POTENTIAL OF ELECTRON BEAM IRRADIATED HDPE/EPR BLEND AS SHOES SOLE

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Keywords: Polymer blends, High Density Polyethylene (HDPE), Ethylene Propylene Rubber (EPR), Mechanical properties, Morphology, Electron beam, Sole shoe.

ABSTRACT

This study focuses on the mechanical effect of different composition of polymer blend. Polymer blend of high density polyethylene (HDPE) and ethylene propylene rubber (EPR) were selected and varied by three different compositions which are 70:30, 50:50 and 30:70. HDPE-EPR blend is believed to be the best material for sole shoe. In which, HDPE has good flexibility while, EPR can maintain optimum performance at high and low temperature as well as provide better gripping characteristic that suits for insole and outsole sport shoe. On the other hand, the time efficiency of electron beam radiation on these polymer blends helps in improving the croslinking of HDPE-EPR blend. The aim of this paper was to find the optimum composition of electron beam irradiated polymer blends for sole shoes especially in sports application. These irradiated polymer blends were produced by melt blending, underwent compression moulding and then were irradiated by electron beam at 100 kGy/s. Mechanical test of tensile and hardness test were investigated and the morphology of the failure fracture was analysed by field emission scanning electron microscopy (FESEM). The polymer blend with 70% of HDPE and 30% of EPR showed the optimum result of tensile strength, tensile modulus and hardness as well as ductile failure image.

INTRODUCTION

The selection of a sport shoes emphasizes on few criteria such as lightweight, flexibility and adequate grip where these features would offer comfort to athletes and would also improve the performance in their sports field. By using suitable material of the shoe especially the sole would definitely give advantage to the athlete in terms of satisfaction, health, ergonomic and biomechanical during training. The performances of athletes are related to selection of the sport shoes whereby the properties of sole shoes give tremendous effect on the comfortableness during walking, running and jumping. The selection of polymer blend of High Density Polyethylene (HDPE) and Ethylene Propylene Rubber (EPR) as the polymer base matrix of sole shoes is believed to be the best material for sole shoes due to its own excellent properties in which these criteria are nearly important for a production of comfort sole shoes. For instance, HDPE provide flexibility for insole and outsole shoes and exhibits better impact resistance as well as manufacturability [1]. Meanwhile, better gripping characteristic and able to maintain optimum performance at high and low temperature of EPR has contributed to the effectiveness of the sole shoes [2].

Moreover, even though blending of HDPE with EPR is attractive due to the component's mutual chemical compatibility, this polymer blend has to be introduced to crosslinking techniques generally to facilitate crosslinking as well as overcome any immiscibility or incompatibility between polymer matrix and filler [2, 3]. There are various method of crosslinking includes physical and chemical crosslinking. Electron beam (EB) radiation is one type of physical crosslinking technique considerably attractive technique since it is simple, straight forward and faster processing times. In fact, EB radiation is also an environmentally friendly which no chemicals are required nor produce any chemical residues during the process like chemical crosslinking technique [4, 5]. The most interesting of EB radiation is the changes of molecular structure of material due to the electron beam itself that makes the material has unique properties. The radiation dose of electron beam also needs to be controlled in order to obtain the best properties. For example, at higher dose rate which above 100 kGy results in poor mechanical properties due to chain degradation [6].

The additional of chemical agent or so called compatibilizer agent such as maleic anhydride polyethylene (MAPE) chemical into a polymer material is known as chemical crosslinking. This technique has the ability to reduce the interfacial tension between two phases and improve miscibility of polymer matrix and nanocomposite [7]. However, the effectiveness of chemical agent is depending only at certain percentage of chemical agent. For instance, greater than 5% of chemical agent reduces the stiffness and toughness of the material. Thus, the amount of MAPE used as a compatibilizer agent in this study was below than 5 vol% which is 3 vol% [8]. Even though both techniques offered the same incentive such as improve immiscibility between polymer blend, eventually the properties of different crosslinking techniques will significantly varied. The important of selection crosslinking techniques affect the properties of polymer blend especially when dealing with nanofillers. Therefore, the purposes of this study were to determine the best composition of electron beam irradiated polymer blend of HDPE-EPR for sole shoes and to determine and compare the effectiveness of different crosslinking techniques for the best composition of HDPE-EPR polymer blend.

MATERIALS AND METHOD

Materials

High density polyethylene (HDPE) with melt flow index (MFI) 3-6 g/min and density of 900 kg/cm³ was supplied by Cementhai Chemicals Group, Thailand and Ethylene Propylene Rubber (EPR) was supplied by Centre West Sdn. Bhd., Malaysia were used in the experiment.

Preparation of the polymer blend

The polymer blend of HDPE and EPR were prepared at different ratio (Table 1) in the internal mixer of a HAAKE Rheomix 310P at 135°C with a rotor speed of 100 rpm for 13 min. EPR was first melted for 3 min at 135°C purposely for mastication of rubber. Then, the mixing is followed by the addition of HDPE for 10 min to make HDPE-EPR blend.

Table 1: Different compositions of HDPE-EPR blend

Sample	Ratio (wt %)	
	HDPE	EPR
1	70	30
2	50	50
3	30	70

Compression molding

The polymer blend was compression molded by Moore Max Ton Hydraulic Press hot press machine at 135°C and 200 bar metric pressure. The polymer blends were preheated for 5 min and compression moulded for 3 min then were cooled down under pressure until the temperature goes down at 60°C. Then, the specimens for testing were punched out into tensile dumbbell specimens according to ASTM D412 by using pneumatic hollow die punch.

Electron beam radiation

All the samples were exposed under high energy electron beam at 100 kGy whereby the acceleration energy, beam current and dose rate were set to 2 MeV, 5 mA and 50 kGy/pass respectively.

Mechanical properties

Tensile test was performed on the polymer blend samples in order to obtain the optimum ratio of HDPE-EPR blend by using the universal testing machine manufactured by Lloyd with 10 kN load cell and at a crosshead speed of 50 mm/min. Shore A hardness was measured using a TecLock (Japan) hand-held Shore A Durometer according to ASTM D2240A.

Morphological observation

Tensile samples after fracture were gold-coated before been observed using JEOLJSM 6700F field emission scanning electron microscope (FESEM).

RESULTS & DISCUSSION

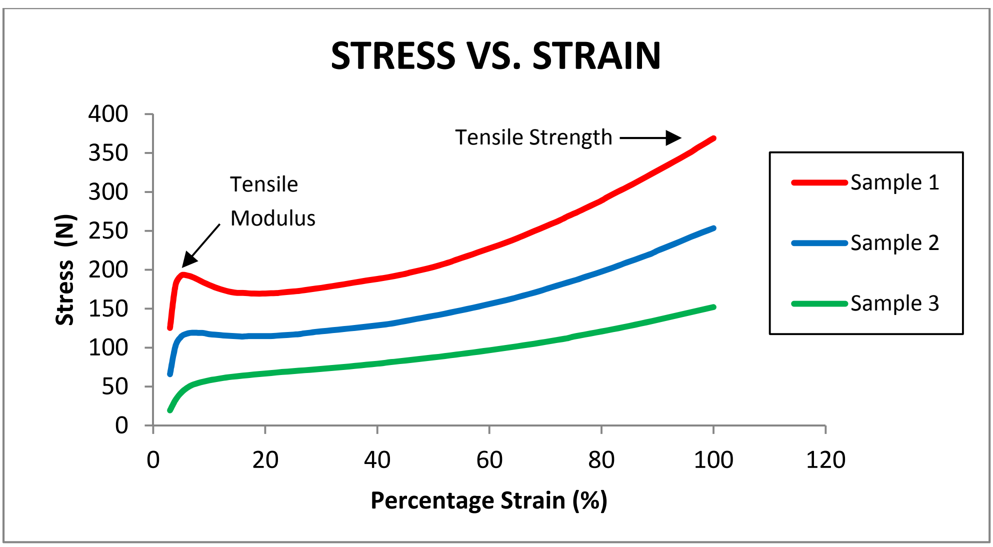
The mechanical effects of variation on compositions of HDPE and EPR of 70:30, 50:50 and 30:70 are demonstrated in Table 2.

Table 2: Results of tensile test, density measurement and hardness test of HDPE-EPR blends

Sample	Tensile Modulus (MPa)	Tensile Strength (MPa)	Percentage of Strain (%)	Density (g/cm^3)	Hardness
1	283.25	20.00	593.82	0.995	98
2	126.47	16.13	649.72	0.996	94
3	14.289	13.98	489.05	0.994	88

From the result obtained, Sample 1 with ratio of 70:30 (HDPE-EPR) has dominated the tensile modulus, tensile strength and hardness results with the values of 283.25 MPa, 20.00 MPa and 98 respectively. Among the samples, the hardest result hardness goes to Sample 1 followed by Sample 2 and Sample 3. The hardness behaviour displays in the polymer blends is due to exposure of electron beam radiation that improves polymer crosslinking between HDPE and EPR [3]. Tensile strength of a material is the maximum amount of tensile stress that the material can be subjected with load before failure. In this case, Sample 1 acquired the highest value of tensile strength of 20.00 MPa among the others that indicates the composition of 70% of HDPE has contributed to the ability of withstanding the stress being subjected to the polymer blend before it fails. Due to less flexibility characteristic of polymer blend upon less composition of HDPE, Sample 3 has the lowest tensile strength with value of 13.98 MPa [1,9]. In line with that, the greatest tensile modulus also dominated by Sample 1 whereby this parameter could also be shown in stress-strain curve (Figure 1). The remarkable values of percentage of strain for all samples were obtained between 490% and 650% in which sample 2 has the most favourable percentage of strain by 649.72% followed by Sample 1 (593.82%) and Sample 3 (489.05). The greatest percentage of strain or also known as elongation at break value indicates the ability of the polymer blend to extend before fracture. It was also observed that the relationship between both the tensile modulus and tensile strength with elongation at break of different ratio of polymer blend is inversely proportional. Meanwhile, an average of 0.995 g/cm^3 of density for all polymer blends were obtained which density signifies the important of lightweight characteristic of sole shoes. It is believed the improvement of crosslinking between HDPE and EPR by radiation of elecron beam has contributed the lightweight of polymer blends.

Figure 1: Stress-strain curve of HDPE-EPR blends



The stress-strain curve of HDPE-EPR blends of Sample 1, Sample 2 and Sample 3 are illustrated in Figure 1. Sample 1 which is HDPE-EPR blend of ratio 70:30 shows the highest value of stress-strain curve, followed by Sample 2 and Sample 3. Based on Figure 1, it can be observed that Sample 1 has the uppermost tensile modulus at the curve significantly confirmed with the value obtained is 283.25 MPa for tensile modulus during tensile test and followed by Sample 2 (16.13 MPa.) and Sample 3 (13.98 MPa). Both values of tensile modulus and tensile strength somehow can be verified by the behaviour of failure fracture resulted from tensile test.

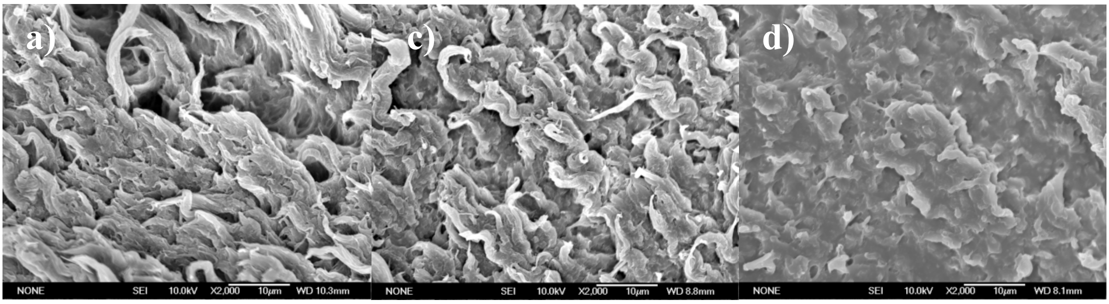


Figure 2: Failure Fracture of Electron beam irradiated polymer blend of HDPE-EPR at 2000x magnification. a) HDPE-EPR; 70:30 b) HDPE-EPR; 50:50 c) HDPE-EPR; 30:70

FESEM micrographs of irradiated polymer blend samples are presented in Figure 2. It is observed that the surface area of fracture failure resulted from tensile test of all the samples. Observation from the micrographs of HDPE-EPR of 70:30 and 50:50 were fracture in ductile manner that represents by the rough surface area. Meanwhile for HDPE-EPR of 30:70 was failure in brittle manner that has smooth surface. Ductile manner of failure indicates that the polymer blend are capable of absorbing large amount of energy thus makes them to endure the stress before prior to failure. Therefore, 70% of HDPE and 30% of EPR (Figure 2a) has the highest tensile strength and modulus. Whereas, polymer blend that exhibits very little amount of HDPE (Figure 2c) displays very little inelastic deformation and poor in resisting high stress. Hence they are likely easy to fail as more stress is given [10,11].

Instead of physically crosslinked polymer blend HDPE-EPR like high electron beam irradiated, there are many crosslinking techniques offered including chemical crosslinking. In this case, the 70:30 of EB irradiated HDPE-EPR polymer blend was compared with the same ratio of HDPE-EPR (70:30) chemically crosslinked by 3 vol% of maleic anhydride polyethylene (MAPE) chemical [7] acts as the compatibilizer agent. Figure 3 and 4 show the tensile strength and tensile modulus for three different systems, untreated (unmodified system), MAPE (chemical crosslinking) and EB (physical crosslinking). It should be noted that, all systems have the same ratio of HDPE-EPR polymer blend.

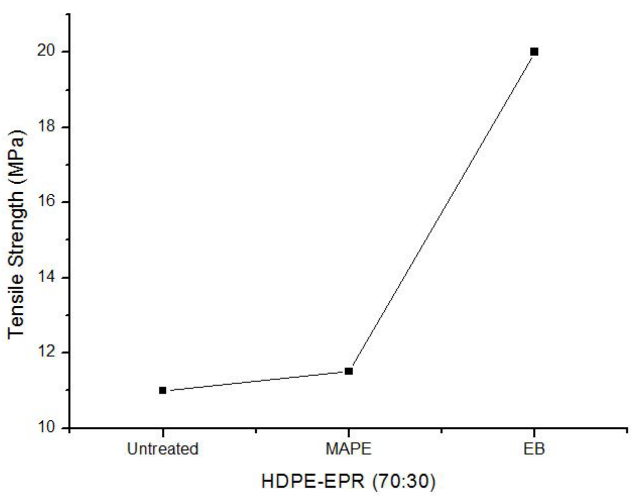


Figure 3: Tensile strength for untreated, MAPE and EB radiated systems at 70:30 of HDPE-EPR

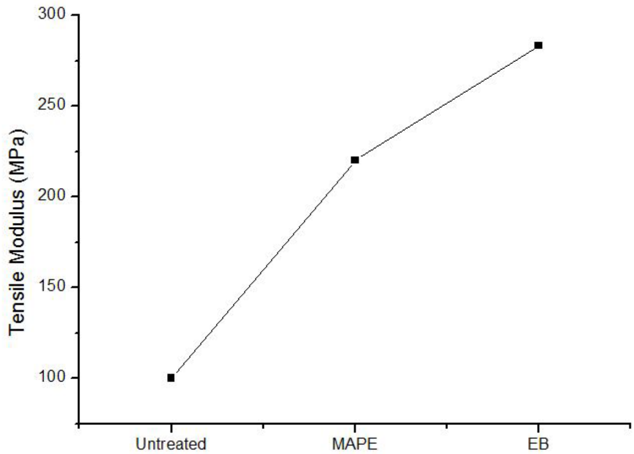


Figure 4: Tensile modulus for untreated, MAPE and EB radiated systems at 70:30 of HDPE-EPR.

Generally, all systems show the same trend where the tensile strength and tensile modulus improved as the HDPE-EPR polymer blend are being treated with different crosslinking techniques. The greatest tensile strength and tensile modulus are both dominated by EB radiated system. An increment of 82% and 5% were observed for tensile strength of EB radiated system and MAPE system, respectively. A slight increased in tensile strength with the presence of MAPE was believed due to its compatibility with polymer blend due to strong interactions such as hydrogen bonding and chemical reaction. A remarkable increased in tensile strength of EB irradiated polymer blend compared to untreated and MAPE systems may be due to the increased in the crystallinity and formation of crosslinking in the crystalline and amorphous regions. Besides that, the formation of radiation induced crosslinking in the HDPE and EPR which can be verified by further gel content analysis. The 100 kGy of EB radiation have caused sufficient formation of crosslink network structure between the polymer blend to become stiffer thus result in the increased of tensile modulus of EB irradiated polymer blend [6].

CONCLUSION

Experimental results showed that polymer blend of 70% of HDPE and 30% of EPR shows the best composition for sole sport shoes due to greater stress-strain curve, higher tensile strength and tensile modulus values, higher hardness value and considerably low density. Besides that, fracture failure in ductile manner indicates that HDPE-EPR (70:30) blend is able to endure more stress before it breaks. This is due to the presence of more composition of HDPE that contributed to the excellence of sole shoes. Regarding to the results obtained, it is compatible for sole shoes as they are dealing with violent movement. Apart of that, physically crosslinked of high electron beam (EB) radiation showed the effectiveness of crosslinking compared to the untreated and the chemical croslinking (MAPE) techniques. It is believed that, the mechanical and thermal properties of 70:30 of HDPE-EPR polymer blend can be remarkably enhanced by further reinforcing them with nanocomposites for sole shoes application. As such, HDPE-EPR reinforced with nanoclay and carbon nanotube for insole and outsole shoes.

ACKNOWLEDGEMENT

The work was supported by Malaysia Institution of Higher Education for funding this research under the PRGS12-003-0003; the Department of MME of International Islamic University Malaysia for providing the facilities and assistance in conducting this study.

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