# Effects of Homogeneous Electron Beam Irradiation Prior to Hot-Press on Adhesion Force of PTFE/PE

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## 1. INTRODUCTION

Composite polymers have been prepared for numerous biomedical applications by laminating them with heating and glue. However, these methods often degrade the adhesive strength and chemical properties, thereby affecting human health. Development of rapid adhesion without heating and glue would remedy this. To solve the problem, the development of rapid and safe adhesion method between Polytetrafluoroethylene (PTFE) and Polyethylene (PE) sheets has been expected [1]. PTFE constructed with main chains exhibits high wear resistance as well as high strength and fracture toughness. It can be applied to artificial blood vessels. PE, one of typical polymers, also constructed with main chains exhibits high wear resistance and high strength as well as transparency. It can be applied to artificial lunge. Homogeneous low energy electron beam irradiation (HLEBI) improves the mist resistance and wetting of inorganic materials, and increases polymer adhering to glass fibers raising impact strength in GFRP. Improvements are mainly caused by the irradiation with the formation of dangling bonds in polymers. Dangling bonds enhance surface energy, which is probably the mechanism for joining the different polymers. Thus, rapid and safe adhesion between different polymers by using HLEBI can be expected. In addition, treatment time of HLEBI-sterilization is only a few seconds, although sterilizing with ultraviolet light irradiation requires a few hours. Thus, HLEBI is expected to be an excellent method for not only gluing different polymers without volatilization, but also simultaneously sterilizing them for biomedical applications. The double-step treatment with hot-press after HLEBI is a useful method to activate the surface to enhance the adhesive force. Therefore, the effects of HLEBI prior to hot-press lamination on the adhesive force of PTFE/PE laminated sheets are introduced.

## 2. Experimental procedure

**2.1 Homogeneous irradiation of electron beam:** Composites sheets were constructed with PTFE (10 mm × 40 mm × 0.05 mm, Skived tape MSF-100, Chukoh Chemical Industries Co. Ltd., Japan) and PE (10 mm × 40 mm × 0.08 mm, High-star PF 100, Star plastic Industry Inc., Japan) [1]. Both stainless steel springs and 0.015 mm thick nylon6 supporting film, which loaded the compressive stress (80 kPa) at interface, reproducibly connected each polymer surface. Samples were set on the stainless spring and stainless steels or urethane sheets. They were compressed under 80 kPa by nylon6 film with 15 μm. When the compressive stress of more than 80 kPa was loaded for more than 1.0 h, a high reproducibility of adhesion force of peeling was obtained. Since no peeling force was observed at the interface between the nylon6 supporting film and the jig in the composites, it was easy to remove the supporting film after irradiation. The sample at the outer surface of the nylon film was homogeneously irradiated by an electron-curtain processor (Type CB175/15/180L, Energy Science Inc., Woburn, MA, Iwasaki Electric Group Co., Ltd., Tokyo). The samples were homogeneously irradiated with an electron beam through a titanium window attached to a 240 mm-diameter vacuum chamber. A tungsten filament in a vacuum was used to generate the electron beam with an electric voltage of 0.17 MeV and an irradiating current of 2.0 mA. To prevent oxidation, the samples were kept in a nitrogen atmosphere of 0.10 MPa with a residual oxygen concentration of less than 0.040%. The flow rate of the nitrogen gas was 1.5 L/s. To be twined around each polymer, PTFE/PE composite film lamination was subsequently performed by the uni-directional hot-press at 433K for 3 min under 5 MPa atmosphere after HLEBI.

**2.2 Adhesion test:** Composite samples were prepared for the T-peeling test to evaluate the influence of HLEBI on the adhesive force ($F_p$) of peeling resistance [1].The peeling force and its peeling distance were obtained by the peeling test (see Fig. 1), which was performed by using an micro load tensile tester (F-S Master-1K-2N, IMADA Co. Ltd., Japan) with a strain rate of 10mm/min. Tensile shear strength tests were performed by a micro load tensile tester (F-S Master-1K-2N, IMADA Co. Ltd., Japan) with a strain rate of 10 mm/min on the samples [2]. The shear stress ($\tau$)-strain ($\varepsilon$) curves were obtained where shear strength ($\tau_B$) is defined at the maximum shear stress.

## 3. Results and Discussion

Although the large adhesive load of peeling resistance has never been measured before irradiation, the laminated sheets constructed with PTFE and PE have been prepared with and without HLEBI. Optimal dose of HLEBI laminates the PTFE with the PE films, although additional dose of HLEBI decays the adhesion because of radiation damage. Figure 1 depicts the adhesive force of peeling resistance ($F_p$) peeling distance ($d_p$) curves of the PTFE and PE laminated sheet with and without HLEBI at mean $P_p$ of 0.50. Increasing the $d_p$ value raises the $F_p$ value of PTFE/PE with HLEBI, although adhesion cannot be observed of PTFE/PE without HLEBI. The long distance peeling gradually reduces the $F_p$ value of laminated sheet before fracture, as shown in Fig. 1. On the other hand, the shear strength of the PTFE and PE adhesive sheets with and without HLEBI was measure. Figure 2 depicts the shear stress ($\tau$) - strain ($\varepsilon$) curves of the PTFE and PE adhesion with and without HLEBI. The shear strength ($\tau_B$) is defined at the maximum shear stress. The shear strength of the sample with HLEBI is higher than that without HLEBI.

Since both polymers were perfectly constructed with main chains, PTFE polymers cannot be twined around PE polymers, resulting in adhesion free without HLEBI prior to hot-press (see Fig. 1 and 2). On the other hand, chemical bonds between terminated monomers of cross-linked PTFE and PE polymers with dangling bonds occur for PTFE/PE prior to hot-press. When HLEBI cut the chemical bonds, it generated active terminated atoms with dangling bonds at cross-linked PTFE and PE polymers. The constitutional formula of chemical bonds is $[PTFE]_n$-$[PE]_m$ and $[PE]_m$-$[PTFE]_n$ of cross-linking zone of PTFE and PE laminated composites sheet. When the cross-linking occurs at interface between PTFE and PE samples, chemical atomic bonds between active terminated carbon atoms in cross-linked PE and PTFE polymers probably attribute to the HLEBI-adhesion.

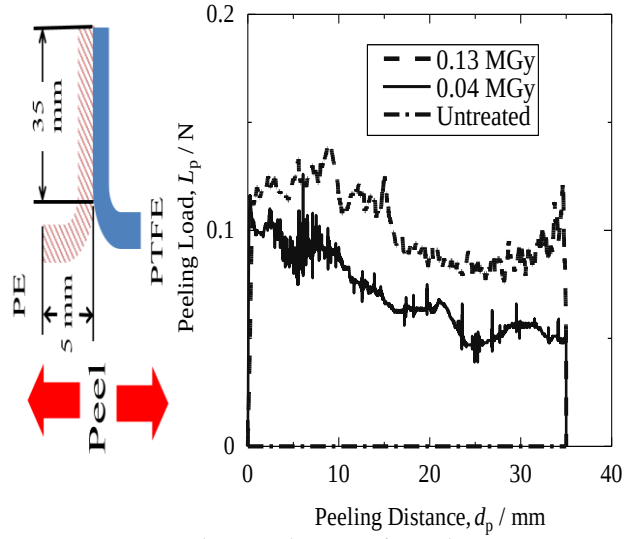


***Figure 1:*** *Schematic drawing of T-peeling test and adhesive force of peeling resistivity ($F_p$) distance ($d_p$) curves of PTFE and PE laminated sheet with and without HLEBI at 0.13and 0.04 MGy at mean $P_p$ of 0.50.*

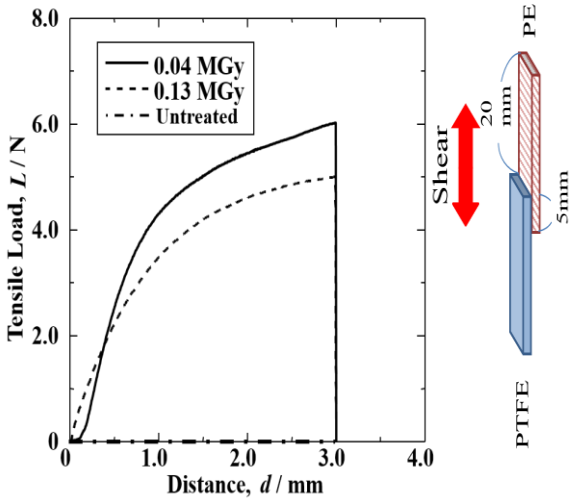


***Figure 2:*** *Schematic drawing of shearing test and tensile shear stress ($\tau$) strain ($\varepsilon$) curves at $P_s$ of PTFE and PE laminated sheet with and without HLEBI at 0.13 and 0.04 MGy at mean $P_s$ of 0.50.*

## References


[1] Masato Uyama, Masae Kanda and Yoshitake Nishi, Creation of Adhesive Force between Laminated Sheets of Polytetrafluoroethylene (PTFE) and Polyethylene (PE) by Homogeneous Low Energy Electron Beam Irradiation Prior to Hot-Press for Bio-Adaptable Application, Materials Transactions, Vol. 55, No. 3 (2014) pp. 566 to 571

[2] Chisato Kubo, Arata Yagi, Masae Kanda and Yoshitake Nishi, Effects of Electron Beam Irradiation on Shear Strength of Laminated Sheet of Bio-Adaptable Polydimethylsiloxane (PDMS) and Polytetrafluorethylene (PTFE) with Fracture Toghness, Materials Transactions, Vol.56, No.4 (2015) pp. 529 to533