy milling equipment are used to produce nanopowder. They differ in their capacity, efficiency of milling and additional arrangements for cooling, heating, etc.

Attritor ball milling is selected for milling the Iron & Graphite to nanosize. Powder metallurgy is defined as mixing different metal powders to form finished and semi-finished components by compressing it. After compressing material is subjected to heating at elevated temperature in a furnace under a progressive atmosphere is done, so as to obtain satisfactory strength, density without losing essential shape. The powder metallurgy technique involves four major steps: Powder manufacture, Powder blending, Compacting, and Sintering. The matrix material and the reinforcement material used in this process of powder metallurgy are iron and graphite which is of very fine powder form.

II. METHODOLOGY

1. Preparation of Iron –Graphite nanocomposites with varying amounts of Graphite.
2. Characterization of the prepared powder by using Scanning Electron Microscope (SEM) study.
3. Compaction of the powdered sample by using uniaxial hydraulic press at a desired pressure.
4. Sintering of the prepared pellets in a controlled atmosphere at a pre-decided temperature.
5. Characterization of the sintered nano composites by using Scanning Electron Microscope (SEM).
6. Analysis of the results and establishment of suitable mixture ratio for the best thermal properties.
7. Validation of obtained data with available literature.
8. Results will be concluded with suggestion for the future scope.

I. Attritor Ball Mill

Attritors are the mills in which large quantities of powder (from about 0.5 to 4 kg) can be milled at a time (Fig). Attritors of different sizes and capacities are available.The media to exert both shearing and impact forces on the material. The apparatus consists of steel ball bearing different sizes and the iron & graphite pellets are put into it to be converted into powder.

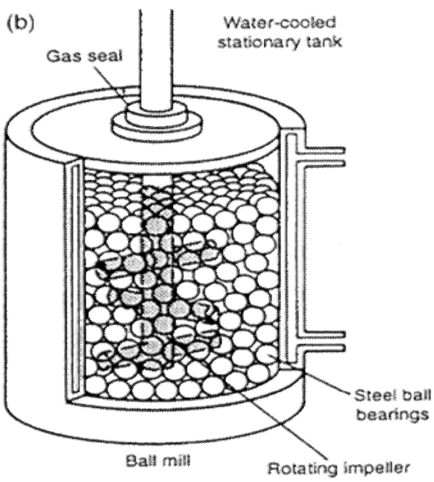


Fig 1: Attritor Ball Mill

II. Ball Milling Process Carried Out

- Type of mill: Attritor Mill.
- Medium: Spherical Balls.
- Material of Balls: Stainless Steel.
- Size of Balls:
    1. 5.9 mm Dia. SS Balls.
    2. 7.9 mm Dia. SS Balls.
    3. 9.9 mm Dia. SS Balls.
- Weight of Graphite: 50 gm.
- Weight of Balls: 500 gm.
- Weight ratio: 10:1.
- Time duration: 100 mins.

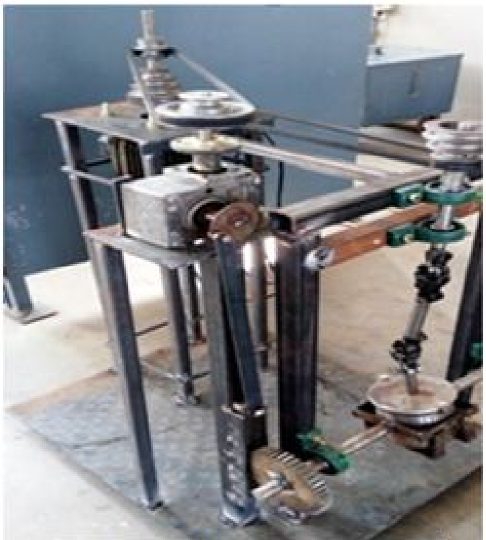


Fig 2. Available ball milling machine

Machine Specifications:
Motor Capacity: 1 HP
Voil: ID = 100mm
OD = 120mm
Thickness = 10mm
Shaft Dia: 20mm
Bearing: 16404
d = 20mm, D = 40mm, B = 8mm

III. SEM RESULTS OF IRON & GRAPHITE MILLED NANOPOWDER

Fig 3: Graphite

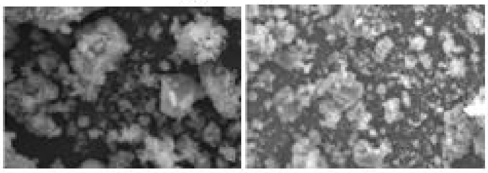


Fig 4: Iron

IV. COMPACTION

Fig 5: Compaction Apparatus

Compaction of powder mixtures is generally carried out using dies to close tolerances. Dies are made typically from die steels or cemented carbides. Equipment used for compaction includes mechanical or hydraulic presses.

The main purpose of compaction is to

- Consolidate the powder into desired shape
- Impart desired level and type of porosity
- Produce green compacts with sufficient strength to withstand further handling operations.

The iron- graphite powder mixture with different composition of graphite is put into the compaction machine & a pressure of 665 Mpa is applied & held for 5 mins.

Fig 6: Obtained Pellets after Compaction

V. SINTERING

Fig 7: Muffle Furnace for Sintering

Green compacts do not have sufficient strength and they may collapse even under small loads, because the particles are loosely bonded with each other. They also contain porosity between the particles. In order to eliminate porosity and to establish metallurgical bond between powder particles, sintering is carried out after compaction. Sintering is the process in which the compact is heated to a temperature below melting point in order to achieve chemical bonding of particles by the process of interparticle diffusion, plastic deformation, grain formation and grain growth.

The green compacts with different iron-graphite compositions are now taken to the muffle furnace for sintering. The sintering temperature is kept at 900°C & is held for 5 mins in it.

VI. TESTING

I. Testing of Electrical Resistance

Fig 8: Testing of Electrical Resistance by Multimeter

Compositions	Electrical Resistance($\mu\Omega$)
99.5 %Fe, 0.5 % C	6.658
99 %Fe, 1 % C	9.9162
98 %Fe, 2 % C	6.4731
97 %Fe, 3 % C	6.5952
95 %Fe, 5 %C	3.5851

Table No. 1: Electrical Resistances of different Iron- Graphite composites.

II. Calculating Electrical conductivity

Sample No.01

Fe - 99.5%, Graphite - 0.5%.
Length of the Sample = 4 mm =0.004 m.

Area of the Sample = $\frac{\pi}{4} d_2$
where,
d = 1 cm = 0.01 m.

$A = \frac{\pi}{4} (0.01)_2 = 7.853 \times 10^{-5}\ m^2$

$R \alpha \frac{L}{A}$

$\therefore R = \rho \times \frac{L}{A}$

where,

$\rho = Resistivity$

$\rho = \frac{RA}{L}$

$\rho = \frac{6.6580 \times 10^{-6} \times 7.853 \times 10^{-5}}{0.004}$

$\boldsymbol{\rho = 1.307 \times 10^{-7}\ \Omega m}$

$\rho = \frac{1}{\sigma}$

$\sigma = \frac{1}{\rho}$

$\sigma = \frac{1}{1.307 \times 10^{6}}\ \Omega$

$\boldsymbol{\sigma = 7.6511 \times 10^{6}\ S/m}$

III. Calculating Thermal Conductivity

We can calculate thermal conductivity from electrical conductivity with the help of “Weidmann-Franz law”

According to “Weidmann- Franz law”,

$\frac{K}{\sigma} = L \times T$

$K = 2.44 \times 10^{-8} \times 300 \times 7.651 \times 10^{6}$

$K = 56.7\ W/mk$

Area for all Samples (A) = $7.853 \times 10^{-5} m^2$
Temperature $27°C = 300\ K$

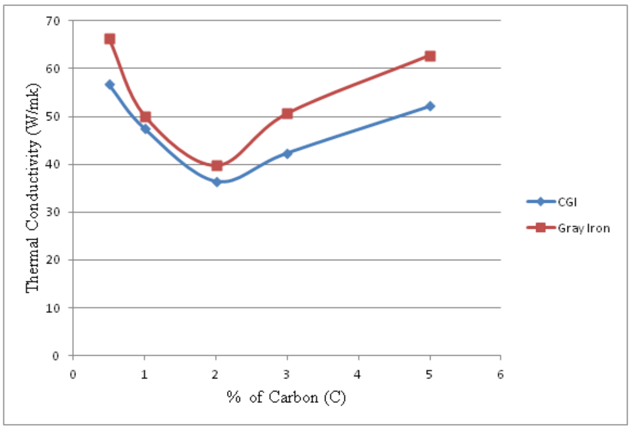
Composition / Parameter	99.5 % Fe, 0.5 % C	99 % Fe, 1 % C	98 % Fe, 2 % C	97 % Fe, 3 % C	95 % Fe, 5 % C
Length (L) (m)	0.004	0.005	0.0025	0.003	0.002
Resistance (R) (Ω)	6.658×10^{-6}	9.9162×10^{-6}	6.4731×10^{-6}	6.5951×10^{-6}	3.5851×10^{-6}
Resistivity (ρ) (Ωm)	1.307×10^{-7}	1.5574×10^{-7}	2.033×10^{-7}	1.742×10^{-7}	1.407×10^{-7}
Electrical Conductivity (σ) (S/m)	7.6511×10^{6}	6.4207×10^{6}	4.9180×10^{6}	5.7377×10^{6}	7.1038×10^{6}
Thermal Conductivity (K) (W/mk)	**56.7**	**47.5**	**36.5**	**42.4**	**52.2**

Table No.2: Thermal Conductivity of all Samples

VII. COMPARISON BETWEEN GRAY IRON AND COMPACTED GRAPHITE IRON (CGI)

Composition / Thermal Conductivity	99.5 % Fe, 0.5 % C	99 % Fe, 1 % C	98 % Fe, 2 % C	97 % Fe, 3 % C	95 % Fe, 5 % C
Compacted Graphite Iron(CGI)	56.7	47.5	36.5	42.4	52.2
Gray Iron	66.4	50.1	39.7	50.6	62.8

Table No.3: Comparison between Gray Iron and Compacted Graphite Iron



VIII. STUDY OF COEFFICIENT OF THERMAL EXPANSION OF DIFFERENT COMPOSITION OF IRON-GRAPHITE

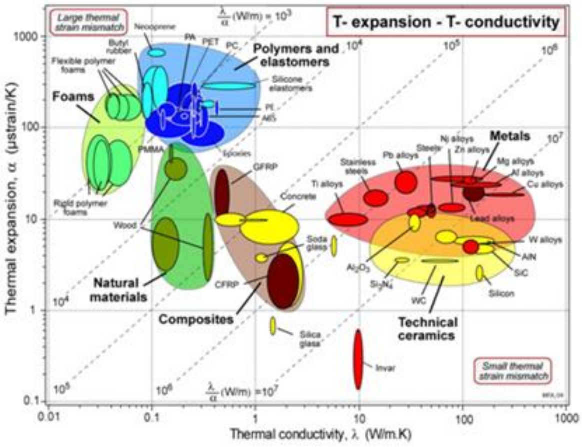


Fig 9: Coeffcient of thermal expansion chart

Materials for the automotive parts not only require low thermal conductivity (TC) but also a reduced coefficient of thermal expansion (CTE). In the case of metal- graphite composites increasing the volume content of graphite enables to reduce the CTE.

From the above characteristics and various journals we conclude that the CTE of iron-graphite composites goes on decreasing with increase in graphite contain.

IX. CONCLUSION

- As the carbon content went on increasing, the thermal conductivity went on decreasing upto 2% of carbon but the thermal conductivity again increased at 5% of carbon content.
- The Coefficient of thermal expansion goes on decreasing with increase in graphite content in the Iron-graphite composites.
- From the above result, we conclude that the thermal conductivity of Compacted Graphite Iron is less than Gray Iron.
- From various compositions of Fe-C composites, the composite consisting 2% C and 98% Fe shows the required optimum properties.
- Compacted graphite iron has characteristics midway between ductile and gray iron and combines many of the properties of both.

X. APPLICATION

- Compensating pendulums and balance wheels for clocks and watches,
- Moving parts that require control of expansion such as pistons, cylinders, and cylinder heads of internal -combustion engines.
- Brake drums and disks.
- Various aircraft parts.
- To manufacture cutting tools with chromium coating.
- Exhaust manifolds of vehicles.

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