

Spectroscopic Study of Ultra High Molecular Weight Polyethylene (UHMWPE) and Mg-Ni-doped ZnFe₂O₃ Nano Composites

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Abstract The present study aims at investigating the effect of incorporating nano scale Mg_xNi_xZn_{1-x}Fe₂O₃ (where x=0.15) as nano fillers on the physical and chemical stability of ultra high molecular weight polyethylene (UHMWPE). The effect of adding 1% and 2% (by weight) nano fillers on the physicochemical properties of UHMWPE/Mg_xNi_xZn_{1-x}Fe₂O₃ nano composites have also been investigated by using FTIR, Raman, and UV-VIS spectroscopy. FTIR data of UHMWPE/Mg_xNi_xZn_{1-x}Fe₂O₃ nano composites reveal that the addition of Mg_xNi_xZn_{1-x}Fe₂O₃ up to 1% induces significant chemical and physical structural alterations in UHMWPE matrix. However, this behavior is found to reduce on increasing the concentration of nano fillers from 1% to 2%. Raman spectroscopic data shows that crystalline contents of UHMWPE remain unaffected with the addition of nano fillers, however; a significant increase in amorphous contents and decrease in *all-trans* interphase region is observed. This behavior is attributed to the chain scission reactions due to addition of Mg_xNi_xZn_{1-x}Fe₂O₃ followed by compression moulding process at high pressure and elevated temperature. Absorption spectroscopy analysis revealed that the incorporation of Mg_xNi_xZn_{1-x}Fe₂O₃ results in decrease of energy band gaps from 2.14 eV to 2.08 eV (for direct transition) and from 1.54 eV to 1.38eV (for indirect transition) due to band gap energy which is induced because of Mg_xNi_xZn_{1-x}Fe₂O₃ incorporation as nano fillers within the PE matrix.

Keywords: FTIR spectroscopy, Raman spectroscopy, UV-VIS spectroscopy, nano composites, UHMWPE, Mg_xNi_xZn_{1-x}Fe₂O₃, energy bands

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1. Introduction

Research on the structural investigation of nanocomposites is a growing with immense pace in order to produce stable materials with desirable properties [1,2,3,4]. This fast development is particularly due to its potential use in the field of optical biosensors, electronic circuits, automobiles, drug carriers, microelectronics packing, shielding material, coating, fire-retardant, bullet proof jackets, etc. [5,6,7,8,9,10]. Basically nanocomposites are the mixtures of matrix of standard materials and nano sized particles such that the effective amount of incorporated nano particles remains between 0.5 to 5 % to achieve the dramatic improvement in the properties of matrix of standard materials [10]. The standard material could be metal, ceramic, polymer depending on the nature of application. However, the researchers are paying much of their attention towards polymer nanocomposites due to their prosperity in real life applications, ease of use, and cost effectiveness [5,11].

Among the polymers, ultra high molecular weight polyethylene (UHMWPE) which falls to polyethylene (PE) class is a versatile polymer and is currently used in number of industrial applications including textile machinery, dump trucks, bottle production lines as runners, ship bumpers and harbors sidings, hip cup liners, knee plateau and for other number of medical applications [12,13]. Although, UHMWPE has outstanding chemical and physical properties such as excellent abrasive, wear, and impact resistance, inertness for toxic environment, biocompatibility etc. but researchers are still working to enhance its service life with various state of art techniques [13]. However, more recent development and progress in nanotechnology open new horizons for the scientist/engineers/medical physicians working with UHMWPE to enhance/alter its properties for desirable application while preparing composites with compatible nano particle i.e. UHMWPE nanocomposites [14,15].

Majority of recent research work is mainly focused on preparing UHMWPE nano composites with carbon based nano scale particles i.e. with carbon nano tubes (CNTs),

graphene, graphene oxide etc. in order to enhance the properties (thermal, mechanical, electrical) of UHMWPE [15,16,17]. Furthermore, the use of Quartz, kaolin, zirconium particles, carbon fiber, and clay [20] as the fillers for the preparation of UHMWPE composites has been reported in literature [15]. However, the information about UHMWPE composites with ferrites as nano filler is still missing in the literature according to best of our knowledge.

Ferrites is the class of magnetic materials having wide range of technological applications such as gas sensing applications, magnetic cores, magnetic memory chips, plasmonic bandgap crystals, noise reduction filters, electromagnetic interference shielding etc. [18,19] due their low cost and magnetic properties like irreversibility, relaxation dynamics and reallocation in hysteresis loops etc [20,21]. The ferrites exhibit different kinds of magnetic properties depending on the particle size. Moreover, when their size is reduced to nano scale, it exhibits unusual physical and chemical properties [22] and might results in adverse effects as far as structural properties of host polymer matrix (here in this study UHMWPE) is concerned. Therefore, it is worth to understand the role of nano ferrites as filler and their effect on the structural, optical and chemical properties of host polyethylene matrix before going to test these polymer/ferrites nano composites for particular application.

The present study aims at investigating the effects of adding nano scale $Mg_xNi_xZn_{1-x}Fe_2O_3$ (where x belong 0.15 % by wt.) ferrites on the structural and morphological stability. For this purpose, the composites of UHMWPE with $Mg_xNi_xZn_{1-x}Fe_2O_3$ nano-ferrites (from here on written as UHMWPE/ferrite nano composites) were differentiated via Fourier Transform Infra Red (FTIR), and Raman spectroscopic techniques. In addition to this, effect of incorporating the $Mg_xNi_xZn_{1-x}Fe_2O_3$ on the band gap optical properties of UHMWPE was also the topic of interest during this studied and UV-VIS spectroscopy to investigate the effect on these properties.

2. Experimental & Research Methodology

2.1. Sheet Preparation of Composites

Powder form of pure UHMWPE was used to form sheets of 1mm thickness via hot press at temperature and pressure 190°C and 20MPa with grasp time of 10 minutes. After the compression action, the samples were cooled to room atmosphere at 20MPa. For the preparation of UHMWPE/ferrites nano composites, the appropriate concentrations (i.e. 1% & 2 % by weight) of nano-scale $Mg_xNi_xZn_{1-x}Fe_2O_3$ were dispersed in acetone (100mL) for approximately 45 to 50 minutes. The blend of UHMWPE and dispersed $Mg_xNi_xZn_{1-x}Fe_2O_3$ nano particles (in acetone) is prepared by shaking the admixture for 15 minutes. The acetone was then vanished from slurry at 60-70°C with the help of an oven. Samples were ball milled for 2 hours at 200 rpm at Pakistan Institute of Engineering and Applied Sciences, 45650, Islamabad Pakistan to obtain the regulated mixing of nano scale $Mg_xNi_xZn_{1-x}Fe_2O_3$ within the UHMWPE matrix. Finally, homogenized

UHMWPE/ferrites nano composites were pressed by using hot press (Gibitre instruments laboratory press) and micron size molded sheets were grouped. The compression molding of composites was performed in three orders of steps given below and labeled as P-0, PF₁-0, and PF₂-0 respectively where 'P' stands for UHMWPE, 'F' for $Mg_xNi_xZn_{1-x}Fe_2O_3$ and number in subscript represent the percentage of $Mg_xNi_xZn_{1-x}Fe_2O_3$:

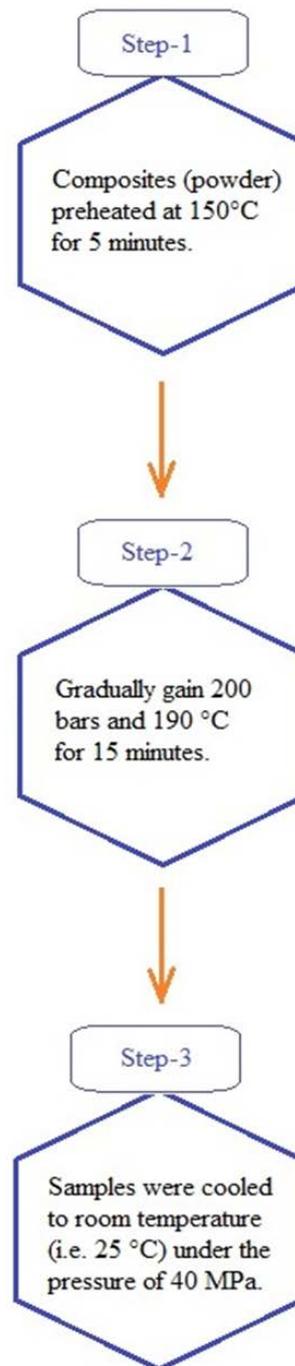


Figure 1. Systematic steps for sheets preparation

3. Characterization

3.1. FT-IR Spectroscopy

FT-IR spectroscopy is an experimental spectroscopic technique for analysis of molecular structures and

chemical bonds of conjugated polymers. Nicolet-6700 Fourier transform infrared spectrophotometer (Thermo Electron Corporation, Waltham, MA, USA) was used to form infrared spectra in attenuated total reflection (ATR) mode and intrigued in transmission mode. The spectra were taken in the range of 500cm^{-1} to 4000cm^{-1} at a resolution of 6cm^{-1} after attaining 216 scans for each measurement.

3.2. Raman Spectroscopy

An EzRamman-M Raman Analyzer by Enwave Optronics Inc. was used to assemble the Raman spectra from 250cm^{-1} to 2350cm^{-1} . Crystalline and amorphous regions were premeditated from the Intensity bands at 1416cm^{-1} and 1080cm^{-1} . Internal standard was chosen at the sum of the intensities of 1295cm^{-1} and 1303cm^{-1} . The values of inter-phase region were set as the balance after the calculation of the amorphous and crystalline contents [23].

3.3. UV-Visible Spectroscopy

Optically induced transition can be analyzed with the help of optical absorption method and is helpful in studying optical properties such as band gap energies and band structure of solid state materials. Samples were tested with the help of an automated Muller Matrix spectro-polarimeter which was handled using Axo-Scan TM (manufactured by Axometrics, 2006). Spectral Muller Matrix polarimeter used during experiment is illustrated schematically in Figure 2. Briefly, spectro-polarimeter setup has

- Xenon lamp of 150 Watt rating as a light source.
- Diffraction grating mono chromator with desired wavelengths i.e. from 400nm to 800nm with some accuracy 6 ± 0.5 of required wavelength.
- A polarization state generator which was used to pass polarized light from source to light up sample via fiber optic cable.

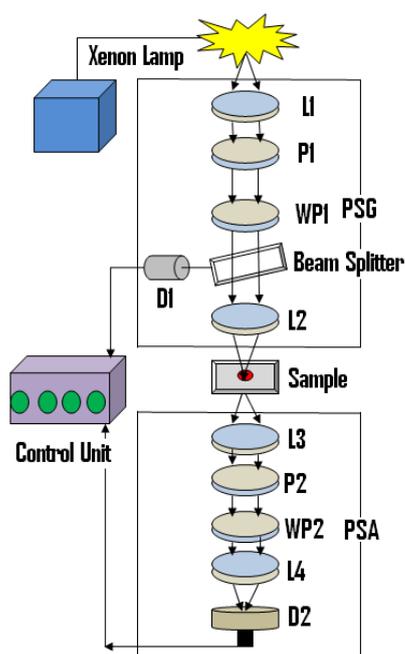


Figure 2. Schematic representation of Muller matrix polarimeter [26]

Output light was detected after passing through the sample. The resulted files consist of transmittance information corresponding to each wavelength with varying polarization characteristics were obtained and Urbach edge method and modified Urbach formula by Mott and Davies were used to investigate the effect of adding nano scale $\text{Mg}_x\text{Ni}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_3$ on band gap optical properties of UHMWPE. The variations like sample placement, laboratory environment, built-in optics alignment, source power etc may change results including transmittance, therefore, three to four readings of transmitted data were recorded and averaged before finding the optical properties. Comprehensive details about the Urbach formula, method, and spectro-polarimeter can be found in literature [24,25,26].

4. Results and Discussion

4.1. FTIR Study

Figure 3 (a) shows FTIR spectra of $\text{Mg}_x\text{Ni}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_3$ from 400cm^{-1} to 4000cm^{-1} along with the zoomed in segments from 400cm^{-1} to 2000cm^{-1} and 400cm^{-1} to 650cm^{-1} , respectively. The synthesized tracked by thermal annealing at 500°C sample explains typical absorptions of ferrite phase at around 600cm^{-1} and feeble absorption from 410cm^{-1} to 450cm^{-1} [27]. This variation in band location is expected due to variation in the $\text{Mg}^{2+}\text{-O}^{2-}$ distance for octahedral as well as tetrahedral compounds. Waldron [28] considerde this vibrational spectra as ferrites and assigned 600cm^{-1} as strong absorption region which is due to the pure vibrations caused by tetrahedral and octahedral groups.

There is strong absorption in the region of 1600cm^{-1} which suggests the existence of residual carbon contents. This strong absorption indicates that significant amount of remaining carbon left after the synthesis process. The wave numbers belonging to this absorption indicate residual carbon contents exist as complex carbonates. Annealing of this synthesized sample at 500°C for 24 hour results in decrease of this absorption [29,30]. The absorption bands at 3150 and 3450cm^{-1} , a large absorption feature to OH groups is originated. The most attractive range of the IR spectra for Ni-Zn ferrites, is the $400\text{-}650\text{cm}^{-1}$ [31,32] which is shown as inset of Figure 3(a). This range is allocated to ionic vibrations in the crystal lattice and ferrites in this range usually represents two prominent absorption envelopes (see Figure 3 (a)). Between 500cm^{-1} and 800cm^{-1} , the ν_1 band is present which is due to $\text{Fe}^{\text{III}}\text{-O}$ and $\text{Zn}^{\text{II}}\text{-O}$.

Figure 3 (b) shows FTIR spectra of UHMWPE nano composites with 1% and 2% of $\text{Mg}_x\text{Ni}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_3$ added in the UHMWPE matrix. All samples at 2924 and 2849cm^{-1} exhibit the feature of the $-\text{CH}$ stretching vibration of the CH_2 group and at $1470\text{cm}^{-1}/1460\text{cm}^{-1}$ $-\text{CH}_2$ bending vibration and long chain rocking deformation of $-\text{CH}_2-$ groups occur at 730 and 717cm^{-1} , respectively. It can be seen that the addition of ferrites induce significant changes in the aforementioned functional groups. A slight increase in the region of $\text{C}=\text{C}$ unsaturation is observed in UHMWPE/ferrites nanocomposites containing 1% of $\text{Mg}_x\text{Ni}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_3$.

However, increasing the concentration of $Mg_xNi_xZn_{1-x}Fe_2O_3$ further from 1% to 2% have almost negligible effect on the concentrations of C=C unsaturation within the polyethylene (PE) matrix. A significant increase in the absorbance from $1650-1850cm^{-1}$ and $3000-3750cm^{-1}$ shows that the addition of $Mg_xNi_xZn_{1-x}Fe_2O_3$ followed by hot pressing the material at $200^\circ C$ induces the chain breaking and oxidation degradation via free radicals chain reaction mechanism. These free radicals further react with the diffused as well as oxygen of ferrites and results in enhancing the oxidation degradation of nano composites of UHMWPE [33,34]. The increase in absorbance from $1460-1470 cm^{-1}$ indicates that the crosslink density

increases within the UHMWPE matrix with the addition of ferrites. As far as $Mg_xNi_xZn_{1-x}Fe_2O_3$ absorbance peaks are concerned, the increase in absorbance in the $400-650cm^{-1}$ range which is due to Ni-Zn Ferrites absorbance and the strong absorbance peak at $1600cm^{-1}$ which is due to residual carbon vanishes completely after the molding process. High temperatures during the compression molding process of UHMWPE nano composites might be the reason for elimination of this absorbance peak because it has previously been reported that heat treatment of ferrites at and around $250^\circ C$ results in total disappearance of this peak indicating the entire exclusion of residual carbon from the sample [27,28].

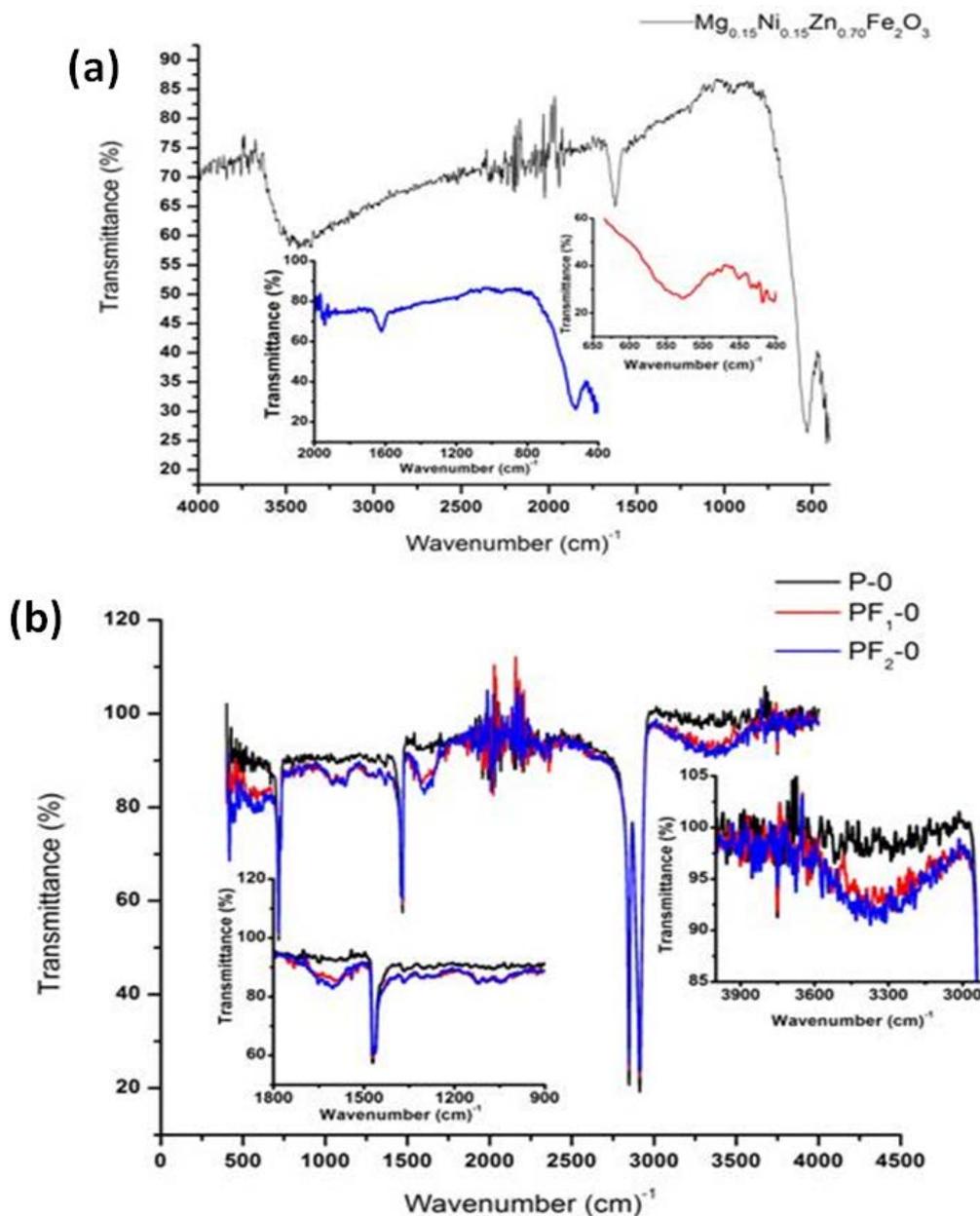


Figure 3. FTIR spectra of $Mg_xNi_xZn_{1-x}Fe_2O_3$ (a) and UHMWPE/ $Mg_xNi_xZn_{1-x}Fe_2O_3$ nano composites containing 1% and 2% by weight of $Mg_xNi_xZn_{1-x}Fe_2O_3$ (b)

4.2. Raman Spectroscopy

In order to evaluate the incorporation effect of $Mg_xNi_xZn_{1-x}Fe_2O_3$ on three phase morphology of UHMWPE, Raman spectroscopy has been run out to

calculate % crystalline, interphase and amorphous regions of PE in each sample since Raman spectroscopy has been carried out by others in recent past [23,35] to evaluate % age of interphase region that serves as transition area between the crystalline and amorphous regions of PE.

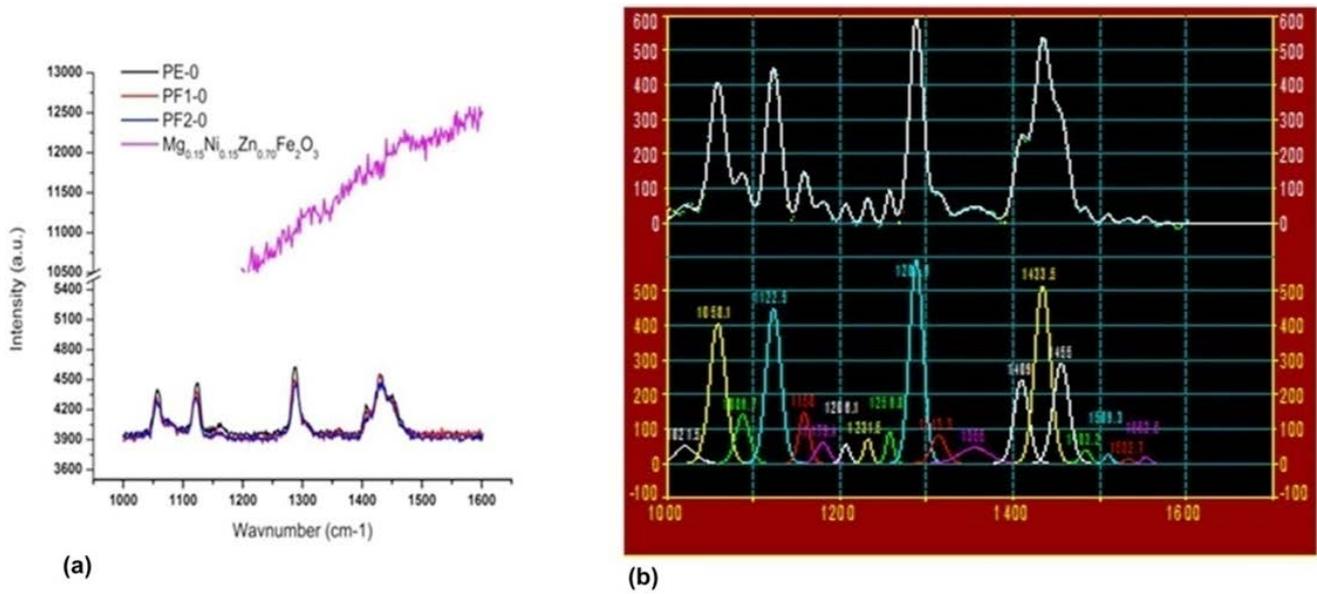


Figure 4. Raman spectra of pure UHMWPE and its nano composites with 1% and 2% of $Mg_xNi_xZn_{1-x}Fe_2O_3$ (a) and representative de-convoluted spectrum of pure UHMWPE (b)

Table 1. Calculated % values of PE crystalline, amorphous, and inter-phase regions with Raman spectroscopy

| Sample Code/Name | % Crystalline | % Amorphous | % Inter-phase |
|------------------|---------------|-------------|---------------|
| P-0 | 42 % | 23 % | 35 % |
| PF1-0 | 43 % | 30 % | 27 % |
| PF2-0 | 42 % | 28 % | 30 % |

Figure 4 (a) represents the Raman spectra of pure UHMWPE and its composites with 1 % and 2% of $Mg_xNi_xZn_{1-x}Fe_2O_3$ along with the Raman spectra of $Mg_xNi_xZn_{1-x}Fe_2O_3$ within the region of interest during this study i.e. from 1000cm^{-1} to 1600cm^{-1} . De-convolution of the spectra (representative de-convoluted spectrum is shown in Figure 4 (b)) in the region $1000\text{-}1550\text{cm}^{-1}$ and centered peak intensity values at 1416cm^{-1} have been used to calculate percentage contents of CH_2 components i.e. % crystallinity (orthorhombic packing). The peak values of intensity occurring at 1080cm^{-1} has been used to calculate the amorphous contents while the peak values at or around 1295cm^{-1} have been chosen as internal standard. The selection of peak intensity values is selected to avoid the contributions of strong Raman active bands of PE at 1440cm^{-1} and 1460cm^{-1} . The % values of crystalline, interphase and amorphous regions are obtained using following formulas and tabulated in table.

$$(\%) \text{ Crystalline} = \left[\frac{A_{1416\text{cm}^{-1}}}{(A_{1295\text{cm}^{-1}} \times 0.493)} \right] \times 100 \quad (1)$$

$$(\%) \text{ Amorphous} = A_{1080\text{cm}^{-1}} / A_{1295\text{cm}^{-1}} \times 100 \quad (2)$$

$$(\%) \text{ Interphase} = 100 \square [\% \text{ Crystalline} + \% \text{ Amorphous}]. \quad (3)$$

It can be noted that % crystalline fraction for all samples are found almost constant, while the % interphase and % amorphous regions has physical dependence on the application of $Mg_xNi_xZn_{1-x}Fe_2O_3$. It is found that on

adding the nano scale $Mg_xNi_xZn_{1-x}Fe_2O_3$, % amorphous contents increases while a significant decrease in all trans-interphase regions has been experimentally observed. This might be due to chain scission reactions induced (close to crystalline lamella of UHMWPE) because of addition of $Mg_xNi_xZn_{1-x}Fe_2O_3$ followed by sheet preparation under high pressure and temperature. These results suggest that ferrites are the potential candidates for initiating chain scission reaction within the UHMWPE matrix without disturbing its % crystalline contents and this factor is higher for UHMWPE/ $Mg_xNi_xZn_{1-x}Fe_2O_3$ containing 1% of $Mg_xNi_xZn_{1-x}Fe_2O_3$ as compared to samples containing 2% of $Mg_xNi_xZn_{1-x}Fe_2O_3$ as fillers. Moreover, a similar trend has been observed for the composites containing 5% of $Mg_xNi_xZn_{1-x}Fe_2O_3$ (data not shown here). These results evidentially show the effectiveness of $Mg_xNi_xZn_{1-x}Fe_2O_3$ to initiate the PE chain scission reactions without upsetting the crystalline contents of UHMWPE and its suitable effective concentration.

4.3. UV-Visible Spectroscopy

The method of optical absorption can be employed for the analysis of optically induced transition and is helpful in studying optical properties such as energy gaps and band structure of UHMWPE and the effect of incorporating the ferrites as nano fillers on these optical properties [24,25]. The relevant spectra and graphs for UHMWPE and its nano composites with 1% and 2% of $Mg_xNi_xZn_{1-x}Fe_2O_3$ are shown in Figure 5 and calculated values of Urbach energy, indirect and direct band gap energies are given in Table 2. It is evident from the results that incorporation of $Mg_xNi_xZn_{1-x}Fe_2O_3$ results in a significant increase of optical absorption, increase in Urbach energy (for up to 1% concentration of $Mg_xNi_xZn_{1-x}Fe_2O_3$), and decrease in band gap energies (please see Figure 5 and Table 2).

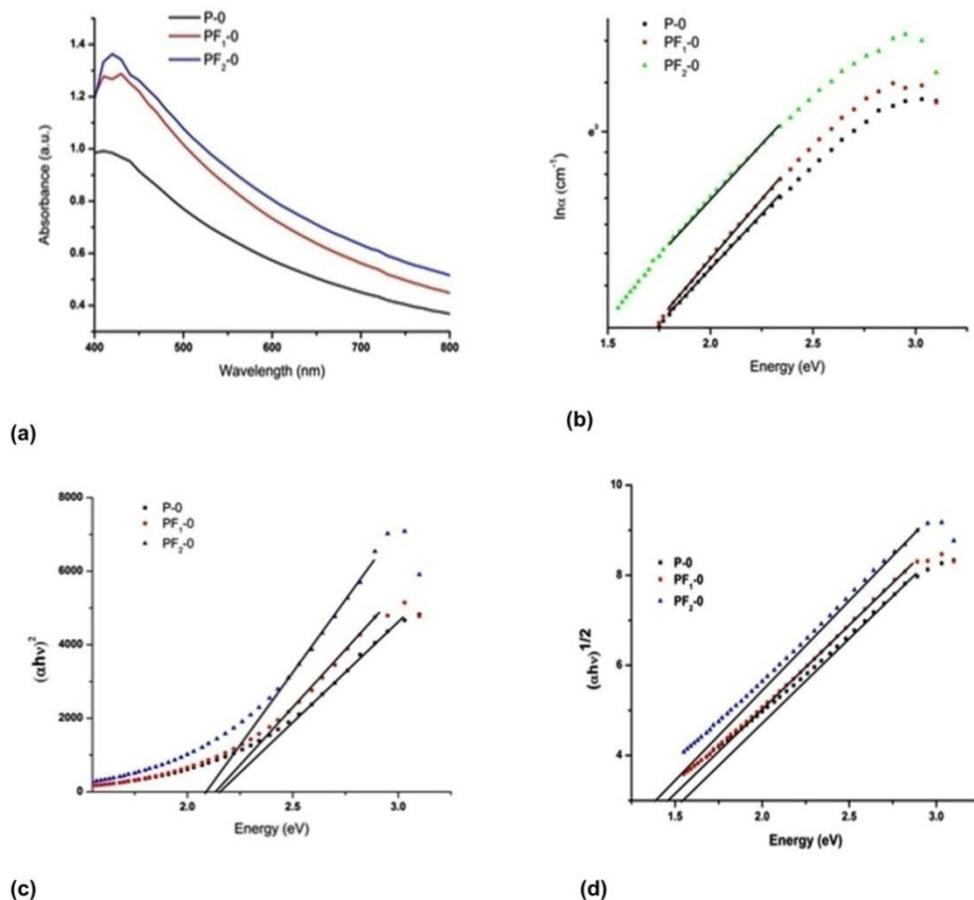


Figure 5. UV-Visible spectra (a) Natural logarithm of absorption coefficient plotted as a position of photon energy ($h\nu$) for the calculation of Urbach Energy (b) Represents direct band gap energies (eV) (c) Represents indirect band gap energies (eV) (d) Calculation of carbon atoms for direct and indirect band gap energies

Table 2. Urbach energy, band gap energies (direct or indirect) and number of carbon atoms in a bunch are tabulated from methods stated in the experimental part)

| Sample code | Urbach energy (meV) | Energy band gaps (eV) | | Carbon atoms (N) in a cluster | |
|--------------------|---------------------|-----------------------|----------|-------------------------------|----------|
| | | Direct | Indirect | Direct | Indirect |
| P-0 | 103 | 2.14 | 1.54 | ≈8 | ≈12 |
| PF ₁ -0 | 119 | 2.13 | 1.40 | ≈8 | ≈13 |
| PF ₂ -0 | 81 | 2.08 | 1.38 | ≈9 | ≈13 |

The following reasons are responsible for the aforementioned changes in Urbach energy and band gap properties of UHMWPE on addition of $Mg_xNi_xZn_{1-x}Fe_2O_3$:

- Due to the addition of $Mg_xNi_xZn_{1-x}Fe_2O_3$, it is reported by Manikandan et al., [36] that for Mg-doped $ZnFe_2O_3$ containing higher contents of Zn there is a blue shift in the UV-VIS spectra. This shift is accredited to extra subordinate band gap energy levels which are stimulated by addition of $Mg_xNi_xZn_{1-x}Fe_2O_3$ as nano fillers within the PE matrix.
- Configuration of chains of C=C unsaturation due to $Mg_xNi_xZn_{1-x}Fe_2O_3$ induced chain scission reactions.
- Increase in light scattering from filler surfaces and interface defects
- Due to changes occurred in PE physical and/or chemical properties by post mixing treatment under hot press at high pressure of UHMWPE/ $Mg_xNi_xZn_{1-x}Fe_2O_3$ nano composites.
- Due to structural deformation during ball milling for obtaining the homogenized mixture of $Mg_xNi_xZn_{1-x}Fe_2O_3$ and UHMWPE

Each sample with number of carbon atoms “N” in a cluster is associated with band gap energy “ E_g ” and Tauc’s equation was used to determine band gap energy and was tabulated in Table 2 [24,25].

$$N = 2\beta\pi / E_g \quad (4)$$

“ 2β ” represents band gap energy of a pair of adjacent π sites where π to π^* optical transitions in -C=C-structure occur and value of $\beta = 2.9$ eV. It is evident from the data that carbon atoms in -C=C- are in indirect relationship with band gaps whether it is direct or indirect energy band gap.

5. Conclusion

UHMWPE/ $Mg_xNi_xZn_{1-x}Fe_2O_3$ (for $x=0.15$) nano composites containing 1% and 2% contents of $Mg_xNi_xZn_{1-x}Fe_2O_3$ were successfully prepared with ball milling the admixture at 200 rpm for 2 hours. These composites were then pressed into the sheets of micron size and tested with FTIR, Raman and UV-VIS spectroscopy in order to

evaluate their chemical and physical stability. FTIR spectra revealed that addition of $Mg_xNi_xZn_{1-x}Fe_2O_3$ as nano fillers induced chemical and structural alterations within the matrix of UHMWPE due to the oxygen induced chain scission reactions close crystalline lamellae with almost negligible effects on the crystalline contents of UHMWPE confirmed through Raman spectroscopic analysis too. In addition to this, UV-VIS spectroscopy showed the shifting of absorption edge towards smaller wavelength regions i.e. blue shift with enhanced scattering events. Moreover, energy band gaps whether direct or indirect were found to reduce due to additional band gaps induced because of $Mg_xNi_xZn_{1-x}Fe_2O_3$ incorporation. Conclusively, the reported results during this study showed that addition of $Mg_xNi_xZn_{1-x}Fe_2O_3$ had roughly minor effects on the crystalline contents of polyethylene and can be used as potential filler for preparing the nano composites sheets/films for some new applications like EMI shielding etc.

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References

- [1] H. W. Baac, "High-Amplitude Photoacoustic Ultrasound Transmitters using Nanostructured-Composite Films," in *Advanced Photonics 2016 (IPR, NOMA, Sensors, Networks, SPPCom, SOF)*, Vancouver, 2016, p. SeTu1E.1.
- [2] K. S. Giesfeldt, R. M. Connatser, M. A. De Jesús, N. V. Lavrik, P. Dutta, and M. J. Sepaniak, "Studies of the Optical Properties of Metal-Pliable Polymer Composite Materials," *Applied Spectroscopy* 57, 1346-1352 (2003).
- [3] D. Hay, P. Bagge, I. Khaw, L. Sun, O. Wood, Y. Chen, *et al.*, "Ni-TaN Nanocomposite Absorber For Next-Generation Extreme Ultraviolet Lithography," in *Frontiers in Optics 2016*, Rochester, New York, 2016, p. FTu1F.2.
- [4] G. Jia, Y. Zhang, and P. Wang, "Nano-photo-thermal energy drive MoS₂/ZnO nanoheterojunctions growing," *Optical Materials Express* 6, 876-883 (2016).
- [5] W. Ma, z. liu, Y. Sun, and J. Yuan, "Efficient Hybrid Solar Cells Based on Conjugated Polymer: PbSxSe1-x Nanocrystal Composites---Benefiting from Vertical Phase Segregation," in *International Photonics and Optoelectronics Meetings (POEM)*, Wuhan, 2013, p. ASu2A.3.
- [6] H.-C. Mai and T.-E. Hsieh, "Nano-Composite Recording Layers Applied to Write-Once High-Density Optical Data Storage," in *Optical Data Storage*, Portland, Oregon, 2007, p. MD9.
- [7] J. H. Park, E.-S. Lee, J. Y. Lee, E. S. Lee, T. G. Lee, S.-H. Kim, *et al.*, "Multimodal Nonlinear Optical Microscopy for Simultaneous 3-D Label-Free and Immunofluorescence Imaging of Biological Samples," *Journal of the Optical Society of Korea* 18, 551-557 (2014).
- [8] C.-C. Tu, L. Tang, J. Huang, A. Voutsas, and L. Y. Lin, "Solution-processed photodetectors from colloidal silicon nano/micro particle composite," *Optics Express* 18, 21622-21627 (2010).
- [9] M. Wan, Z. Liu, S. Li, B. Yang, W. Zhang, X. Qin, *et al.*, "Silver Nanoaggregates on Chitosan Functionalized Graphene Oxide for High-Performance Surface-Enhanced Raman Scattering," *Applied Spectroscopy* 67, 761-766 (2013).
- [10] F. Song, X. Shen, M. Liu, and J. Xiang, "Preparation and magnetic properties of SrFe₂O₁₉/Ni_{0.5}Zn_{0.5}Fe₂O₄ nanocomposite ferrite microfibers via sol-gel process," *Materials Chemistry and Physics* 126, 791-796 (2011).
- [11] M. Blaszkiewicz, D. S. McLachlan, and R. E. Newnham, "The volume fraction and temperature dependence of the resistivity in carbon black and graphite polymer composites: An effective media—percolation approach," *Polymer Engineering & Science* 32, 421-425 (1992).
- [12] A. E. Ferreira, M. L. Cerrada, E. Pérez, V. Lorenzo, H. Cramail, J. P. Lourenço, *et al.*, "UHMWPE/SBA-15 nanocomposites synthesized by in situ polymerization," *Microporous and Mesoporous Materials* 232, 13-25 (2016).
- [13] M. S. Mehmood, T. Yasin, M. S. Jahan, B. M. Walters, M. Ahmad, and M. Ikram, "EPR Study of γ -Irradiated UHMWPE Doped with Vitamin E: Assessment of Thermal Effects on the Organic Radicals During Vitamin E Diffusion," *Applied Magnetic Resonance* 44, 531-542 (2013).
- [14] B. Ghafoor, M. S. Mehmood, U. Shahid, M. A. Baluch, and T. Yasin, "Influence of γ -ray modified MWCNTs on the structural and thermal properties of high-density polyethylene," *Radiation Physics and Chemistry* 125, 145-150 (2016).
- [15] M. Shafiee and A. Ramazani S.A, "Preparation and Characterization of UHMWPE/Graphene Nanocomposites Using Bi-Supported Ziegler-Natta Polymerization," *International Journal of Polymeric Materials and Polymeric Biomaterials* 63, 815-819 (2014).
- [16] P.-G. Ren, Y.-Y. Di, Q. Zhang, L. Li, H. Pang, and Z.-M. Li, "Composites of Ultrahigh-Molecular-Weight Polyethylene with Graphene Sheets and/or MWCNTs with Segregated Network Structure: Preparation and Properties," *Macromolecular Materials and Engineering* 297, 437-443 (2012).
- [17] S. S. Khasraghi and M. Rezaei, "Preparation and characterization of UHMWPE/HDPE/MWCNT melt-blended nanocomposites," *Journal of Thermoplastic Composite Materials* 28, 305-326 (2015).
- [18] M. Hashim, Alimuddin, S. Kumar, S. E. Shirsath, E. M. Mohammed, H. Chung, *et al.*, "Studies on the activation energy from the ac conductivity measurements of rubber ferrite composites containing manganese zinc ferrite," *Physica B: Condensed Matter* 407, 4097-4103 (2012).
- [19] S. E. Shirsath, R. H. Kadam, S. M. Patange, M. L. Mane, A. Ghasemi, and A. Morisako, "Enhanced magnetic properties of Dy³⁺ substituted Ni-Cu-Zn ferrite nanoparticles," *Applied Physics Letters* 100, 042407 (2012).
- [20] K. Raj, B. Moskowitz, and R. Casciari, "Advances in ferrofluid technology," *Journal of Magnetism and Magnetic Materials* 149, 174-180 (1995).
- [21] R. H. Kodama, C. L. Seaman, A. E. Berkowitz, and M. B. Maple, "Low-temperature magnetic relaxation of organic coated NiFe₂O₄ particles," *Journal of Applied Physics* 75, 5639-5641 (1994).
- [22] M. Khairy and M. E. Gouda, "Electrical and optical properties of nickel ferrite/polyaniline nanocomposite," *Journal of Advanced Research* 6, 555-562 (2015).
- [23] M. S. Mehmood, J. M. Shah, S. R. Mishra, and B. M. Walters, "The effect of high dose on residual radicals in open air irradiated α -T UHMWPE resin powder," *Radiation Physics and Chemistry* 84, 100-104 (2013).
- [24] S. Raghuvanshi, B. Ahmad, A. Srivastava, J. Krishna, and M. Wahab, "Effect of gamma irradiation on the optical properties of UHMWPE (Ultra-high-molecular-weight-polyethylene) polymer," *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 271, 44-47 (2012).
- [25] A. Abdul-Kader, "Photoluminescence and optical properties of He ion bombarded ultra-high molecular weight polyethylene," *Applied Surface Science* 255, 5016-5020 (2009).
- [26] M. Ahmad, S. Ali, M. S. Mehmood, H. Ali, A. Khurshid, S. Firdous, *et al.*, "Ex Vivo Assessment of Carbon Tetrachloride (CCl₄)-Induced Chronic Injury Using Polarized Light Spectroscopy," *Applied Spectroscopy* 67, 1382-1389 (2013).
- [27] V. Kawade, G. Bichile, and K. Jadhav, "X-ray and infrared studies of chromium substituted magnesium ferrite," *Materials Letters* 42, 33-37 (2000).
- [28] R. Waldron, "Infrared spectra of ferrites," *Physical Review* 99, 1727 (1955).
- [29] L. Costa, I. Carpentieri, and P. Bracco, "Post electron-beam irradiation oxidation of orthopaedic Ultra-High Molecular Weight Polyethylene (UHMWPE) stabilized with vitamin E," *Polymer Degradation and Stability* 94, 1542-1547 (2009).
- [30] V. Sankaranarayanan and C. Sreekumar, "Precursor synthesis and microwave processing of nickel ferrite nanoparticles," *Current Applied Physics* 3, 205-208 (2003).

- [31] E. S. Urkac, A. Oztarhan, F. Tihminlioglu, N. Kaya, D. Ila, C. Muntele, *et al.*, "Thermal characterization of Ag and Ag+ N ion implanted ultra-high molecular weight polyethylene (UHMWPE)," Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 261, 699-703 (2007).
- [32] A. Raghavender, N. Biliškov, and Ž. Skoko, "XRD and IR analysis of nanocrystalline Ni-Zn ferrite synthesized by the sol-gel method," Materials letters 65, 677-680 (2011).
- [33] L. Costa and P. Bracco, "Mechanisms of crosslinking, oxidative degradation and stabilization of UHMWPE," UHMWPE Biomaterials Handbook, 309 (2009).
- [34] M. Martínez-Morlanes, F. Medel, M. Mariscal, and J. Puértolas, "On the assessment of oxidative stability of post-irradiation stabilized highly crosslinked UHMWPEs by thermogravimetry," Polymer Testing 29, 425-432 (2010).
- [35] M. S. Mehmood, B. M. Walters, T. Yasin, M. Ahmad, M. S. Jahan, S. R. Mishra, *et al.*, "Correlation of residual radical's with three phase morphology of UHMWPE: Analysis for the dependence on heat involved during vitamin E diffusion," European Polymer Journal 53, 13-21 (2014).
- [36] A. Manikandan, J. Judith Vijaya, M. Sundararajan, C. Meganathan, L. J. Kennedy, and M. Bououdina, "Optical and magnetic properties of Mg-doped ZnFe₂O₄ nanoparticles prepared by rapid microwave combustion method," Superlattices and Microstructures 64, 118-131 (2013).



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