EFFECT OF DOUBLE-SIDED IRRADIATION DOSE DIFFERENCE ON ILSS FOR POLYMER-MATRIX COMPOSITES FABRICATED BY IN-SITU CURING WITH LOW ENERGY E-BEAM

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ABSTRACT

The electron beam with energies lower than 150keV is applicable in in-situ curing of polymer-matrix composites but poor in penetration ability, leading to significantly attenuation of irradiation dose along the prepreg thickness. Experimental results show that laminates fabricated by prepregs single-sided irradiated are low in ILSS owing to incomplete post-thermal curing at 180 ℃ for 30 min. A double-sided irradiation method is proposed to conquer this difficulty. All prepregs in the laminate are double-side irradiated with different doses on both sides and then placed layer by layer while the surface with high irradiation dose is always adhered to the surface with low irradiation dose of another prepreg. Post thermal curing is conducted thereafter at 180 ℃ for 30 min. In Fig. 1, optimum dose difference was observed wherewith the best ILSS results were obtained under each T-dose (the sum of the irradiation dose on both sides of the prepreg). With a constant T-dose , ILSS results can be significantly improved by tuning the dose difference on both sides: with a constant total dose of 100 kGy, best ILSS appears when the prepregs are irradiated 65-35 kGy, 8.0 % higher than that of prepregs irradiated 80-20 kGy and 46.1 % higher than that of prepregs irradiated 95-5 kGy; same phenomenon is observed with a constant total irradiation dose of 115 and 130 kGy that by optimizing the dose difference between both sides of the prepregs, the ILSS of the laminates can be obviously improved. Differential scanning calorimetry testing results indicate that within a certain dose range, the degree of cure of the prepreg increases with the irradiation dose (Table 1), which means that the adhesive surfaces with different doses are different in curing degree and then uncured flexible resin content.

Irradiation dose(kGy)	5	20	35	50	65	80	95	110
Degree of cure (%)	3.6	12	15	16.8	22.8	51	57	60

Table I Degree of Cure vs. Irradiation Dose.

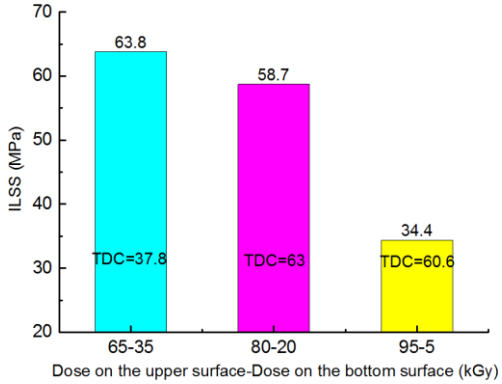

Figure 1 (a) ILSS and TDC results of laminates fabricated with prepregs irradiated under a T-dose of 100kGy;

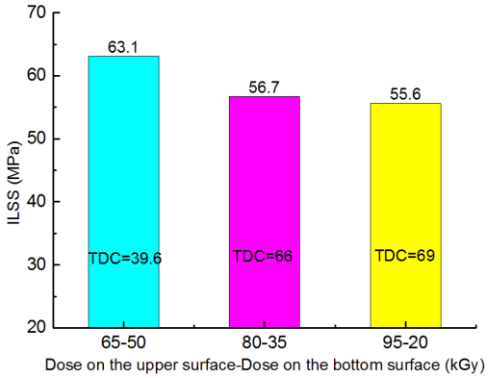

Figure 1 (b) ILSS and TDC results of laminates fabricated with prepregs irradiated under a T-dose of 115kGy;

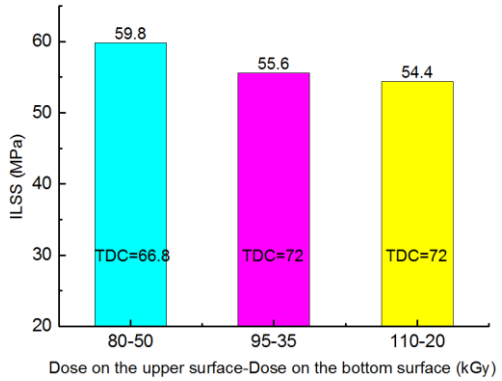

Figure 1 (c) ILSS and TDC results of laminates fabricated with prepregs irradiated under a T-dose of 130kGy.

Although the fact that dose difference between adjacent layers improved the adhere quality owing to the uncured resin flow and cross linking between adjacent layers, ILSS results show that larger dose difference weakened the improving effect. Analysis showed that under a fixed T-dose, dose difference increased means that U-dose increased and the B-dose decreased. If the dose difference surpassed the optimum value, the ILSS of the laminates decreased under the four T-doses. Two reasons contributed to the ILSS decline: As the dose on the upper surface of the prepreg increased, the E-Beam induced degree of cure increased, making it difficult for the uncured resin on the bottom surface of the laying prepreg to flow to the upper surface of the laid prepreg thereby weaken the physical bonding between adjacent prepregs. Table I shows the degree of cure of prepregs irradiated with different doses. Fig 1 shows the ILSS of laminates fabricated by prepregs irradiated with the same total dose but different

dose distributions on both sides. By calculating, the total degree of cure of the adhesive surfaces (abbreviated to TDC) was marked on each laminate. It can be noted in Fig 1 (a) that the best ILSS 63.8 MPa appears at samples irradiated 65-35 kGy, whose TDC are 37.8 %. However, an obvious ILSS decrease was observed when changing the dose distribution to 80-20 kGy with a TDC of 63 %. Similar result is obtained from Fig 1 (b) that with a high TDC of 69%, the ILSS is lower (59.6 MPa) compared with the laminate (ILSS of 63.1 MPa) with a TDC of 39.6%, which means that adequate uncured resin existing on the surface of the prepregs and layers adhere well. With the same total dose, higher TDC results to less uncured resins and adjacent layers hardly adhere to each other in the preforming process. Besides, it appears that with the same total dose, laminates that have similar TDC end up with similar ILSS, seen from laminate with 95-35 kGy and 110-20 kGy and also laminate with 95-20 kGy and 80-35 kGy. The finding suggests that the ILSS results confirm closely to the prediction that with the same total dose, the TDC plays an important role in laminate ILSS. Therefore, with the total dose fixed, reducing the TDC would be an efficient way to increase the ILSS of the laminate.

Besides, surfaces irradiated with a higher dose were cured faster compared to surfaces with a lower dose during the post-curing process. This can be explained by the fact that the cationic initiator in the prepreg decomposed after absorbing the irradiation energy and the curing proceeded during the irradiation. As the curing reaction went on, the resin medium got higher viscosity and the free cations' diffusion was restricted. As a consequence, the reaction rate was reduced by the "vitrification" effect that the free cations were trapped. Once the irradiated prepreg was heated, the trapped free cations were released and the curing reaction went on. After which, the prepreg got fast cured. In a certain dose range, the content of decomposed free cations in prepregs increased with irradiation dose. With a dose difference between the adjacent surfaces, the surface with a high dose would be completely cured first, after which the resin flow and chemical bonding between the adjacent layers became impossible. That is to say larger dose difference made the curing synchronism between the adjacent surfaces worse, which in return decreased the ILSS.

In conclusion, optimized dose difference in double-side irradiation method enhances the interlaminar shear strength of the laminate because of cross-layer resin flow and chemical bonding, but shows a weakening effect with excessive dose difference.