December 2008 Volume 4 Issue (2-3)

Macromolecules

An Indian Journal

Trade Science Inc.

Full Paper

MMAIJ, 4(2-3), 2008 [149-153]

Effect of electron beam irradiation on the tribological properties of poly(m-phenylene isophalamide)

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Received: 17th November, 2008 ; Accepted: 22nd November, 2008

ABSTRACT

The effect of electron beam irradiation at dose of 5×10^5Gy, 5×10^6Gy, 1×10^7 Gy on the tribological properties of poly(m-phenylene isophalamide) (PMIA) was studied using a block-on-ring friction and wear tester. The chemical changes of the PMIA were investigated using X-ray Photoelectron Spectrometer (XPS) and electron spin resonance(ESR). The morphologies of worn surface of steel ring were observed using electron probe microanalysis (EPMA). Experimental results showed that electron beam irradiation contributed to a reduction in the friction coefficient and wear rate of PMIA. The friction coefficient and wear rate decreased with increasing the irradiation dose. EPMA investigations indicated that the smoother surface with more carbon element distribution on the surface of ring could decrease the friction coefficient and wear rate of irradiated PMIA. XPS results indicated that the chemical reaction consisting of carbonization occurred during the PMIA being irradiated. This was the reason that the more carbon element enriched on the worn surface which the steel ring sliding against irradiated PMIA and thus greatly reducing the friction and wear of the irradiated PMIA.

KEYWORDS

PMIA;
Irradiation;
Friction and wear;
Surface analysis.

1. INTRODUCTION

With the development of advanced materials used in space, further demands on good mechanical and physical properties especially anti-radiation properties have been posed to polymer materials. Haruvy[1] pointed out that various radiation sources such as fast electrons, fast protons, ultraviolet ray,γ-ray, energetic heavy particles etc. exist in the cosmic space. According to approximate computation of scientists, the maximum dose of radiation at the surface of a material mounted on a space system is 2500Mrad/yr. Therefore, for good application of polymer materials in space field, we hold to carry out systematic research into the effect of radiation on basic properties and tribological properties of polymer and provide theoretical basis for the application of polymer in space field would be a very valuable work.

The effect of irradiation on the mechanical properties of polymers and their composites had been researched by many workers in the world with their wildly application[2-6]. The trobological properties of irradiated polymers such as polytetrafluoroethylene (PTFE), polyethylene (PE), polyamide（PA）also had been studied by a few workers[7-13]. However, the effect of irradiation on the friction and wear properties of polymer is not very cleared.

In this work, the effects of electron beam irradiation on tribological properties of a aromatic polyamide, poly(m-phenylene isophalamide) (PMIA), had been investigated using a block-on-ring friction and wear tester. The chemical change of the PMIA was investigated using X-ray Photoelectron Spectrometer (XPS) and electron spin resonance（ESR）. The morphologies of worn surface of steel ring were observed using electron probe microanalysis (EPMA).

2. EXPERIMENTAL

PMIA was produced by Oiles Corporation (in Japan), it was a thermoplastic polymer. Its chemical structure was shown in figure 1. The polymer specimens for irradiation and friction and wear tests were prepared by mould pressing during which polymer powder was heated at a rate of 5^0Cmin^{-1} to 330^0C, held there for 15min and then cooled to room temperature. Before it being irradiated, the surface of the PMIA block was polished with number 900 water-abrasive paper, cleaned with cotton dipped in acetone, and dried in air. The electron beam irradiation was performed on a linear electron accelerator at the Lanzhou Institute of Modern Physics, Chinese Academy of Science. Irradiation was carried out at ambient temperature and around nitrogen gas. PMIA specimens were irradiated at dose of 5×10^5Gy, 5×10^6Gy, 1×10^7Gy respectively using electron beam current 1mA. The irradiation resulted in change of the PMIA sample appearance. With increasing dose , the sample color was from pale yellow to yellow, then to yellowish brown, finally to sandy beige when the dose was 1×10^7Gy.

The friction and wear tests were conducted on a MM-200 model friction and wear tester at room temperature in ambient atmosphere. The contact schematic diagram of the frictional couple was shown in figure 2. Before each test, the plain carbon steel(AISI 1045 steel ring) and PEK-C block were polished with No. 900 water-abrasive paper. Then the surfaces of the steel ring and PEK-C block were cleaned by cotton dipped in acetone and then dried in air. In this work, three to five samples were tested at each condition, the friction coefficient and wear rate were the average values of three replicate test results. Sliding was performed under dry ambient conditions at a speed of 0.42m/s, under a load of 49N and over a period of 60 min.

The chemical change of the PMIA was examined using a PHI-5702 Multi-technique Small Area X-ray Photoelectron Spectrometer (XPS). Curve fitting was carried out using fitting program PHI PC-Access 6.0. The electron spin resonance spectra were recorded at room temperature on an ER200D-SRC spectrometer

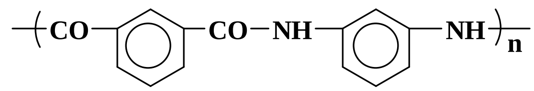


Figure 1 : Chemical structure of PMIA

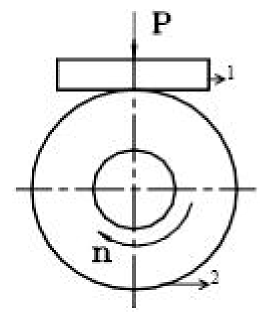


Figure 2 : The contact schematic diagram for the friction couple (P:Load, 1:Sample, 2:Rotating ring)

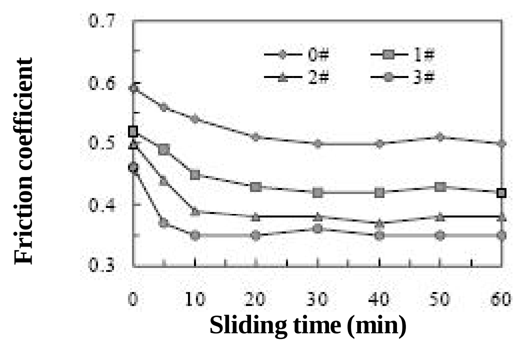


Figure 3 : Friction coefficient as a function of sliding time for unirradiated and irradiated PMIA sliding against steel ring 0# unirradiated PMIA, 1# 5×10^5Gy dose irradiated PMIA, 2# 5×10^6Gy dose irradiated PMIA, 3# 1×10^7Gy dose irradiated PMIA.(Sliding was performed under dry ambient conditions at a speed of 0.42m/s, under a load of 49N and over a period of 60 min.)

(ESR). The morphologies of worn surface of steel ring were observed using an EMP-810 electron probe microanalysis (EPMA).

3. RESULTS AND DISCUSSION

3.1. Friction and wear properties of irradiated PMIA

Figure 3 gives the friction coefficient as a function of sliding time for unirradiated and irradiated PMIA sliding against steel ring. For unirradiated PMIA, firstly, the friction coefficient decreases with increasing sliding time, and then reaches to a relatively stable friction coefficient about 0.50. The irradiated PMIA shows a similar friction curve to the unirradiated PMIA. It is noted that initial and stable friction coefficient of irradiated PMIA is lower than that of being unirradiated. The values of initial and stable friction coefficient all decrease with increasing irradiation dose. The lowest friction coefficient about 0.35 in this work is obtained while irradiation dose is 1×10^7Gy.

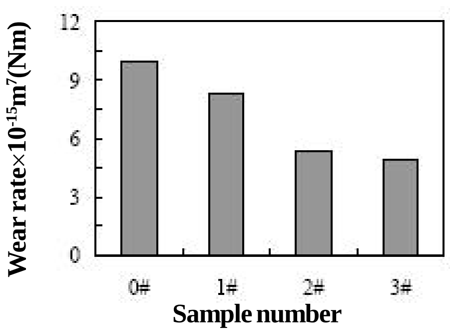


Figure 4 : Effect of irradiation dose on the wear rate of PMIA; 0# unirradiated PMIA, 1# 5×10^5Gy dose irradiated PMIA, 2# 5×10^6Gy dose irradiated PMIA, 3# 1×10^7Gy dose irradiated PMIA.(Sliding was performed under dry ambient conditions at a speed of 0.42m/s, under a load of 49N and over a period of 60 min.)

Figure 4 shows the effect of irradiation dose on the wear rate of PMIA. It can be seen that the wear rate of irradiated PMIA decrease with increasing irradiation dose too. Especially, when irradiation dose is 1×10^7Gy, the wear rate of irradiated PMIA is only 50% of that of being unirradiated. It can be seen that wear rate was accompanied by a sharp decrease. The above results indicate that irradiation contribute to a reduction in the friction coefficient and wear rate of PMIA.

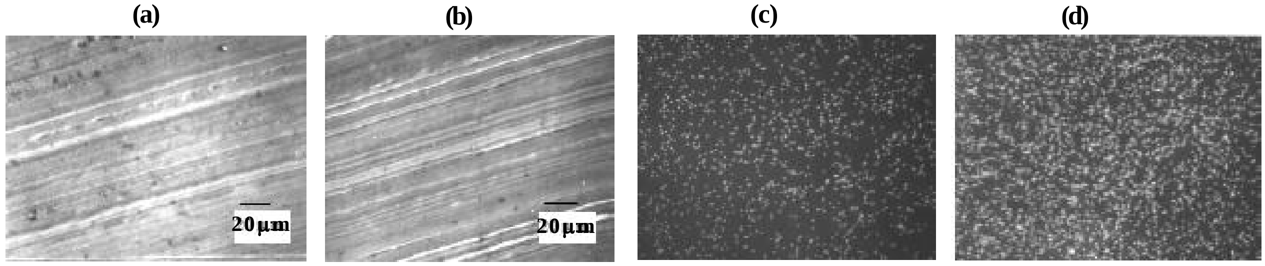
3.2 EPMA analyses

Figure 5a and 5b give scanning electron micrographs of the worn surfaces of steel ring sliding against the unirradiated PMIA and irradiated PMIA respectively. Figures 5c and 5d give the related carbon element distributes on the worn surface of ring. It can be seen that smoother surface of ring sliding against irradiated PMIA than that of being unirradiated is obtained. It is necessary to point out that there is more carbon element distributes on the worn surface of ring against irradiated PMIA. It is well known that the carbon has a good lubrication. It is just the smoother surface with more carbon element distribution on the surface of ring decrease the friction coefficient and wear rate of irradiated PMIA. In a word, it is just the transfer film that was responsible for the improved triblogical properties of the irradiated PMIA. That is, with the formation of the relative uniform and coherent transfer film, the subsequent sliding occurred between the surface of the irradiated PMIA block and the transfer film. Consequently, lowered wear rate and friction coefficient of PMIA are reached.

3.3 XPS and ESR analyses

In order to investigate the chemical changes during

(a) **(b)** **(c)** **(d)**



Ring against unirradiated PMIA **Ring against unirradiated PMIA** **Ring against irradiated PMIA** **Ring against irradiated PMIA**

Figure 5 : SEM of worn surface(a,b) of counterpart ring and carbon element distribution map(c,d)

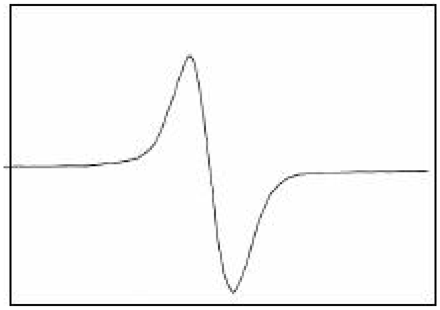
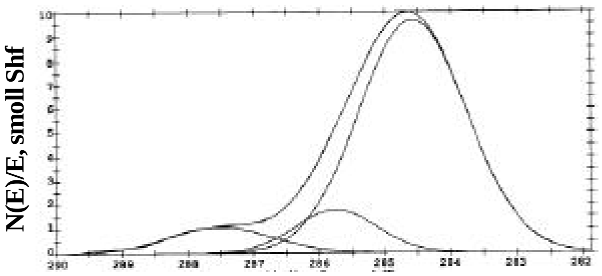
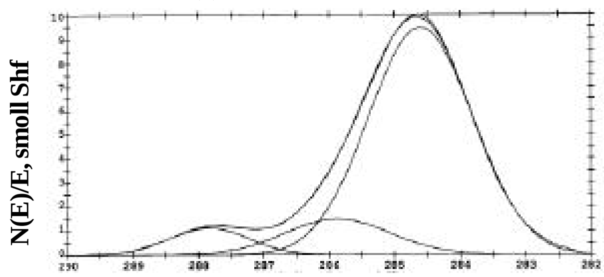


Figure 6: ESR spectra of PMIA after irradiation (R= 1×10^7 Gy)



Binding Energy (ev)

(a) unirradiated PMIA



Binding Energy (ev)

(a) irradiated PMIA

Figure 7 : C1s spectra of PMIA

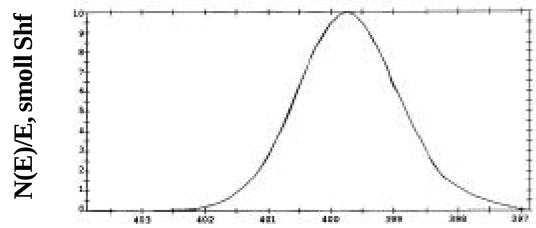
TABLE 1 : The Relative atomic concentration of the unirradiated and irradiated PMIA

	Relative atomic concentration %		
	C	N	O
Unirradiated PMIA %	81.7	8.8	9.5
Irradiated PMIA %	87.9	6.9	5.2

irradiating, the unirradiated and irradiated PMIA are analyzed by XPS and ESR.

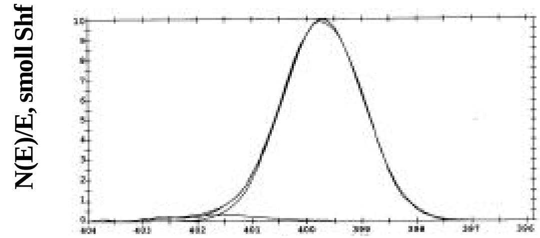
The results about XPS analysis of relative atomic concentration of the unirradiated and irradiated PMIA are listed in TABLE 1.

As shown in TABLE 1, the relative atomic concentration of carbon element on the surface of the PMIA increases after it being irradiated, while oxygen and nitrogen elements both decrease. This is the evidence that the transfer of carbon element on the surface of steel



Binding Energy (ev)

(a) unirradiated PMIA



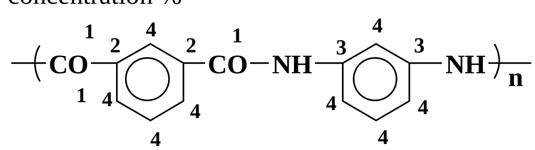
Binding Energy (ev)

(a) unirradiated PMIA

Figure 8 : N1s spectra of PMIA

TABLE 2 : Curve fitting results from C1s spectra of the unirradiated and irradiated PMIA

	Unirradiated PMIA	Irradiated PMIA	Functional group*
Binding energy eV	287.6	287.8	C1
Atomic concentration %	10.6	7.3	
Binding energy eV	285.8	285.9	C2 and C3
Atomic concentration %	16.8	12.6	
Binding energy eV	284.6	284.6	C4 and/or Graphitised carbon
Atomic concentration %	72.6	80.1	



ring for irradiated PMIA is much more than those for unirradiated PMIA, and thus greatly reducing the friction and wear of the irradiated PMIA. The test results also indicate that the chemical reaction occurred under the process of irradiation. Figure 6 shows the ESR spectra of PMIA after it being irradiated. The results of ESR analyses show that no signal can be detected for unirradiated PMIA, while a wide ESR signal is captured for irradiated PMIA. This is other evidence that the chemical reaction occurred during irradiating.

Figures 7a and 7b give the C1s spectra of the unirradiated and irradiated PMIA. The curve-fitting results are listed in TABLE 2. Functionality corresponding to binding energy of C1s was also listed in TABLE 2.

As seen from figure 7 and TABLE 2, the unirradiated and irradiated PMIA all give three binding energy peaks of C1s. By comparing the unirradiated and irradiated PMIA, it is noticed that the atomic concentration of carbon element with the binding energy around 284.6eV contribute to C4 or/and graphitized carbon increases and the binding energy around 285.8eV and 287.6eV decrease. Therefore, the reason of increase of carbon element concentration on the irradiated PMIA might be caused by the generation of graphitized carbon, that is, the chemical reaction consisting of carbonization which occurred on the surface of the PMIA during irradiation.

Figures 8a and 8b show the N1s spectra of the unirradiated and irradiated PMIA. It can be seen that the N1s spectra of unirradiated PMIA only gives a peak at a binding energy of 399.8eV. While the N1s spectra of irradiated PMIA gives a strong peaks at binding energy of 399.7eV and a weak peak at binding energy of 401.2eV. The analysis results illustrate cross-linking may be occurred owing to formation of N-N bond or other N bond. This is may be the other reason that electron beam irradiation decreases the wear rate of PMIA. Further study is still needed.

3. CONCLUSIONS

From the above, the following conclusion could be drawn:

1. Electron beam irradiation contributes to a reduction in the friction coefficient and wear rate of PMIA. The friction coefficient and wear rate decrease with increasing the irradiation dose.
2. The smoother surface with more carbon element distribution on the surface of ring could decrease the friction coefficient and wear rate of irradiated PMIA. There is a relatively uniform and coherent transfer film being formed on the ring surface. The transfer film contributed largely to the decreased friction coefficient and wear rate of the irradiated PMIA.
3. The chemical reaction consisting of carbonization and cross-linking may be occurred during the PMIA being irradiated.

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