



IJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** IV **Month of publication:** April 2025

DOI: <https://doi.org/10.22214/ijraset.2025.67957>

www.ijraset.com

Call:  08813907089

E-mail ID: ijraset@gmail.com

Development of Epoxy-MgO Nanocomposite Material for High Voltage Electrical Insulation

Abhijith T Dinesh¹, Krishna Satheesh², Pranav K³, Shona Thomas⁴, Dr. Siny Paul⁵, Dr. Reenu George⁶
 Department of Electrical and Electronics Engineering Mar Athanasius College of Engineering, Kothamangalam, Kerala

Abstract: This paper investigates the dielectric properties of epoxy-MgO nanocomposite materials, focusing on their dielectric constant and breakdown strength. The synthesis of epoxy-MgO nanocomposites with varying nanoparticle concentrations using magnetic stirring, ultrasonication and thermal curing will be done. Key parameters including dielectric constant and breakdown strength, will be evaluated through high voltage testing to assess performance of the material under electrical stress. This project will also evaluate the cost-effectiveness of epoxy as a polymer matrix, being more affordable and accessible than other polymers; making it suitable for large-scale applications. Additionally, the effects of nanoparticle dispersion and interfacial interactions on dielectric characteristics will be explored to identify optimal loading conditions. The resulting nanocomposites with enhanced dielectric properties could make them promising candidates for high voltage electrical insulation, where high dielectric strength and thermal stability are critical.

Index Terms: Epoxy resin, nanocomposites, high voltage electrical insulation, interparticle distance

I. INTRODUCTION

Then an ocomposites are advanced materials consisting of a base matrix reinforced with nanoparticles, nanotubes, or nanofibers, leading to enhanced mechanical, thermal, electrical, and optical properties. Engineered at the nanoscale, these materials exhibit unique characteristics due to the high surface area and aspect ratio of nanofillers, making them superior to conventional composites. Their applications span aerospace, automotive, and electronics.

In high-voltage insulation and energy storage, nanocomposites offer improved dielectric properties, higher breakdown strength, and reduced dielectric losses, enhancing power system efficiency and reliability. Epoxy-magnesium oxide (MgO) nanocomposites, in particular, integrate epoxy resin with MgO nanoparticles, enhancing mechanical strength, thermal stability, and dielectric performance. These advancements contribute to the development of durable and efficient insulation materials for power transmission and distribution.

II. THEORETICAL MODEL OF DIELECTRIC NANOCOMPOSITE

A. Inter Particle Distance

The interparticle distance depends on the amount of filler added. The filler particles are spherical in shape and they are arranged in a simple cubic lattice then the interparticle distance can be calculated as:

$$D = \sqrt[3]{\frac{\pi \rho_n \cdot 100}{6 \rho_m} \left(\frac{wt\%}{100} - \frac{\rho_m}{\rho_n} \right)^{-1}} \quad (1)$$

D- is the interparticle distance

d- is the diameter of the nanoparticle

ρ_n - is the density of epoxy

ρ_m - is the density of MgO

Table 1 presents the interparticle distance of epoxy- magnesium oxide (MgO) nanocomposite at various weight percentages of MgO. The interparticle distance quantifies the spacing between particles in the composite material, expressed in nanometers (nm). The data in the table illustrates the relationship between interparticle distance and weight percentage of filler ratios.

TABLE I

CALCULATED INTERPARTICLE DISTANCE D FOR DIFFERENT WEIGHT PERCENTAGES OF MgO NANOPARTICLES (20 NM DIAMETER).

Weight Percentage (%)	Interparticle Distance (nm)
1	87.47
2	65.11
5	42.28
10	28.86
15	22.17
20	17.84
25	14.67
30	12.19
35	10.15

Analysis of the data reveals that as the weight percentage of the filler increases, the interparticle distance decreases, indicating that the particles are repositioned closer together. This relationship is visually represented in Fig.1. The methodology and findings shed light on the interparticle distance as a key factor in determining the composite's properties. As the weight percentage of MgO nanoparticles increases, the interparticle distance decreases, indicating a closer packing of particles,

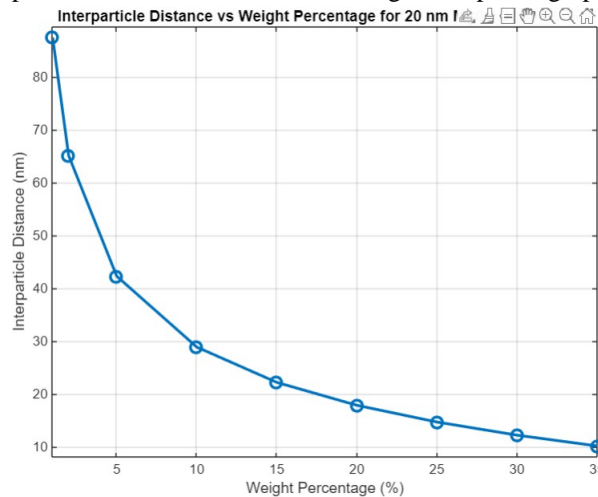


Fig.1. Interparticle distance Vs Weight Percentage

which may influence the dielectric properties. These findings are critical for optimizing the design of epoxy-MgO nanocomposites, as understanding the particle dispersion and spacing will aid in tailoring the material's dielectric performance for applications in electronics and insulation. The comprehensive simulation and testing approach offers valuable insights into the design and development of high-performance epoxy-based nanocomposites.

B. Simulation

Simulation of the epoxy MgO nanocomposite is done using COMSOL Multiphysics software. It investigates the distribution of the electric field within the nanocomposite material under high voltage conditions. The simulations were conducted using the Finite Element Method (FEM) with COMSOL Multiphysics V6.0.

COMSOL divides the nanocomposite geometry into a finite number of mesh elements which are symmetrically identical and solves problems by approximating derivatives using finite differences. In COMSOL multiphysics, the electrostatics module was used to compute the distribution of electric field inside the nanocomposite. Polymers and fillers were assumed as isotropic materials. It was expected that uniform dispersion of nanoparticles existed in polymer matrix. It was thought that the connection between the particles and epoxy was perfect. The geometry considered is a nanocomposite sample with electric field stress that has been subjected to it and a uniform thickness. Unit cell technique is employed to model the nanocomposite. Based on filler concentration which corresponds to inter-particle distance, the unit cell size is determined.

The sum of the nanoparticle diameter and the inter-particle distance is chosen for each side of the unit cell (cube) shown in Fig. 2. The top face of the block receives voltage while the bottom face is grounded. The other faces are untouched, making the geometry look like a parallel-plate capacitor. Meshing is one of the important steps as it divides the geometry into finite number of elements.

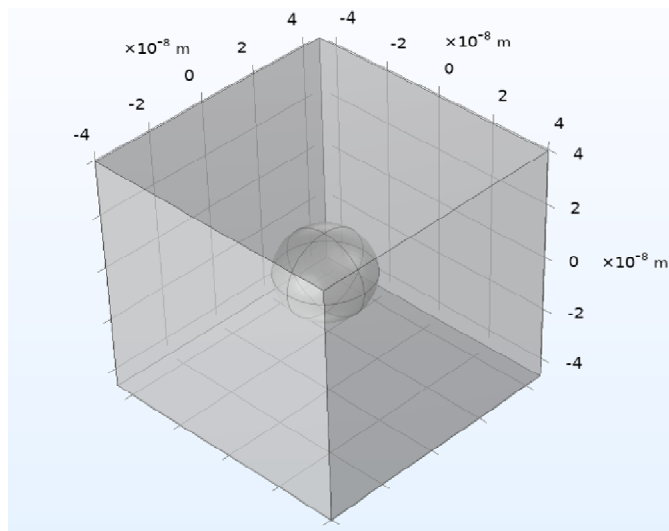


Fig.2. Single unit cell of Nanocomposite Model

C. Electric Field Distribution Analysis

Upon obtaining the computation results, it is noted that if the material were solely epoxy, the electric field distribution would be uniform throughout the block. However, adding MgO nanoparticles introduces non-uniform electric field distribution. To analyze this effect, a potential of 1.75V was applied to the top face of the nanocomposite unit cell in the simulation model, with the bottom face grounded. At 5 percent MgO concentration, this voltage generated a breakdown strength of 42.4 kV/mm, which aligns closely with the breakdown strength of pure epoxy. When the same voltage was applied to nanocomposites with increasing MgO concentrations, the breakdown strength progressively improved, indicating that higher MgO content enhances dielectric strength and breakdown resistance. These findings highlight how MgO dispersion and concentration can modify the electric field landscape within nanocomposites, thereby increasing their effectiveness for high-voltage insulation applications.

- 1) *MgO at 2% weight ratio*: After applying a potential of 1.75V at top face of the unit cell, the electric field distribution of the MgO nanocomposite at 2% weight ratio is shown in Fig. 3. From this figure we can infer that the breakdown strength is 30.6 kV/mm at 2% weight ratio.
- 2) *MgO at 5% weight ratio*: After applying a potential of 1.75V at top face of the unit cell as shown in Fig. 4, the electric field distribution of the MgO nanocomposite at 5% weight ratio is shown in Fig. 5. From this figure we can infer that the breakdown strength is 42.4 kV/mm at 5% weight ratio.
- 3) *MgO at 10% weight ratio*: After applying a potential of 1.75V at top face of the unit cell, the electric field distribution of the MgO nanocomposite at 10% weight ratio is shown

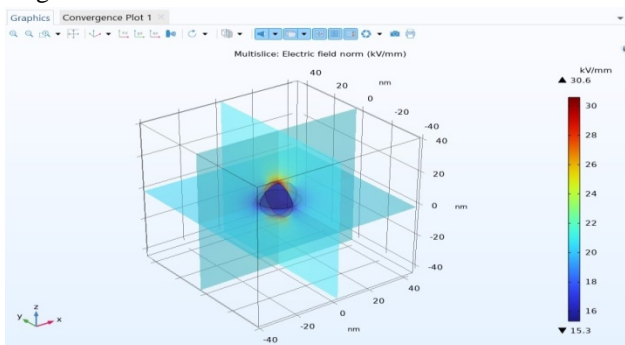


Fig.3. Electrical Potential Distribution in Nanocomposites

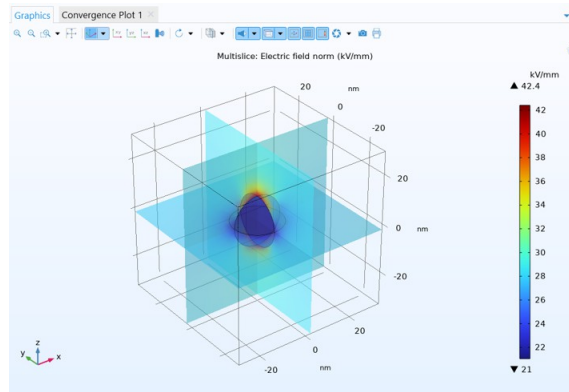


Fig.4. Electrical Potential Distribution in Nanocomposites

in Fig.6. From this figure we can infer that the breakdown strength is 53.9 kV/mm at 10% weight ratio.

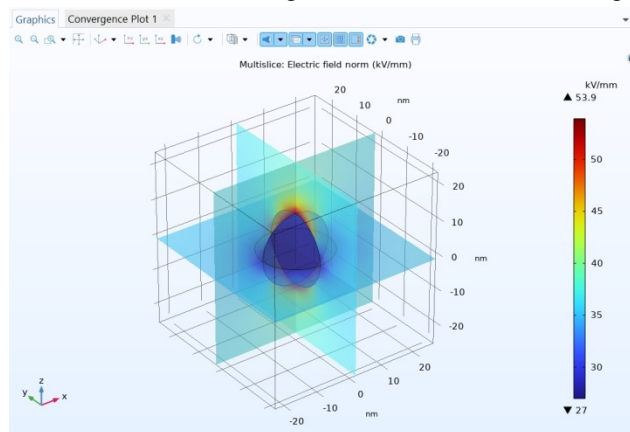


Fig.5. Electrical Potential Distribution in Nanocomposites

The results from the COMSOL simulations indicate that epoxy nanocomposite materials are suitable for high voltage insulation applications. The incorporation of MgO nanoparticles significantly enhances the material's resistance to electrical breakdown, particularly when the nanoparticles are evenly distributed throughout the epoxy matrix. The simulation findings demonstrate that as the weight percentage of MgO nanoparticles increases, the breakdown voltage of the nanocomposite also rises, thereby improving its overall dielectric strength.

III. SAMPLE PREPARATION

A. Preparation Procedure

The base polymers utilized were Bisphenol-A-Epoxy resin (CY1300) and the corresponding hardener (HY956), both supplied by Haksons. To shape the samples into round discs of specified dimensions, a stainless steel mould was custom-built for this purpose. The mould consists of 4 circular discs of diameter 6 cm and a thickness 1 mm in a rectangular sheet made of stainless steel. This design was chosen for its affordability and practicality in accommodating the testing device. The testing device is specifically designed to accommodate round discs, aligning with the circular form of the mould. This configuration was chosen based on considerations of cost-effectiveness and functionality. The mould's volume is calculated using a formula,

$$\pi \times r^2 \times h \quad (2)$$

where 'r' is the radius and 'h' is the thickness. In the direct dispersion method employed for creating pure epoxy samples, the process initiates by taking appropriate amounts of Bisphenol-A-epoxy resin (CY1300) in a beaker. The required percentage weight of nanomaterial MgO is measured and added to the pure epoxy resin. Subsequently, manual stirring is conducted for 5 minutes, followed by 8-10 minutes of stirring using a magnetic stirrer in a water bath maintained at 60°C. If the mixture becomes highly viscous, heating is applied during this stage. Ultrasonication is then performed for 8-10 minutes.

1) *Magnetic stirring*: A magnetic stirrer is a widely used laboratory apparatus having either a rotating magnet or a stationary electromagnet and hence produces a rotating magnetic field.

Its main function is to mix solutions by introducing a bar which spins within it. A rotating magnet or stationary electromagnet inside the device creates the required magnetic field thereby enabling efficient mixing quickly among liquids in industrial laboratories.

- 2) **Ultrasonication:** An ultrasonicator is a versatile device commonly used in scientific, medicinal and industrial fields for tasks like cell disruption, sample preparation, and emulsification. A sonicator harnesses the power of ultrasonic waves to create cavitation bubbles within a liquid medium. These bubbles form due to the rapid alternation of high and low-pressure waves produced by the sonicator. When these bubbles collapse, they generate intense pressure and temperature gradients, creating micro-jets and shockwaves that physically disrupt cells, tissues, or other objects in the sample. The components of a typical sonicator include a generator which produces high-frequency electrical signals, a transducer that converts these signals into mechanical vibrations and a probe or horn that transmits these vibrations into the sample. The probe is usually submerged in the liquid medium containing the sample. During sonication, the sample is placed in a container such as a test tube or beaker covered with a suitable liquid medium. The sonicator probe is then immersed in the liquid and activated producing high-frequency sound waves. These waves cause the liquid to vibrate, creating cavitation bubbles throughout the sample. As the bubbles rapidly expand and collapse, they generate intense pressure and temperature gradients, leading to the disruption of the sample at the microscopic level. This disruption is crucial for various applications such as cell lysis, particle size reduction, and homogenization.
- 3) **Heating in oven:** The moulds are put together onto an OHP sheet with a little grease applied between them. Next, the mixture is poured into the moulds. These assembled moulds are then placed inside a preheated oven at 60°C for a period that lasts four hours without interruption. After this time period, one has to carefully remove the samples from the oven. This step helps in both solidifying of the mix as well as removing air bubbles from the composite material.

Perfect samples can only be obtained through proper execution of these steps. If insufficient hardener is added to the mixture, it may turn out slimy which makes it improper for further testing procedures. Also, if the required temperature of the material is not achieved while it is being heated in an oven during processing, it can set wrong, fail to achieve complete setting and as a result become slimy. Attention to these things helps to remove samples from OHP sheet successfully and a perfect sample can be obtained as shown in Fig.7



Fig.6.Prepared samples

Epoxy-MgO samples are prepared by mixing a suitable amount of hardener with the resin. The samples are molded as 6 cm diameter discs with a thickness of 1 mm. They undergo a series of preparation stages, including magnetic stirring, ultrasonication, and oven curing. These processes are crucial for achieving a uniform dispersion of the epoxy matrix.

IV. BREAK DOWN ANALYSIS

This chapter focuses on the DC breakdown analysis of nanocomposite samples. The test done is very much similar to conventional High voltage breakdown test except that the sample material is immersed in insulating oil. Transformer oil is used as an insulating oil because it exhibits good insulating properties. Prepared samples undergo DC breakdown studies. It is through the use of high voltage DC testing apparatus as shown in Fig.7 that the voltage at which breakdown occurs is measured.

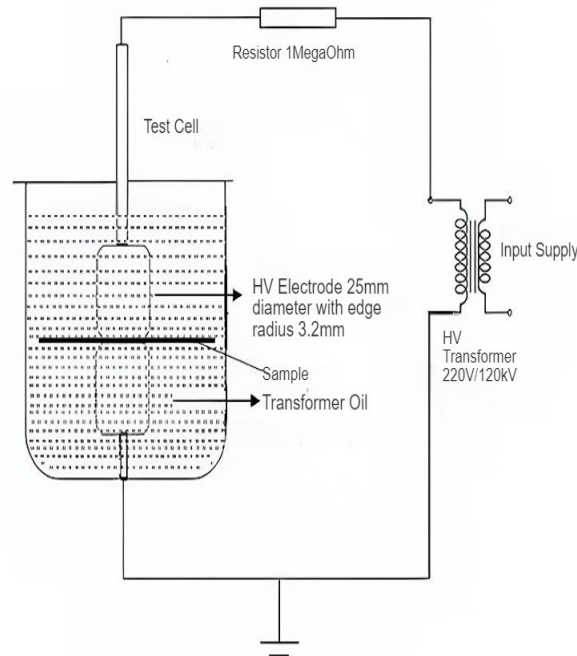


Fig.7.Experimental Setup

A. DC Break Down Test

The sample is subjected to a DC breakdown test where a voltage higher than that of an operational system fails it electrically. With this process one can be able to find out how much voltage the sample can take before it starts conducting electricity. In order to prevent flashover on its surface during testing, electrode setup was completely submerged inside a container full of transformer oil. The electrodes used are made of copper and had diameter 25 mm with edge radius of 3.2 mm.

They were connected to the high voltage side of the transformer that converts 220V to 120kV in DC. At the last stage, the voltage was introduced on the high voltage electrode till a point where failure occurred. The sample failures were puncture ones. These samples have an average thickness between 1mm and 2 mm measured using a digital vernier caliper before testing. $E=V/d$ is applied in calculating DC breakdown strength, where V represents the breakdown voltage and d means thickness of sample at failure point.

On increasing weight percentage up to 8% tremendously improves breakdown strength by giving 65% increase compared with pure epoxy sample. However, beyond this optimal concentration, specifically at 10% weight, the breakdown strength rapidly falls. This suggests that there is a threshold for weight percentage that necessitates optimization of concentration at 8% in order to maximize breakdown strength.

TABLE II
BREAKDOWN PROPERTIES UNDER DC CONDITIONS

Weight%	Thickness(mm)	Breakdown Properties	
		Voltage(kV)	Strength(kV/mm)
Pure epoxy	1.28	43.89	34.28
2% MgO	1.57	52.75	33.59
5% MgO	1.33	54.39	40.89
8% MgO	1.47	77.88	52.97
10% MgO	2.19	71.87	32.82

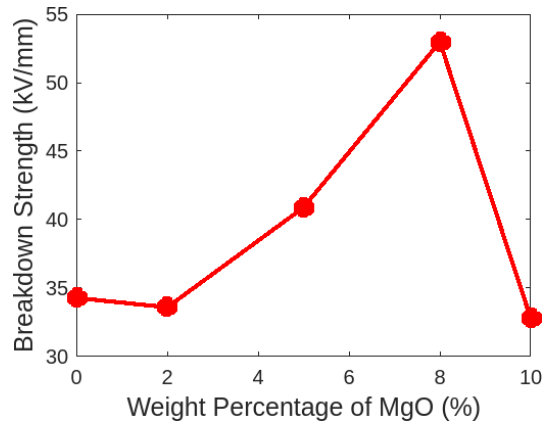


Fig.8.breakdownstrengthvsweightpercentage

V. CONCLUSION

Improvement of dielectric properties of Epoxy-MgO nanocomposites is investigated. Multiple samples of Epoxy- MgO nanocomposite at different filler loadings are prepared. High Voltage DC breakdown tests were conducted to evaluate the dielectric strength of the material at different filler concentrations. DC breakdown strengths of 5wt% and 8wt% are found to be greater than that of unfilled epoxy, while for 10 wt% the breakdown strength decreases. The maximum value of DC breakdown strength was obtained as 52.89 kV/mm at 8% filler loading. The improvement in breakdown strength is about double as that of pure epoxy. Simulation studies also were conducted using COMSOL Multiphysics to analyse the electric field distribution in the matrix. The study shows MgO nanoparticles can greatly improve the electrical insulation capabilities of epoxy resins. Further research should be conducted in order to validate whether these kinds of nanocomposites can withstand long-term applications in industry. Nevertheless, promising results have been obtained on these materials, which suggest that epoxy-silicon nanocomposites could transform high voltage insulation area by developing more effective and reliable materials.

REFERENCES

- [1] E.J.Eid, L.S.Nasrat, A.H.Shaheen "Estimation of Breakdown Voltage of Epoxy/SiO₂ Nanocomposites Insulators Using Machine Learning Algorithm," 23rd International Middle East Power Systems Conference (MEPCON), pp 1-6, Dec 2022
- [2] Xie, Z, Li, H., Zhang, S, Gong, A, Liu, P, Peng, Z, and Wang, Q. "Research on Electrical Properties of Surface-Modified Nano-SiO₂/Epoxy Composites," IEEE International Conference on High Voltage Engineering and Application, pp 1-4, 2020
- [3] A. B. Al Sawafi, N. A. Abdulzahra and J. F. Odah, "Improvement of Dielectric and Mechanical Properties of Epoxy/SiO₂ Nanocomposites," 12th International Conference on Developments in Systems Engineering (DeSE), Kazan, Russia, pp 77-82, 2019
- [4] W.Wang, Q.Li, Y.Liu, H.Wang, R.Wang and H.Jin, "Enhanced Thermal Properties of Epoxy Resin Composites: The Role of Tailoring Surface Chemistry of Nano-SiO₂," IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), Vancouver, BC, Canada, pp 403-406, 2021
- [5] X.Huetal, "Glass transition temperatures and Charge Transport Characteristics of Epoxy/SiO₂ Composites," IEEE International Conference on High Voltage Engineering and Application (ICHVE), Beijing, China, pp 1-4, 2022
- [6] S.Nakamura et al, "Effect of temperature on electrical treeing and partial discharges in epoxy/silica nanocomposites", IEEE Transactions on Dielectrics Electrical Insulation, vol. 27, no. 4, pp. 1169-1177, Aug 2020
- [7] M. T. Riaz et al., "Investigation of Electrical Properties of Epoxy Resin Composite with the Surface Modification of SiO₂ Nanoparticles," 2021 International Conference on Computing, Electronic and Electrical Engineering (ICE Cube), Quetta, Pakistan, pp. 1-5, 2021
- [8] M.Liang, K.L.Wong, R.Shanks and V.Bansal, "Study of dielectric and mechanical properties of epoxy/SiO₂ nanocomposite prepared by different processing techniques," 2015 IEEE 11th International Conference on the Properties and Applications of Dielectric Materials (ICPADM), Sydney, NSW, Australia, pp.48-51, 2015
- [9] J.Xiang, C.Zhang, S.Wang, H.Fu, Z.Xing and J.Li, "Surface Corona Aging of Epoxy/SiO₂ Nanocomposites," 2019 2nd International Conference on Electrical Materials and Power Equipment (ICEMPE), Guangzhou, China, pp.317-320, 2019
- [10] P. Karunarathna, K. Chithradewa, S. Kumara, C. Weerasekara, R. Sa-narasinghe and T. Rathnayake, "Study on Dielectric Properties of Epoxy Resin Nanocomposites," 2019 International Symposium on Advanced Electrical and Communication Technologies (ISAECT), Rome, Italy, pp.1-5, 2019
- [11] Siny Paul and T.K. Sindhu, "Development of epoxy-aluminium Nanocomposite Dielectric Material with Low Filler Concentration for Embedded Capacitor Applications", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 21, No.2, pp. 460-466, 2014



10.22214/IJRASET



45.98



IMPACT FACTOR:
7.129



IMPACT FACTOR:
7.429



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089  (24*7 Support on Whatsapp)