This PhD research is focused on the synthesis of carbon based composites of magnesium aluminate ($MgAl_2O_4$). These composites are designed to serve dual purposes: as efficient photocatalysts and electrode materials for high performance supercapacitors. In this regard, magnesium aluminate nanopowder grouped with reduced Graphene Oxide ($MgAl_2O_4$/rGO), Carbon Nanotubes ($MgAl_2O_4$/MWCNT), and their combination (MWCNT/$MgAl_2O_4$/rGO) were prepared. Total four experiments were conducted, as listed below:

Natural sunlight-driven photocatalytic degradation of methyl blue using spinel $MgAl_2O_4$/rGO nanocomposite (Published in Applied Nanoscience 2022)

Chemically synthesized magnesium aluminate-reduced graphene oxide nanocomposite as supercapacitor electrode material with boosted electrochemical performance.

Facile Fabrication of $MgAl_2O_4$/MWCNT nanocomposite for efficient and stable solar-driven degradation of organic dye.

Synthesis of MWCNT/$MgAl_2O_4$/rGO photocatalyst for organic dye degradation

A brief overview of research work is given below;

In the **first experiment**, spinel magnesium aluminate ($MgAl_2O_4$) anchored reduced graphene oxide (rGO) nanocomposite ($MgAl_2O_4$/rGO) was synthesized through a facile chemical precipitation route for augmented photocatalytic behavior. XRD, SEM, and FTIR were done to investigate the structure, morphology, and functional groups of the spinel $MgAl_2O_4$/rGO nanocomposite. UV-vis spectroscopy showed a reduction in the bandgap from 3.02 to 2.82 eV. $MgAl_2O_4$/rGO proved itself a better photocatalyst with photocatalytic efficiency (99.9%) by degrading Methyl Blue (MB) in 70 min under natural sunlight irradiation. Moreover, it demonstrated excellent cyclic stability and reusability (97%) even after six cycles. The augmentation in photocatalytic properties is mainly attributed to rGO which helped to enhance the surface area, reduced electron–hole recombination, and provided more active sites. In the future, spinel $MgAl_2O_4$/rGO nanocomposite may be an auspicious candidate for the exclusion of waste-water pollutants in industries.

Supercapacitors have appeared as potential alternative to traditional energy storage technologies for fulfilling the energy requirements worldwide. The secret to their exceptional performance lies in the choice of electrode material. Among various materials, mixed metallic oxides stand out for their superior supercapacitive properties, offering a tempting sight into a sustainable future. In the **second experiment**, we synthesized a mixed metallic oxide spinel, Magnesium Aluminate ($MgAl_2O_4$), and anchored it onto reduced graphene oxide (rGO) by using a facile chemical co-precipitation method to create a composite material ($MgAl_2O_4$/rGO). Anchoring of $MgAl_2O_4$ on reduced graphene oxide augments the electrochemical activity as compared to $MgAl_2O_4$. The higher specific capacitance value 629 F/g is achieved by $MgAl_2O_4$/rGO at 1 A/g. This enhancement is credited to characteristic structure of reduced graphene oxide that offers a continuous network as well as numerous active sites for redox reactions. $MgAl_2O_4$/rGO also exhibits good retention (83% of the original value) over 5000 cycles.

In the **third experiment**, we reported the synthesis and characterization of Magnesium Aluminate ($MgAl_2O_4$) and Magnesium Aluminate/Multi Walled Carbon Nanotube ($MgAl_2O_4$/MWCNT) nanocomposites by facile chemical co-precipitation method for the dye degradation application. $MgAl_2O_4$ and $MgAl_2O_4$/MWCNT nanocomposite are characterized by Scanning Electron Microscopy (SEM), X-Ray Diffractometery (XRD), Raman spectrometry, UV-Vis Spectrophotometery (UV-Vis), Fourier Transform Infrared Spectrometry (FTIR), and X-ray Photoelectron Spectroscopy (XPS). Surface morphology of $MgAl_2O_4$/MWCNT nanocomposite exhibits entangled needle like structures while $MgAl_2O_4$ spinel comprises of agglomerated nanoparticles of different sizes. XRD confirms the formation of $MgAl_2O_4$. XPS identifies the chemical states and binding energies of constituent elements present in the sample. Optical properties reveal that addition of MWCNTs in $MgAl_2O_4$ decreases the optical bandgap energy from 3.02 eV to 2.78 eV. $MgAl_2O_4$/MWCNT nanocomposite shows reduced bandgap compared to pristine $MgAl_2O_4$ due to increased chemical defects or vacancies in intergranular regions and chemical interaction between $MgAl_2O_4$ and MWCNT, leading to formation of new energy levels in $MgAl_2O_4$/MWCNT nanocomposite. The addition of MWCNTs provides large surface area, more active sites, and enhances electrons mobility between energy levels. $MgAl_2O_4$/MWCNT nanocomposite proves itself a better photocatalyst due to fast degradation of Methyl Blue (MB) in 65 min as compared to $MgAl_2O_4$ which degrades the dye in 90 minutes. $MgAl_2O_4$/MWCNT nanocomposite also shows good stability and reusability even after performing the six cycles of dye degradation.

In the **fourth experiment**, a unique and inexpensive photocatalyst was prepared by the combination of carbonaceous materials (MWCNTs and rGO) and $MgAl_2O_4$ by a facile chemical coprecipitation method. The synthesized photocatalysts $MgAl_2O_4$ and MWCNT/$MgAl_2O_4$/rGO were used to degrade Methyl Blue (MB) under natural sunlight irradiation. Scanning Electron Microscopy (SEM) revealed nano-sized particles of $MgAl_2O_4$ as well as entangled needle and rod like structures of rGO and MWCNTs respectively. X-ray Diffractometery (XRD) of both samples confirmed the formation of $MgAl_2O_4$. No rGO or MWCNTs peak is observed due to small quantity of rGO and MWCNTs. From UV-Vis Spectrophotometery (UV-Vis), the obtained bandgap energies were 3.02 eV for $MgAl_2O_4$ and 2.72 eV for MWCNT/$MgAl_2O_4$/rGO. Fourier Transform Infrared Spectroscopy (FTIR) confirmed metal-oxygen bonds in the both samples and carbon in MWCNT/$MgAl_2O_4$/rGO nanocomposite. X-ray Photoelectron Spectrometry (XPS) deconvoluted spectra confirmed the presence of all the constituent elements in the synthesized samples. MWCNTs and rGO provide large surface area, more active sites, reduce agglomeration, improve electronic conductivity and reduce band gap. These characteristics collectively contributed to making MWCNT/$MgAl_2O_4$/rGO a better photocatalyst for dye degradation. MWCNT/$MgAl_2O_4$/rGO nanocomposite photocatalyst degraded 97.8% of MB in just 65 min. Minor decrement in degradation efficiency was observed even after performing six cycles, which proved that MWCNT/$MgAl_2O_4$/rGO has excellent reusability and stability. Thus, MWCNT/$MgAl_2O_4$/rGO nanocomposite photocatalyst can be ranked as industrial level photocatalyst for waste water treatment.