Mechanical Properties of CFRP/EVA Composites According to Lamination Ratio

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Abstract: Carbon fiber reinforced Plastics (CFRP) composite materials have excellent mechanical characteristics such as specific strength, specific stiffness, and corrosion resistance. However, the greatest disadvantage for the application of CFRP is its weakness to shock. Therefore, when CFRP is applied to members of structures that require safety of people such as airplanes and automobiles, they can receive impact damage by colliding with various types of materials such as small stones or fragments. In this study, tensile test was performed according to the test specifications and method specified in the ASTM standard at different lamination ratio and method of CFRP and EVA (Ethylene Vinyl Acetate) sheet which shows excellent characteristics in the flexibility of crack resistance to analyze the mechanical characteristics of the CFRP/EVA hybrid material and the existence of defects in the combination between CFRP and EVA.

Key-Words: : Carbon Fiber Reinforced Plastics, Ethylene Vinyl Acetate, Tensile test, Scanning Electron Microscope, Toughness, Elasticity Modulus

1 Introduction

The rapid evolution of a highly specialized industrial society of late has necessitated the development and application of new materials. Among the researches on new materials, studies on carbon composite materials have been actively pursued. Carbon fiber reinforced plastics (CFRP) composite material is more advantageous than the metal alloy as it can reduce the weight by 20~50%. It also exhibits excellent mechanical properties, such as specific strength, specific stiffness, and corrosion resistance.

The most important factors that determine the characteristics of the carbon fiber reinforced plastics are impact damage, failure, absorbed energy, fiber-based fracture since they are vulnerable to damage by foreign body impact. The damage due to the impact of the foreign body occurs easily due to the lamination characteristics of the CFRP. In addition, delamination occurs when a compressive load is applied to the area damaged by the foreign body impact. As local buckling occurs, the detachment becomes more severe through unstable propagation, resulting in total destruction [1-3]. Since the brittle carbon fiber reinforced plastics are damaged by the impact, their repair and maintenance are difficult. This limits the applications of CFRP for the structures involving lot of impacts.

The mechanical strength can be improved by polymer lamination during molding to enhance the low impact strength and flexibility of the brittle carbon-fiber composite materials. Hence, the mechanical strength was analyzed by varying the lamination method and the lamination ratios of CFRP and ethylene vinyl acetate(EVA). The mechanical strength was analyzed by a tensile test. The preparation of the specimens and the experiments were conducted according to ASTM D 5083 for the tensile test.

2 Test Methods

In this study, the tensile test was performed to analyze the mechanical properties of the hybrid laminated composites prepared according to the lamination method and the mixing ratio of the lightweight material, CFRP prepreg (3K), and Ethylene Vinyl Acetate polymer. The woven fabric carbon fiber prepreg, WSN-3K, from SK Chemical was used as the CFRP composite, while HI-EVA(HEV6F) from Hwaseung Industries Co., Ltd. was used as the EVA sheet.

Five types of specimens were prepared by varying the mixing ratio of CFRP and EVA. Type1 is referred to CFRP-24ply, Type2 is CFRP-20ply

EVA-2ply, Type3 is CFRP-16ply EVA-4ply, Type4 is CFRP-12ply EVA-6ply, and Type5 is CFRP-8ply EVA-8ply. Subsequently, the five specimens were produced by dividing CFRP based on EVA lamination method. The schematic diagrams of the five specimen types according to the mixing ratios and the lamination methods are shown in Table 1. The physical properties of Prepreg(3K), and EVA with VA content of 33%, procured from the different companies are presented in Table 2 and 3, respectively.

Table 1. Several Types of Laminating Method

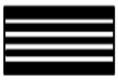
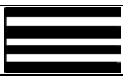
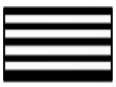
Specimen	Lamination method	
1		$CFRP_{24}$
2		$CFRP_7$+EVA_1+ $CFRP_6$+ EVA_1+ $CFRP_7$
3		$CFRP_3$+ EVA_1+ $CFRP_3$+ EVA_1+ $CFRP_4$+ EVA_1+ $CFRP_3$+EVA_1+ $CFRP_3$
4		$CFRP_3$+ EVA_2+ $CFRP_3$+ EVA_2+ $CFRP_3$+ EVA_2+ $CFRP_3$
5		$CFRP_2$+ EVA_2+ $CFRP_1$+ EVA_2+ $CFRP_2$+ EVA_2+ $CFRP_1$+EVA_2+ $CFRP_2$

Table 2 Composition of WSN 3K [4]

Thickness (mm)	Fiber Areal Wt ([illegible])	Resin Content (%)	Total Wt ([illegible])
0.227	240	41	336
Tensile Strength [illegible]	Tensile Modulus [illegible]	Fiber Density [illegible]	Resin Density [illegible]
450	[illegible]	1.77	1.2

Table 3 Composition of EVA [5]

VA content (%)	Specific gravity	Tensile strength [illegible]	Elongation (%)
33	0.96	85	800
Tensile modulus [illegible]	Hardness	Softening point (Vicat)℃	Thickness (mm)
900	60	Below 40	0.45

2.1 Mechanical Test

The dimensions of the specimens and the experimental methods of the tensile test were based on ASTM D 5083 [6] standard. The test was conducted using 3 specimens of each type. Fig. 1 show the dimensions of the specimen.

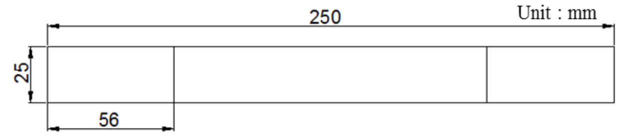
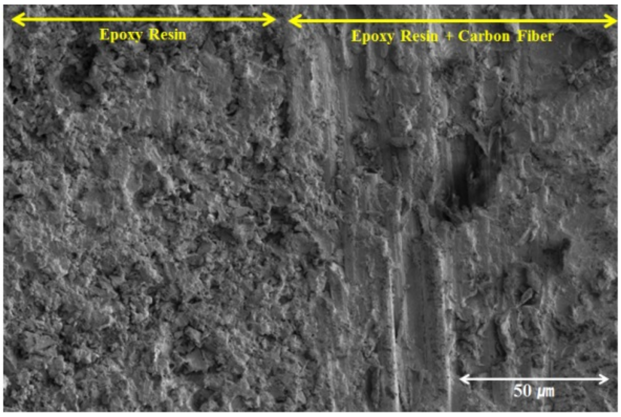


Fig. 1 Tensile Specimen

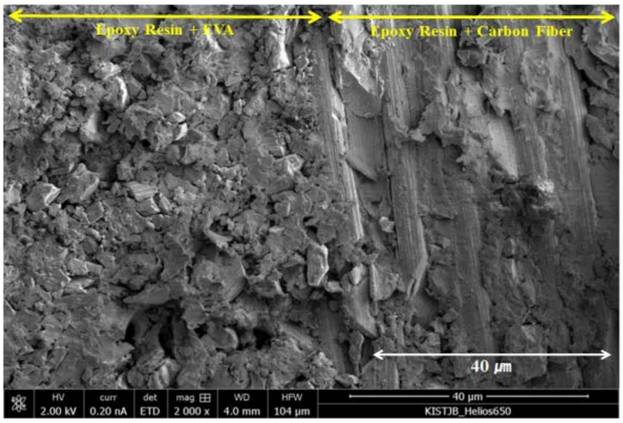
3 Results and Discussion

3.1 Scanning Electron Microscope

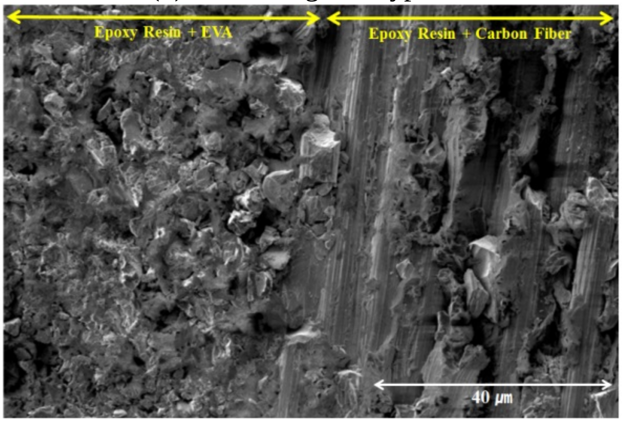
Before evaluating mechanical properties, five types of laminated CFRP and EVA sheets were tested for interfacial properties and defects such as pores using a scanning electron microscope (SEM). Figure 2(a) shows the laminated type of pure CFRP. It is seen that the section that holds much epoxy resin and the section that holds carbon fibers combined with epoxy resin are separated by the interface in the middle and that these two sections are closely combined without any defect. Figure 2(b)-Figure 2(e) show the SEM images of the types that have CFRP with increased lamination of EVA sheets. The section that holds epoxy resin combined with much EVA and the section that holds carbon fiber combined with epoxy resin are separated in the same way by the middle section. It is seen that epoxy resin and EVA are closely combined without any defect.



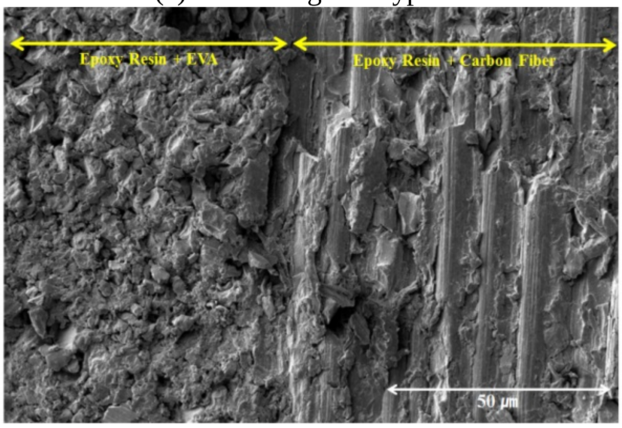
(a) SEM Image of Type 1



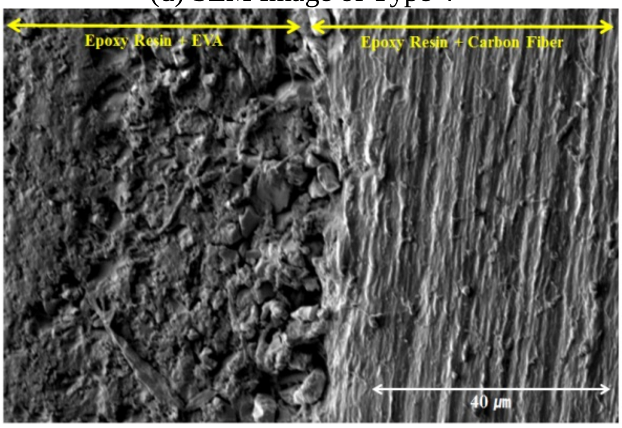
(b) SEM Image of Type 2



(c) SEM Image of Type 3



(d) SEM Image of Type 4



(e) SEM Image of Type5

Figure 2 SEM Image of Five Types

3.2 Results of Tensile Test

In the tensile test, the five specimen types prepared by varying the lamination method and the ratios of CFRP and EVA were tested 3 times to determine the tensile strength and the strain. In addition, the average values of the tensile strength and the strain from the different specimens were compared. The results of the tensile tests from the five specimen types are summarized in Fig. 3~7 and Table 4.

The result of the tensile test for Type 1 comprising 24ply pure CFRP laminations is shown in Figure 3. Type 1 exhibited the best result among the 5 Types with an ultimate tensile strength of 811.11 MPa, a tensile modulus of 39.55 GPa, and a strain at break value of approximately 2.26 %.

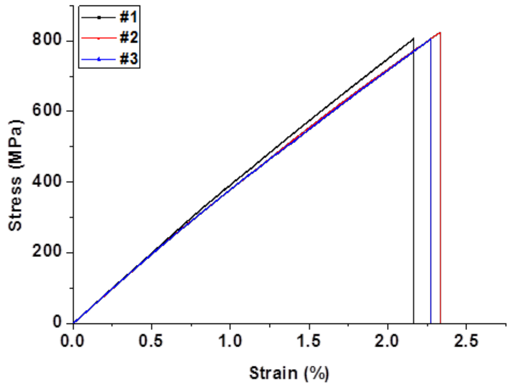


Fig. 3 Result of Type 1

Fig. 4 shows the result of the tensile test for Type 2 consisting of 2plyEVA laminations with each 1ply between CFRP 3K 20ply. The average ultimate tensile strength was 619.98 MPa, the tensile modulus was 28.13 GPa, and the strain at break was approximately 2.50%. The ultimate tensile strength of Type 2 decreased by about 20%, while the elastic modulus decreased by about 29% when compared to those of Type 1. However, the strain at break increased by about 114% compared to that of Type 1. This might be due to the presence of EVA lamination with high flexibility.

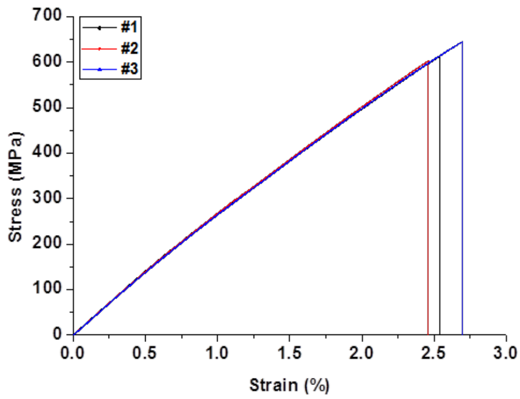


Fig. 4 Result of Type 2

Fig. 5 shows the result of the tensile test for type 3, in which 4ply of EVA was uniformly laminated individually between CFRP 3K 16ply. Unlike type 1 and type 2, the strain-stress curve of type 3 increased linearly and then the first and second ruptures were observed. Thus, the strain and the stress were confirmed from the first and the second results. The ultimate tensile strength at the first rupture was 327.81 MPa, while it was 315.05 MPa at the second total rupture. The strain at the first max. stress was approximately 1.82%, while the second strain at total rupture was about 3.15%. The tensile modulus of Type 3 was found to be 21.37 GPa. The tensile strength of Type 3 in the first rupture decreased by 59% compared to that of Type 1. Meanwhile, 60% reduction was observed in the second rupture. The strain reduction in the first rupture was about 20%, while it increased to 143% in the second rupture. The elastic modulus was reduced by about 45%. The reduction of the ultimate tensile strength by 5.5%, from 327.81 MPa in the first rupture to 312.05 MPa in the second rupture was observed for Type 3.

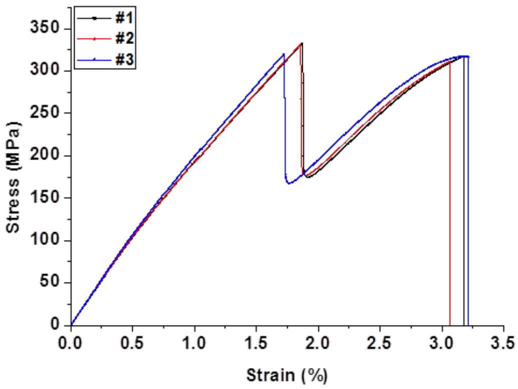


Fig. 5 Result of Type 3

Fig. 6 shows the result of the tensile test for Type 4, in which each 2ply of 6 ply EVA was uniformly laminated between CFRP 3K 12ply. Similar to Type 3, second rupture occurred in Type 4. The ultimate tensile strength at the first rupture was 308.34 MPa, while the tensile strength at the second total rupture was 263.37 MPa. The strain at the first Max. Stress was approximately 1.87%, while the second strain at total rupture was about 3.93 %. The tensile modulus of Type 4 was found to be 19.42 GPa. The tensile strength of Type 4 at the first rupture decreased by 60% when compared to that of Type 1. Meanwhile, 65% reduction was observed at the second rupture. The strain was decreased by 15% at the first rupture and increased to 174% at the second rupture. The elastic modulus was reduced by about 50%. For Type 4, the tensile strength at the second rupture was approximately 85% of that at the first rupture.

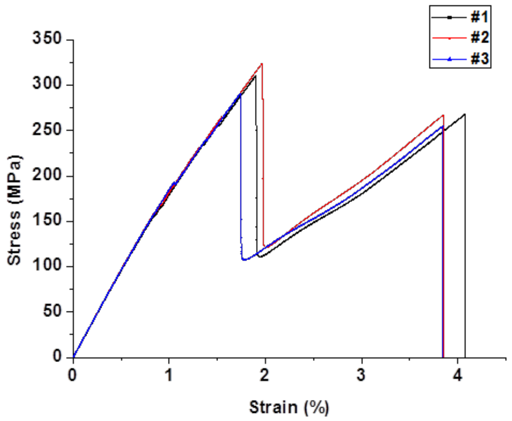


Fig. 6 Result of Type 4

Fig. 7 shows the result of the tensile test for Type 5, in which each 2ply of 8 ply EVA was uniformly laminated between CFRP 3K 8ply. The ultimate tensile strength at the first rupture was found to be 196.11 MPa, while the tensile strength at the second total rupture was found to be 103.29 MPa. The strain at the first Max. Stress was approximately 1.55%, while the second strain at total rupture was about 2.56 %. The tensile modulus of Type 5 was found to be 13.74 GPa. The tensile strength of Type 5 at the first rupture decreased by 75% when compared to that of Type 1. Meanwhile, 87% reduction in the tensile strength was observed at the second rupture. The strain reduction observed at the first rupture was about 39%, while 13% increment was observed at the second rupture. The elastic modulus decreased by about 65%. The second tensile strength of Type 5 decreased by 47% compared to the first tensile strength.

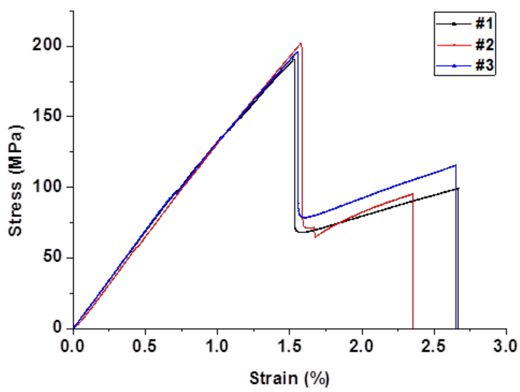


Fig. 7 Result of Type 5

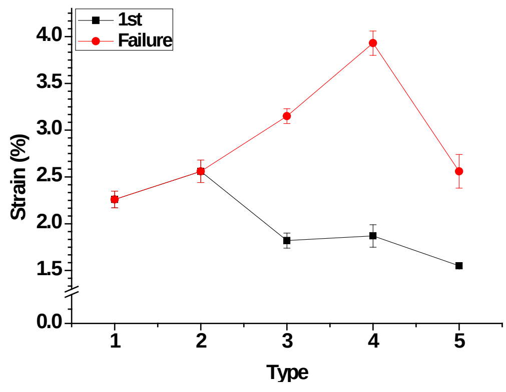
Table 4 Tensile Test Results of Five Types

Type	Area mm^2	Max. Load kN	Tensile Stress MPa	Strain %
1	46.04	28.03	811.11	2.26
2	118.45	44.05	619.98	2.56
3	113.64	22.34	327.81	1.82
4	104.58	19.23	308.34	1.87
5	101.61	11.95	196.11	1.55

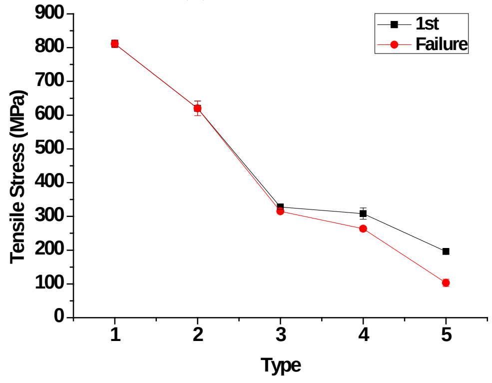
As the lamination ratios of CFRP and EVA in Type 1 and Type 2 were 10:0 and 9:1, respectively, the tensile test graphs showed similar trends, indicating the dominant role of CFRP in the materials. The tensile test graphs of the remaining 3 types showed two stages of rupture, unlike the stress-strain curve of the pure CFRP, indicating the mixed roles of CFRP and EVA. Although the modulus and the tensile strength decreased with increase in the number of EVA lamination, an increase in the elongation could be confirmed. Thus, they can be applied for components requiring low strength and high elongation.

Fig. 8(a) shows the comparison of the strain the five types of specimen. The strain increased from Type 1 comprising the pure CFRP lamination to Type 4 consisting of CFRP and EVA with a lamination ratio of 7:3. On the other hand, although Type 5 has the highest EVA lamination ratio, the strain was found to decrease to the level of Type 2, which consists of CFRP and EVA with lamination ratio of 9:1. In the composite of CFRP and EVA, the latter was confirmed to have a significant effect on the strain. However, it was difficult to observe an increase in the strain when the lamination ratios of EVA and CFRP were higher than 7:3.

Fig. 8(b) shows a graph comparing the tensile strengths of the 5 Types. Type 1 with the pure CFRP lamination exhibited the highest results. When the EVA lamination ratio in the composite of CFRP and EVA was increased, the tensile strength was weakened. The CFRP has a greater effect on the tensile strength compared to the EVA. Thus, it might be difficult to expect beneficial effects from the EVA lamination in terms of the tensile strength.



(a) Max. Strain



(b) Max. Stress

Fig. 8 Tensile Test Result of Five Types

Fig. 9 and Table 5 shows a graph comparing the chord modulus of elasticity and the modulus of toughness of the five lamination types. The modulus was found to decrease with the CFRP lamination ratio. It could be determined that the EVA lamination in the composite of CFRP and EVA did not have beneficial effects on the modulus. However, the Modulus of Toughness decreased from Type 1, and showed an increase at Type 4 which consists of CFRP and EVA with a lamination ratio of 7:3. In spite of the low tensile strength, Type 4 exhibited the highest elongation, indicating high fracture toughness.

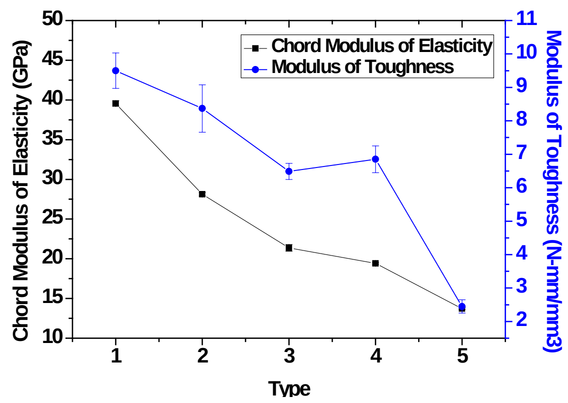


Fig. 9 Elasticity and Toughness Modulus Curve for Tensile Test

Table 5 Results of Modulus each Types

Type	Tensile Chord modulus GPa	Modulus of Toughness ▱ □□□□□f
1	39.55	9.50
2	28.13	8.37
3	21.37	6.49
4	19.42	6.85
5	13.74	2.45

4 Conclusion

In this study, five types of hybrid composite materials with different CFRP/EVA blend ratios and lamination methods were prepared by applying the EVA polymer on the carbon fiber composite material in order to compensate the brittleness of CFRP.

1. The interface between CFRP and EVA of each type was investigated. It was seen that CFRP and EVA were closely combined on the interface without any defect due to the excellent formability, kneadability, and adhesion of EVA.

2. Among the 5 Types, the highest tensile strength was observed for Type 1 which consisted of only CFRP lamination. Type 4 consisting of CFRP and EVA with lamination ratio of 7:3 exhibited the highest strain value. The numbers of the CFRP and the EVA laminations were proportional to the tensile strength and the strain value, respectively. Therefore, Type 4 may be used as a light weight material for applications requiring low tensile strength and high elongation.

3. When comparing the results of the Chord Modulus of Elasticity and the Modulus of Toughness for the 5 lamination types, it could be observed that the modulus value decreased with the CFRP lamination ratio. It could be confirmed that the EVA lamination in the composite of CFRP and EVA did not have beneficial effects on the Chord Modulus. However, the Modulus of Toughness decreased from Type 1, and showed an increase at Type 4 which consists of CFRP and EVA lamination ratio of 7:3. In spite of the low tensile strength, Type 4 exhibited the highest elongation, indicating high fracture toughness.

4. The comparison of the tensile strength of each specimen type confirmed that the highest tensile strength was exhibited by the specimen containing EVA and the tensile strength was higher when the dispersion level of EVA was lowered. When the EVA was laminated in trisection or quadrisection, the brittle CFRP material was divided by the EVA, thereby lowering the tensile strength. However, the rupture of specimen could be prevented in the first test, while it was observed in the second test. This phenomenon occurred when 2-3ply EVA was laminated in a row and the layers of CFRP and EVA had uniform thickness.

Acknowledgements

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