Alumina-Based Nanocomposites Using Graphite Nanoplatelets as Reinforcement

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Abstract
Graphene has outstanding mechanical properties and unique electrical and thermal properties which makes it an attractive filler and a good reinforcement for producing multifunctional ceramics for a wide range of applications. Here, alumina (Al₂O₃) based nanocomposites have been developed using exfoliated graphite nanoplatelets (xGnP) as reinforcement. The xGnP were synthesized by subjecting a graphite intercalation compound (GIC) to a thermal shock. The Al₂O₃ and xGnP powders were mixed by milling them for a short period of time in a planetary ball mill using zironica vials and balls in order to ensure homogeneous distribution of xGnP in the Al₂O₃ matrix. Al₂O₃-0.2, 0.5, 0.8, 3 and 5 vol. % xGnP nanocomposites were developed by powder metallurgy route. Sintering was done by the conventional sintering process at 1650°C for different periods of holding time (2, 3 and 4 h). The hardness, fracture toughness and tribological properties of the composites having different vol. % xGnP loading were investigated. Results show a significant improvement in the wear resistance of the Al₂O₃-xGnP composites having more than 0.8 vol. % xGnP loading. The improvement in mechanical properties is attributed to the uniform dispersion of the xGnP and toughening mechanisms such as xGnP bridging, crack deflection and strong interaction between xGnP and Al₂O₃ at the interfaces. Results of the dry sliding wear tests of the composites with different vol. % xGnP loading suggest a significant improvement in the wear resistance of the composites upto the addition of 3 vol. % xGnP. The hardness of the composites also show a gradual increase upto the addition of 3 vol. % xGnP beyond which there is a deterioration in both the hardness and the wear properties.

Key words: Alumina Based Composites, Graphite Nanoplatelets, Wear, Fracture Toughness

References:
Alumina – Based Nanocomposites using Graphite Nanoplatelets as Reinforcement

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Synthesis of Graphite Nanoplatelets by Thermal Exfoliation of GIC (Grpahite Intercalation Compound)
"Graphene" is a combination of graphite and the suffix -ene, named by Hanns-Peter Boehm, who described single-layer carbon foils in 1962.

2D Allotrope of Carbon $\rightarrow$ Single layer of Graphite $\rightarrow$ Consisting of planer, one atom thick sheets $\rightarrow$ Atoms arranged in hexagonal honeycomb lattice $\rightarrow$ One atom forms each vertex.

The term graphene first appeared in 1987 to describe single sheets of graphite as a constituent of graphite intercalation compounds (GICs); conceptually a GIC is a crystalline salt of the intercalant and graphite.

It is one-atom-thick layer of sp$_2$-bonded carbon with a molecular bond length of 0.142 nm. Layers of graphene stacked on top of each other form graphite, with an interplanar spacing of 0.335 nm.

Graphene is a single atomic plane of graphite, which is sufficiently isolated from its environment to be considered freestanding. In simple terms, graphene is a thin layer of pure carbon.

The carbon lattice in graphene has a very strong and directional bond implying that defects do not easily propagate through the lattice like the dislocations in the case of metals.
Properties

The one-atom-thick fabric of carbon in graphene uniquely combines:

- Extreme Mechanical Strength, Exceptionally High Electronic and Thermal Conductivities, Impermeability to Gases, with many other supreme properties, all of which make it highly attractive for numerous applications.

- Graphene is the strongest material ever tested, with an intrinsic tensile strength of 130 GPa and a Young's modulus of ~ 1TPa (for graphene sheets with thickness below 10 nm).
- Best conductor of heat at room temperature (~ 5300 W·m⁻¹·K⁻¹).
- Best conductor of electricity known (µ=15,000 cm²·V⁻¹·s⁻¹).
- Unique levels of light absorption of white light (πα~ 2.3 %).
- A very low film density (~2.0 g/cc).
- A very low coefficient of friction.
- Enormous surface area (up to 2630 m²/g).

Applications

Since the discovery of graphene, advancements in different scientific disciplines have exploded and huge gains are obtained particularly in the fields of composites. The addition of graphene to a host matrices have achieved a number of enhanced properties with promising applications in many industries, such as Aerospace, Electronics, Energy, Structural and Mechanical.
• Isolated 2D crystals cannot be grown via chemical synthesis beyond small sizes even in principle, because the rapid growth of phonon density with increasing lateral size forces 2D crystallites to bend into the third dimension.

• An expanding set of production techniques has supplemented the early approaches of cleaving multi-layer graphite into single layers or to grow it epitaxially by depositing a layer of carbon onto another material. In all cases, the graphite must bond to some substrate to retain its two-dimensional shape.

• Various synthesis routes like chemical vapour deposition, epitaxial growth, liquid-phase exfoliation and electrochemical exfoliation have recently been devised for mass production of graphene to address the needs of the different industries.

Major methods are:
• Exfoliation
• Reduction of graphite oxide (GO)
• Intercalation
• Liquid-phase exfoliation
Objectives

• Initially exfoliated graphite nanoplatelets (xGnP) have been synthesized by thermal exfoliation of GIC followed by sonication.

• Here the effect of sonication on the extent of exfoliation of the thermally exfoliated graphite was analyzed using several analytical techniques like XRD, HRTEM, SEM, SFM, XPS, Raman spectroscopy and FTIR in order to find out the optimum time of sonication which could result in maximum extent of exfoliation in the graphite platelets without imparting defects to it.

• Efforts are made to synthesize xGnP comprising few layered high quality graphene by sonication of the thermally exfoliated graphite.

• The xGnP will be used as a reinforcement to develop polymer matrix composite (epoxy-xGnP composite), ceramic matrix composite (α-Al_2O_3-xGnP composite) and metal matrix composite (Cu-xGnP composite).

• Various compositions of these three composites will be made in order to find out the effect of addition of xGnP on the mechanical and physical properties of the composites. Characterization of all the composites would be done along with the determination of various properties of all the three composite systems.

• The main focus will be given on the mechanical behavior of all the composites including properties like tensile strength, toughness, hardness, wear and fracture surface analysis.
**Sonication and its Relevance:**

Sonication is the act of applying sound energy to agitate particles in the sample. Usually Ultrasonic frequencies are kept > 20 kHz.

- For the production of nanoparticles.
- Speed dissolution, by breaking intermolecular interactions.
- Provide energy for certain chemical reactions.
- For evenly dispersing nanoparticles in liquids.
- Initiate crystallisation process.
- Aid mixing and isolate small crystals.

Acetone has been used for sonication because of its polar nature so it enables sonication process to be carried out at higher energies without resulting the higher temperatures and without detoriating the solute particles.
Experimental Methodology

Processing Route:

Intercalation of as-received Natural Flake Graphite

Solvent Dispersion

Formation of GIC (Expanded Graphite)

(-Gr-H$_2$SO$_4$-Gr-Gr-Gr-Gr-H$_2$SO$_4$-Gr-Gr-Gr-Gr-)

Thermal Exfoliation

Sonication In Acetone For Four Different Time Spans At Room Temperature

Formation of xGnP

Fig. 1 Schematic diagram illustrating the various steps for the synthesis of exfoliated graphite nanoplatelets (xGnP)
6 gm NFG (60 mesh- 98% pure) + 16 ml Conc. Sulfuric Acid (H₂SO₄ - 98%) + 1.5 ml Hydrogen Peroxide (H₂O₂ - 30%) = Graphite Intercalation Compound (GIC)

Magnetic Stirring Of Solution For 2 h

Treatment Of Black filterate (GIC) With Distilled Water To Bring pH In Range of 5-7

GIC Is Dried for 8 h at 60°C in Muffle Furnace In Order To Obtain Completely Dry Resultant Powder.

The Resultant Powder Is Then Given A Thermal Shock At 1000°C For 30 Seconds In A Muffle Furnace Resulting In The Formation Of Thermally Exfoliated Graphite Platelets (xGnP)

1 gm xGnP + 100 ml Acetone , Sonicated For 5,7,12,20 h In Closed Vicinity To Prevent Evaporation Of Acetone

Dry xGnP Powder Is Collected

xGnP Containing Beaker Is Kept In Open Air After Completion Of Sonication Process To Evaporate Acetone.
Results and Discussions

xGnP samples obtained after different sonication time were characterised using different techniques to identify the difference between all and to know what effect sonication produces on the Graphite nanoplatelets.

**X-Ray Diffraction (XRD) Analysis:**

The exfoliated graphite nanoplatelets were characterized using a Panalytical PW 3040 X’Pert MPD X-ray diffractometer using Cu Kα radiation (λ = 1.541 Å).

As-received natural flake graphite

Expanded graphite (GIC) and Thermally Exfoliated graphite
Thermally exfoliated graphite sonicated for various periods of time

Variation of intensity of (002) X-ray diffraction peak

Thermally exfoliated graphite sonicated for various periods of time in 2θ range of 26°

Variation of d-spacing of the GIC, xGnP and thermally exfoliated graphite samples sonicated for various periods of time
<table>
<thead>
<tr>
<th>Sample</th>
<th>d-spacing (Å)</th>
<th>2θ( degree)</th>
<th>Intensity (arb. units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded graphite (GIC)</td>
<td>3.3716</td>
<td>26.413</td>
<td>226561</td>
</tr>
<tr>
<td>Thermally Exfoliated graphite</td>
<td>3.3711</td>
<td>26.417</td>
<td>247777</td>
</tr>
<tr>
<td>Thermally Exfoliated graphite sonicated for 5 h</td>
<td>3.3754</td>
<td>26.382</td>
<td>1185333</td>
</tr>
<tr>
<td>Thermally Exfoliated graphite sonicated for 7 h</td>
<td>3.3787</td>
<td>26.356</td>
<td>1111333</td>
</tr>
<tr>
<td>Thermally Exfoliated graphite sonicated for 12 h</td>
<td>3.3728</td>
<td>26.403</td>
<td>1561235</td>
</tr>
<tr>
<td>Thermally Exfoliated graphite sonicated for 20 h</td>
<td>3.3714</td>
<td>26.415</td>
<td>1769402</td>
</tr>
</tbody>
</table>

d-spacing, 2θ and intensity of the (002) x-ray diffraction peak of NFG, GIC, thermally exfoliated graphite and the thermally exfoliated graphite samples sonicated for various periods of time.
The morphology and elemental composition of the samples were analyzed using:

- JEOL JSM-6480LV scanning electron microscope (SEM) equipped with an INCA PentaFETx3 X-ray microanalysis system with a high-angle ultra-thin window detector and a 30 mm2Si(Li) crystal for EDX(energy dispersive x-ray spectroscopy) analysis.

- A Nova NanoSEM 450/FEI field emission scanning electron microscope (FESEM).

- A JEOL JEM-2100 high resolution transmission electron microscope (HRTEM) having a point to point resolution 0.194 nm.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>SEM Images</th>
<th>HRTEM Images</th>
<th>SAED Patterns</th>
</tr>
</thead>
<tbody>
<tr>
<td>As Received natural flake graphite (NFG) agglomerate</td>
<td><img src="image1" alt="SEM Image" /></td>
<td><img src="image2" alt="HRTEM Image" /></td>
<td><img src="image3" alt="SAED Pattern" /></td>
</tr>
<tr>
<td>GIC</td>
<td><img src="image4" alt="SEM Image" /></td>
<td><img src="image5" alt="HRTEM Image" /></td>
<td><img src="image6" alt="SAED Pattern" /></td>
</tr>
<tr>
<td>Thermally Exfoliated Graphite</td>
<td><img src="image7" alt="SEM Image" /></td>
<td><img src="image8" alt="HRTEM Image" /></td>
<td><img src="image9" alt="SAED Pattern" /></td>
</tr>
<tr>
<td>Hours of Sonication</td>
<td>SEM Images</td>
<td>HRTEM Images</td>
<td>SAED Patterns</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>5 h</td>
<td><img src="image1" alt="SEM Image" /></td>
<td><img src="image2" alt="HRTEM Image" /></td>
<td><img src="image3" alt="SAED Pattern" /></td>
</tr>
<tr>
<td>7 h</td>
<td><img src="image4" alt="SEM Image" /></td>
<td><img src="image5" alt="HRTEM Image" /></td>
<td><img src="image6" alt="SAED Pattern" /></td>
</tr>
<tr>
<td>12 h</td>
<td><img src="image7" alt="SEM Image" /></td>
<td><img src="image8" alt="HRTEM Image" /></td>
<td><img src="image9" alt="SAED Pattern" /></td>
</tr>
<tr>
<td>20 h</td>
<td><img src="image10" alt="SEM Image" /></td>
<td><img src="image11" alt="HRTEM Image" /></td>
<td><img src="image12" alt="SAED Pattern" /></td>
</tr>
</tbody>
</table>
Atomic Force Microscopy (AFM) Analysis:

A Park XE 70 atomic force microscope (AFM) with a 100 x 100 μm XY scanner and 10 μm Z scanner was used to analyze the samples using non-contact mode.

High resolution tapping mode AFM image of the graphite nanoplatelets samples developed by sonication of the thermally exfoliated graphite for various periods of time deposited on a mica substrate.
Raman Spectroscopy Analysis:

Micro-Raman measurements were made with a T64000 Jobin Yvon Horiba system. An Argon-Krypton mixed ion gas laser (2018 RM Spectra Physics) was used as the excitation source.

NFG, Thermally exfoliated graphite, Thermally exfoliated graphite sonicated for 5 h

Thermally exfoliated graphite sonicated for 5, 12 and 20 h
Thermally exfoliated graphite sonicated for 5, 12 and 20 h in the range of 1300-1900 cm\(^{-1}\).
Fourier Transform Infrared Radiation (FTIR) Analysis:

IRPrestige-21 Shimadzu Fourier transform infrared (FTIR) spectroscope was used for analyzing the surface functional groups on the graphite nanoplatelets. The conventional KBr pellet methods may be used to analyze the powder samples.

FTIR of (a) as-received NFG (b, c) thermally exfoliated graphite ultrasonicated for 7 and 20 h.
X-Ray Photoelectron Spectroscopy (XPS) Analysis:

A PHI 5000 VersaProbe II x-ray photoelectron spectroscopy (XPS) using a monochromatic Al K$_α$ x-ray source (1486.6 eV) was used to analyze the samples. The analysis data has been acquired in total 2 sweeps obtained with Pass energy of 23.5 eV at a step size of 0.100 eV in 10 cycles. The scan range for binding energy was considered form 0-1200 eV using a step size of 0.100 eV.

XPS spectra of 5, 7, 12 and 20 h sonicated xGnP samples

High resolution C1s XPS spectra showing C=O and O=C-OH bonds
### Atomic compositions of different sonicated samples by XPS Analysis

#### BET Surface Area Analysis:

A Quantachrome, USA, BET (Brunauer-Emmet-Teller) surface area analyzer was used for surface area and pores size measurements by N\textsubscript{2} adsorption-desorption analysis.

<table>
<thead>
<tr>
<th>Hours of Sonication</th>
<th>Peak</th>
<th>Peak Binding Energy (eV)</th>
<th>Relative % of C and O in Exfoliated Graphite Nanoplatelets (xGnP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 h</td>
<td>C1s</td>
<td>284.906</td>
<td>C- 96.2 atomic % O- 3.8 atomic %</td>
</tr>
<tr>
<td>7 h</td>
<td>C1s</td>
<td>284.72</td>
<td>C- 96.2 atomic % O- 3.8 atomic %</td>
</tr>
<tr>
<td>12 h</td>
<td>C1s</td>
<td>284.906</td>
<td>C- 97.2 atomic % O- 2.8 atomic %</td>
</tr>
<tr>
<td>20 h</td>
<td>C1s</td>
<td>283.29</td>
<td>C- 95.2 atomic % O- 4.8 atomic %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hours of Sonication</th>
<th>Area (m\textsuperscript{2}/g)</th>
<th>Total Pore Volume (cc/g)</th>
<th>Average Pore Diameter (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>2.221 x 10\textsuperscript{-1}</td>
<td>7.694 x 10\textsuperscript{-3}</td>
<td>1.386 x 10\textsuperscript{3}</td>
</tr>
<tr>
<td>12</td>
<td>2.465 x 10\textsuperscript{-1}</td>
<td>8.565 x 10\textsuperscript{-3}</td>
<td>1.390 x 10\textsuperscript{3}</td>
</tr>
<tr>
<td>20</td>
<td>3.047 x 10\textsuperscript{-1}</td>
<td>10.44 x 10\textsuperscript{-3}</td>
<td>1.371 x 10\textsuperscript{3}</td>
</tr>
</tbody>
</table>
Thermal (DSC/TGA) Analysis

(a) DSC and (b) TGA analysis from room temperature to 850°C of natural flake graphite and exfoliated graphite sonicated for 5 h.

(c) DSC and TGA analysis of thermally exfoliated graphite sonicated for 7, 12 and 20 h.
Development of Al$_2$O$_3$-Graphite Nanoplatelets Composites
Mechanical Milling (MM) of Al\(_2\)O\(_3\)-xGnP Composition

- In MM a suitable blend of elemental powder is charged in a high energy ball mill, along with a suitable milling medium. Balls rotate with a high energy inside a container and then fall on a powder particles with gravity force and kinetic energy and hence crush the solid particles into Nano crystalline.
- In our research work, xGnP powder was milled for 30 mins with a conc. of 0.2, 0.5, 0.8, 3, 5 vol\% in Alumina matrix at 150 rpm to form a nanostructured Al\(_2\)O\(_3\)-xGnP composition which was later used for the development of Al\(_2\)O\(_3\)-xGnP nanocomposites.

**Milling conditions:**

- Ball Mill: Planetary Ball Mill Fritsch P5
- Milling Medium: Wet
- PCA: Toluene
- Vials and Balls: Zirconia
- Milling Speed: 150 rpm
- Diameter of Balls: 20mm
- Ball to powder weight ratio = 10:1
FESEM IMAGES

\( \alpha - \text{Al}_2\text{O}_3 \) particles and Graphite Nanoplatelets (xGnP)

<table>
<thead>
<tr>
<th>Powder mixtures of ( \alpha - \text{Al}_2\text{O}_3 )-xGnP</th>
<th>0.2% XGnP-Al(_2)O(_3)</th>
<th>0.5% XGnP-Al(_2)O(_3)</th>
<th>0.8% XGnP-Al(_2)O(_3)</th>
<th>3% XGnP-Al(_2)O(_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Image of FESEM images]</td>
<td>[Image of FESEM images]</td>
<td>[Image of FESEM images]</td>
<td>[Image of FESEM images]</td>
<td>[Image of FESEM images]</td>
</tr>
</tbody>
</table>
HRTEM Images of the Powder Mixture of Al₂O₃- 3 wt.% xGnP
Elemental Maps of Al, C and O in Al$_2$O$_3$ - 5 vol. % xGnP Nanocomposite Sintered 1650$^\circ$C for 4 h
UNSINTERED MILLED POWDER

SINTERED AT 1650°C, 4h
A slight decrease in the relative density of the Al$_2$O$_3$-xGnP composites was found when 5 wt.% of xGnP is added to the Al$_2$O$_3$ matrix for all the three different sintering times. This is due to the effect of agglomeration of the xGnP in the Al$_2$O$_3$ matrix. Upot the addition of 3 wt.% of xGnP a gradual rise in the relative density is found for all the three different holding time periods. All the Al$_2$O$_3$-xGnP composites sintered for 4 h show a slightly high relative density as compared to the sample sintered for a period of 2 or 3 h.
Wear Behaviour

In the case of the 2 h sintered samples the wear depth shows a continuous increase with the increase in time. For the 4 h sintered samples we find that in the case of Al$_2$O$_3$-xGnP samples containing more than 0.2 wt.% xGnP shows better wear resistance as compared to the pure Al$_2$O$_3$ sample. There is significant improvement in the wear resistance of the Al$_2$O$_3$-0.8 and 3 wt.% xGnP composites as compared to that pure Al$_2$O$_3$ sample. Although Al$_2$O$_3$-0.5 wt.% xGnP sample shows considerable improvement in wear resistance however, after about 8 minutes of the wear test the wear resistance property of the composite deteriorates. This is because of the non-uniform sintering of the composite.
Wear Rate

SEM images of the wear debris of the Al\textsubscript{2}O\textsubscript{3}-3 wt.% xGnP samples sintered for (a-c) 3 h and (d-f) 4 h
SEM Images of the Wear Track

2 h sintered

4 h sintered

995.16 µm
891.93 µm
758.06 µm
730.64 µm
719.35 µm

Pure Al₂O₃
Al₂O₃ - 0.2% xGnP
Al₂O₃ - 0.5% xGnP
Al₂O₃ - 0.8% xGnP
Al₂O₃ - 3% xGnP

819.35 µm
983.87 µm
833.87 µm
709.67 µm
679.03 µm

Pure Al₂O₃
Al₂O₃ - 0.2% xGnP
Al₂O₃ - 0.5% xGnP
Al₂O₃ - 0.8% xGnP
Al₂O₃ - 3% xGnP
Crack Bridging and Crack Deflection

SEM images of cracks in sintered pure alumina sample

SEM images of cracks in sintered Al₂O₃ - 0.8 vol. % xGnP sample

SEM images of cracks in sintered Al₂O₃ - 3 vol. % xGnP sample
Crack Bridging in Al$_2$O$_3$-3 vol. % xGNP Composite
Surface Roughness of all the Compositions of Al$_2$O$_3$ - xGnP Nanocomposites Sintered at 1650°C for Dwell Ttime of 2, 3 and 4h at load of 1, 2 and 3 mg
DSC/TGA Analysis of $\text{Al}_2\text{O}_3$-xGnP Composites
Sintered Pure $\text{Al}_2\text{O}_3$ Sample

Sintered $\text{Al}_2\text{O}_3$-3 vol. % xGnP Sample

Sintered $\text{Al}_2\text{O}_3$-5 vol. % xGnP Sample
FTIR of Alumina and xGnP - Al$_2$O$_3$ milled powder at different proportions

<table>
<thead>
<tr>
<th>Range of wave number (cm$^{-1}$)</th>
<th>Supposed chemical groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder bent at 3292, weak peak at 1565</td>
<td>Stretching and bending modes of -OH</td>
</tr>
<tr>
<td>The bands at 3291 and 3095</td>
<td>(Al)O–H stretching vibrations</td>
</tr>
<tr>
<td>The two weak peaks at 2030 and 1971</td>
<td>Vibrational overtones of the surface −OH groups of Al-O–OH</td>
</tr>
<tr>
<td>At 1460 and 1386</td>
<td>Stretching vibration of C=O and C–O from CO$_3$$^{2-}$</td>
</tr>
<tr>
<td>At 1070 and 1150</td>
<td>Al–O–H</td>
</tr>
<tr>
<td>At 1000</td>
<td>Due to nano - alumina</td>
</tr>
<tr>
<td>At 740, 690, and 420</td>
<td>Hydroxyl groups on the surface of the product</td>
</tr>
</tbody>
</table>
## Spark Plasma Sintered Composites

<table>
<thead>
<tr>
<th>Al₂O₃-0.2 wt. % xGnP 95 μm</th>
<th>Al₂O₃-0.8wt. % xGnP 125 μm</th>
<th>Al₂O₃-3wt. % xGnP 150 μm</th>
<th>Al₂O₃-5 wt. % xGnP 390 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>20 μm</td>
<td>85 μm</td>
<td>60 μm</td>
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</tbody>
</table>
Major Findings So Far

• Highly crystalline xGnP having low defect density and consisting of few layers of graphene could be synthesized by sonication of the thermally exfoliated graphite.

• Sonication of the thermally exfoliated graphite beyond 5 h shows gradual increase in crystallinity and decrease in defect density along with the increase in the number of graphene layers in the xGnP.

• Beyond 12 h of sonication both the intensity of the (002) XRD peak and the ID/IG ratio of the Raman spectra come to a saturation suggesting that there is a limit to the extent of exfoliation possible by the sonication process.

• Both the HRTEM and AFM analysis suggest that the xGnP samples sonicated beyond 12 h are well-exfoliated and have thickness less than 1 nm.

• DSC results show that the degradation of xGnP that has been sonicated for a longer period of time starts prior to the degradation of xGnP that has been sonicated for a shorter period of time. The degradation starts at around 620°C and by 800°C the degradation of the xGnP gets completed.

• Both the surface area and total pore volume show an increase with the increase in sonication time but the average diameter of the pores do not show any change with increase in ultrasonication time.
Thank You Sir for Showing me The Light!

Few Things I Learnt From Sir!

1. Try to extract the maximum information form the smallest of experiments that you do.
2. Try to make your conclusions in a single line.
3. Write you research article in the most interesting way so as to keep the reader interested in it till the end.