Effect of polymer matrix type on electromagnetic radiation shielding performances of PbO reinforced / polyethylene, isophytalic polyester and bisphenol A vinylester based composites

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Abstract: - Heavy metal reinforced composites with polymer matrix are new competitors of the conventional lead electromagnetic radiation shields. These composites are reinforced with heavy metals to increase attenuation performance of the material while polymers are used to ensure lightness, cheapness and flexibility. Providing load-stress transfer and giving easy formability and processability to the composite are also role of the polymer component. The potential effect of different polymer matrixes on shielding performance of the composite is generally ignored while effect of filler type is investigated detailed in the literature. Thus in this study effect of different polymer matrixes on composite electromagnetic shields is investigated. In the study PbO reinforced composites were produced by using three different polymer matrixes as linear low density polyethylene (LLDPE), isophytalic polyester (IPE) and bisphenol-A-vinylester (VE). Performance of the composites was investigated by gamma spectrometric methods for 1173 and 1332 keV. It is revealed that isophytalic polyester based composites are the best for two energies and all filler ratios for electromagnetic shielding performances of the composites beside the filler type.

Key-Words: Radiation shielding, Polymer composite, Polyethylene, Isophytalic polyester, Bisphenol-A-vinylester, Lead(II)oxide

1 Introduction

Lead is the most widely used ionizing electromagnetic radiation (IEMR) shielding material due to its high density, high atomic number and cheapness. On the other hand, lead has important disadvantages as its heaviness, poor mechanic and chemical resistance, inflexibility and toxicity. Thus its usage is limited especially when mobile or wearable shielding materials are needed.

Nowadays, the demand for novel shielding materials is increased as the usage areas of IEMR increased with the developing technology. These novel shielding materials have to be light weight, non-toxic and flexible for eliminating disadvantages of lead shields. Composite shielding materials which combines different material’s properties in one material are seem to be a good solution for this problem.

Polymeric composite materials which a polymer is used as matrix material and reinforced with another material are one type of these composite shielding materials. Polymers are used because of their lightness, cheapness and flexibility while heavier particles like metals increases shielding performances of the composites.

Literature reveals that polymer based and inorganic material filled composite materials attenuates IEMR more than pure polymers and less than pure metals [1-7]. But the effect of polymer type on shielding performance is not studied detailed in contrast detail studied effect of filler type on it.

Thus in this study three different polymers were used as composite shielding material matrix material and all of them were reinforced with the same filler material. The shielding performance measurements were carried out and effect of polymer matrix type on shielding performance was investigated.

2 Experimental

2.1 Constituents of the composites

Three different polymers as linear low density polyethylene (LLDPE), isophytalic polyester (IPE) and bisphenol-A-vinylester (VE) were used as matrix material of the composites.

LLDPE is a substantially linear thermoplastic that have significant numbers of short branches with density of 0.918–0.940 cm^{-3} and melting point of 122–124 ^{o}C. LLDPE is a very flexible polymer that elongates under stress with high environmental stress cracking resistance. It has higher tensile strength, higher impact and puncture resistance than low density polyethylene that have long branching. It also has good chemical resistance and low cost of raw material/production. The LLDPE was procured (Ozugur Powder Plastik San., Turkey) in the commercial powdered form.

The other two polymer used as composite matrix were thermoset polymers. IPE with density of ~1.15 gcm^{-3} and VE with density of ~1,044 gcm^{-3} were procured (Poliya Poliester San. Ve Tic. Ltd. Sti.) commercially as PES resin in stirene monomer. Both of the thermosets have intermediate-high reactivity and low volumetric shrinkage. They show different active region properties. VE have active regions at the end of the polymer chains thus it can resist instantaneous loadings by absorbing it with whole molecule chain. Thus it is more flexible and tough than IPE. The chemical resistance of VE is also higher than IPE as its vapor toxicity.

Lead(II)oxide (PbO) was used as reinforcement material of the composites. PbO has molecular weight of about 223.20 $gmol^{-1}$ and density of about 9.53 gcm^{-3}. The PbO used in this study was in orthorhombic crystal structure.

2.2 Preparation of the composites

All the composites were prepared by using 5, 10, 15, 20 and 25% (wt) filler loading ratios.

2.2.1 LLDPE based composite preparation

Mixtures of matrix and filler powder with desired filler compositions were prepared by using a dry powder rocking shaker at 30 rpm for 15 min after filler and matrix compositions were weighted sensitively. Then the mixed powders were taken into stainless steel moulds with diameter of 21 mm and height of 5 mm. A basic melting moulding process was carried out with a constant temperature oven at 130^{o}C for 12 h. Mixture supplementation and pressurizing was done during melting to avoid from descents and voids in the product.

2.2.2 IPE and VE based composite preparation

Free radicalic polymerization process was performed for thermoset resins for formation of crosslinks that would led a rigid three dimensional lattice of the PES thermoset. Methyl ethyl ketone peroxide (MEKP) was used as radical source with cobalt octoate (Coct) catalyst in the polymerization process. Filler particles were dispersed into the resin with a mechanical blender at 120 rpm after weighting of the filler and matrix material sensitively. Then Coct and MEKP were dispersed into the resin by mechanical mixing and crosslinking process was started in the resin. The mixing was continued until gelation point to avoid any precipitation of the filler particles in the thermoset resin and then the mixture was taken into a doubly side closed steel mould. The composites were cured in the mould for 24 hours at room temperature and 8 hours at 80^{o}C constant temperature.

2.3 Electromagnetic radiation shielding performance measurement

The gamma spectrometric measurements were performed with a 110 cm3 well-type HPGe detector coupled with a 64 k channel analyzer. The system had a resolution of 3.78 keV at 1.33 MeV gamma-ray peak of 60Co. The detector was housed in a lead shielding 10 cm thick lined with 1.5 mm thick tin and 1.0 mm thick copper in order to reduce the X-ray interferences.

The IEMR attenuation measurements were carried out

on the basis of a standard 60Co point gamma-source that have photopeaks at 1173 and 1333 keV energies. A cylindrical lead shield with a well hole through the lead was used for the measurements for providing the detector to count only the gamma rays coming through the shielding material by blocking the gamma rays coming through to the detector from other directions. The lead shield was placed above the HPGe detector and the shielding materials with 10 mm thickness were placed at the bottom in the lead shield while the radioactive source was placed onto the shield.

All the performance calculations were done relatively by comparing inlet and outlet radiation intensity to avoid any efficiency calibration errors. Initial radiation intensity (inlet) was measured for only radioactive source without placing any other material between the source and detector.

The data acquisitions were performed for a period of 1500 s. The spectra were evaluated by using the Maestro-ORTEC software program. Then the percent attenuation rates of the composites were calculated.

Percent attenuation rate could be defined as the percent ratio of radiation intensity before (inlet) and after (outlet) interaction with the material, Eq. 1.

$$F\% = ((I_0 - I)/I_0)x100 \quad (1)$$

Here F% is percent attenuation rate, I_0 is the initial intensity of radiation and I is the residual intensity after traversing the material.

3 Results and Discussion

IEMR shielding performance measurements were performed for all of the composite types and 5 different filler loading ratios at two different gamma energies. The results are given in Table 1.

Table 1. Radiation attenuation ratios (%F) of the composites with different filler loadings

	LLDPE based composite		**İPE based composite**		**VE based composite**	
Filler loading (%)	**%F (1173 keV)**	**%F (1332 keV)**	**%F (1173 keV)**	**%F (1332 keV)**	**%F (1173 keV)**	**%F (1332 keV)**
5	2,40	0,67	11,44	6,80	3,31	2,86
10	3,46	2,39	10,94	6,49	5,04	2,74
15	9,23	5,84	4,16	3,40	5,85	1,45
20	8,57	7,95	8,20	5,32	6,27	3,97
25	9,16	5,25	10,72	6,70	4,41	3,14

As it is seen in Table 1, as the IEMR energy increased from 1173 keV to 1333 keV all type of composites showed less attenuation performance at all filler loading ratios. This is an expected result because one of the parameters that effects IEMR attenuation performance of a shielding material is IEMR energy. Attenuation of IEMR is based on the absorbing of the IEMR energy by electrons or nuclei of the shielding material as IEMR is traversing it. If energy of the IEMR is higher, it has to interact with shielding material more to lose its energy that means a thicker shielding material must be used. In the study all the produced shielding materials were 10 mm thick thus as the IEMR energy increased their attenuation performance decreased.

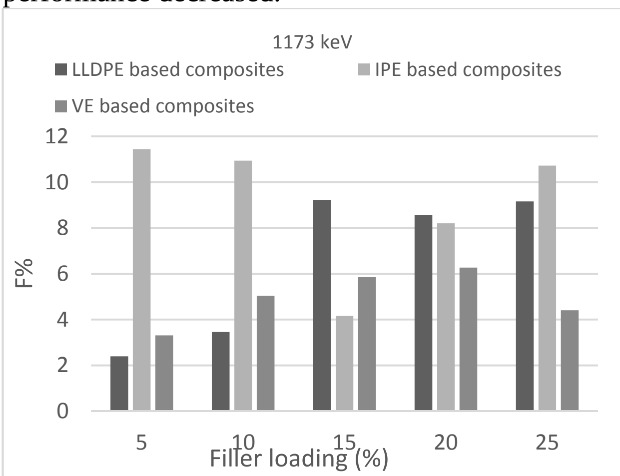

Figure 1. F% values of the composites at 1173 keV IEMR energy

Figure 1 and 2 were plotted to see polymer matrix effect on the performance of the composites more clearly.

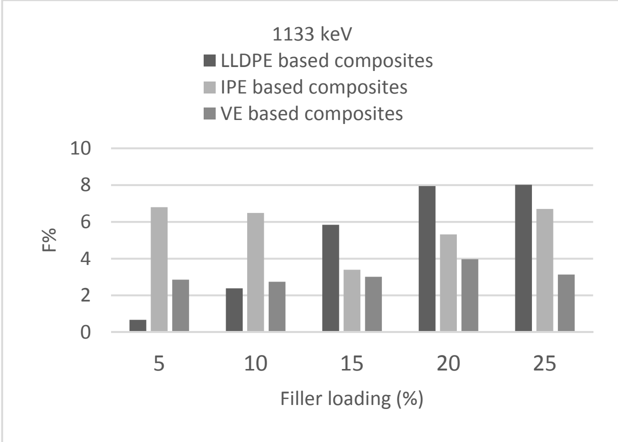

Figure 2. F% values of the composites at 1333 keV IEMR energy

As it is seen in Fig.1. F% values of different based composites at 1173 keV IEMR energy show different tendency. For LLDPE based composites F% values increased as the filler loading ratio increased. But F% values are about the same for 15-20-25% filler loadings. So it can be concluded that the 15% filler is optimum loading ratio for LLDPE based composites. VE based composites F% values increased as the filler loading ratio increased until 20% filler loading value. From this point forward (at 25% filler loading) it decreases. That is to say 20% filler loading value is optimum for VE based composites.

At IPE based composites the F% value is the highest for 5% filler loading value. And the tendency shows a parabolic tendency. So, it can be resulted that the 55 filler ratio is the optimum value for IPE based composites.

As it is seen in Fig.2. F% values of different based composites at 1333 keV IEMR energy show the same tendency as 1173 keV. The only difference is the values are a little small by comparing the results of 1173 keV. It is already the expected result because the attenuation factor decreases as the energy increases for the same type of shielding material and geometry.

4 Conclusion

Polymer material's IEMR attenuation performances are generally low due to their structure loose structure and low atomic weight of the atoms (C, O, H) that forms the molecule. Thus many times only reinforcement components are taken into consideration when IEMR attenuation performance of a polymeric composite studied.

In this study it is aimed to investigate effect of polymer matrix type on a metal oxide reinforced composite IEMR shielding material's performance. Three different polymer matrixes were used in the study with the same reinforcement component. By the results it can be concluded that the IPE based composites have the highest attenuation character in both energies (1173 and 1332 keV) and for all filler loadings.

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