

MECHANICAL PROPERTIES OF UNIDIRECTIONAL ARRAYED CHOPPED STRANDS (UACS) WITH DIFFERENT SLIT PATTERNS

H. Li^{1*}, W.X. Wang², Y. Takao², and T. Matsubara²

¹Department of Aeronautics and Astronautics, Engineering School, Kyushu University,
Motooka Nishi-ku Fukuoka 819-0395, Japan

²Research Institute for Applied Mechanics, Kyushu University, Kasuga, Fukuoka 816-8580, Japan

* Corresponding author (lihang@riam.kyushu-u.ac.jp)

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1 Introduction

Flowability is quite significant to composite laminate since more and more application structures are composed of many complexly shaped components. Conventional CFRP composed of continuous fibers is limited in fabricating complex composite structures due to uneven mechanic properties. Short fiber reinforced polymer composites is a good solution for fabricating structural components of complex shape. For this reason, sheet molding compound (SMC) is widely used in fabrication of components in complex shape due to its excellent formability and relatively low cost [1]. However, SMC is composed of randomly distributed chopped strands and the strength of SMC is much lower compared to conventional laminates due to the fiber agglomeration and random orientation. Therefore, its application has been limited to non-structure due to safety regulation.

Recently, a new short fiber reinforced plastic called unidirectional arrayed chopped strands (UACS), which has higher strength and modulus than SMC, is developed [2]. UACS is made by introducing specific slits into prepreg. This procedure tends to making a new laminate material constructed with unidirectional arrayed discontinuous fiber strands impregnated with resin. UACS has superior flowability and can be shaped into complex structure. Previous research reveals that a rib structure made of UACS is excellently uniform and only a few resin-rich regions have been found. However, the strength of UACS developed in [2] is still lower due to the influence of stress concentration near the ends of slits, which results in that the strength of this kind of UACS is not high enough for fabricating main force bearing structure. Consequently, a series researches on the improvement of the strength without losing its

flowability of UACS have been conducted, such as interlaminar toughening method and continuous slit with small angle method [3, 4].

Taketa et al. [3] presented three interlaminar toughening methods, namely, using a toughen epoxy matrix, inserting a toughen polymer layer between UACS plies, and inserting toughen polymer layer locally around the ends of slits. Experiment results reveals that as the best interlaminar toughening method, inserting polymer layers only around the ends of slits can improve the strength of UACS laminate by more than 20%, but the reduction in the modulus is nearly 10%. Continuous slit with small angle method [4] is another way of improving strength of UACS laminate. Test results have revealed that tensile strength increase as long as the slit angle becomes smaller and the modulus of UACS laminate is very close to that of conventional laminate without slits.

Slit with small angle method has supplied a neoteric idea to the development of UACS. In this study, the effects of slit patterns on the mechanical properties of quasi-isotropic laminates of UACS with small angle slits are investigated to clarify the relationship between slit pattern and mechanical properties of UACS. Several slit patterns including continuous slits, staggered slits and bi-angular slits are introduced into unidirectional CFRP prepreg and tensile tests of UACS with various slit patterns are conducted. In order to compare mechanical properties of UACS with different slit patterns, strength and failure mode of UACS laminate with continuous slit or different patterns of discontinuous slit in the same small slit angle are investigated. In addition, in order to reveal the influence of slit length on the strength of UACS laminate with discontinuous slit patterns, tensile test of UACS with

different length staggered slits and bi-angular slits have been carried on simultaneously.

2 Experiment

2.1 Materials and fabrication

Prepreg used in this experiment is PYROFIL#350 (TR50S) (Mitsubishi Rayon). The longitudinal modulus is 142GPa, Poisson's ratio is 0.32 and longitudinal strength is 2950MPa. It has a V_f of 60% and the thickness of each ply is 0.2mm. First, the prepreg was cut into uniform sheets of 250mm×250mm. Slit patterns including continuous slits, staggered slits and bi-angular slits were introduced into prepreg sheets by hand cutting, as shown in Fig. 1. The slit angle θ for all slit patterns is chosen as 11.3° ($\arctan 5/25$) according to the report of [4]. Meanwhile, L_x was defined as the length of horizontal projection of slit in Fig.1 for UACS with staggered slits and bi-angular slits. In both Fig.1(b) and Fig.1(c), L_x is 5mm. UACS laminates with small slit angle can efficiently reduce the influence of stress concentration around the ends of the slits and suppress the delamination. The fiber length is 25mm in all cases.

Fig.2 is the schematic diagram of UACS laminate with staggered slit. It is shown that in all plies of UACS, the angle between slit direction and fiber direction is the same θ . The slit angle on the upper half of laminate is θ and on the lower half of laminate is $-\theta$.

The prepreg sheets with slits were stacked in a quasi-isotropic laminate of $[45/0/-45/90]_{2s}$ before curing. The laminate is heated up to the curing temperature of 127°C under 0.3MPa pressure for 120min. After that, the laminate have to be remained in the autoclave under pressure until the temperature cools down to room temperature by water cooling system.

The slit micrograph of first ply (45°) of UACS with bi-angular slit pattern after curing is shown in Fig.3. The slit width of staggered slit and bi-angular slit patterns are obviously larger than the slit width of continuous slit UACS laminate. In all cases, the fibers nearby the slit present a certain degree of movement and deflection. Slits appear not absolutely straight owing to the transformation of partial fiber bundle, while staggered slit pattern and bi-angular slit pattern appear obvious movement among these three slit patterns.

The specimens were cut into 250mm in length and 25mm in width with a 150mm gauge length. The slit cycle in the direction perpendicular to the fiber of UACS laminates with staggered slit and bi-angular slit is 10mm and there are at least two slit cycles in each of specimens. As benchmarks, conventional laminate without slits have also been fabricated. Tensile tests are conducted using a MTS 810 material-testing system and the crosshead speed is 0.5mm/min.

2.2 Results and discussion

Fig. 4 presents the tensile strength of conventional laminate and UACS laminates in different slit patterns. Test results reveal that the tensile strength of present UACS laminates with continuous slits, staggered slits and bi-angular slits are 57.8%, 63.5%, and 66.3% compared to that of conventional CFRP laminate without introducing slits into prepreg, respectively. UACS laminates with discontinuous slit appear higher mechanic property than that with continuous slit in the same slit angle. Compare to continuous slit UACS, staggered slit and bi-angular UACS laminate enhance tensile strength by 9.9% and 14.7%, respectively.

Table 1 shows test results of the Young's modulus and Poisson's ratio of various specimens. The modulus of UACS laminates have been decreased a little on account of the influence of slit. Among them, Young's modulus of UACS with bi-angular slit has not suffered from obviously decreasing. Additionally, Poisson's ratio in all cases of UACS laminates appears very small variations.

Various fracture modes have been observed by comparing fracture surfaces of different types of specimens (Fig.5). For conventional laminate without slit, fiber breakage occurs severely and fragments of the specimen scatter in all direction. The fractured specimen with continuous slits has some fiber bundle failure after serious matrix cracking and appears large area of delamination before final failure. UACS specimens with staggered slits and bi-angular slit contain a large number of broken fibers and the fractured section appears a zigzag shape due to the influence of slit patterns. Fracture surfaces of different types of specimens demonstrated that final strength is mainly resulted from more obvious fiber breakage. These results illustrate that different slit patterns show different

failure patterns, which results in the different tensile strength values.

Compared to continuous slit pattern, there is much more evident stress concentration exists in the ends of discontinuous slit pattern including staggered slit and bi-angular slit, which approach to bring about delamination obviously. On the other hand, shear stress between interlaced fiber strands can significantly improve the final strength of UACS. Therefore, discontinuous slit patterns are available for the improvement of the strength of UACS laminates compared to continuous slits.

2.3 Effects of different L_x on UACS strength

Previous research revealed that geometric parameters of chopped strands have significant influence on mechanical properties in random distribution discontinuous short fiber reinforced composite[5]. In order to investigate the influence of geometric parameter of chopped strands on present UACS, laminates of UACS with staggered slit pattern and bi-angular slit pattern of different L_x have been fabricated. Fig. 6 is the schematic of staggered slit pattern and bi-angular slit pattern prepreg. Four cases of $L_x=5, 7.5, 10, 12.5$ (mm) are investigated.

Fig. 7 shows the tensile strength of staggered slit pattern and bi-angular slit pattern UACS laminate with different L_x . Tensile strength displays no significant change when L_x distribute from 5mm to 12.5mm in both staggered slit pattern and bi-angular slit pattern UACS laminate and in all cases of L_x , bi-angular slit pattern UACS appear higher tensile strength. Among them, bi-angular slit pattern UACS with $L_x=5$ mm and 12.5 mm have acquired the highest tensile strength. Differing from random distribution discontinuous short fiber reinforced composite, L_x of chopped strands are not the conclusive factor to discontinuous slit pattern UACS.

Young's modulus and Poisson's ratio of staggered slit pattern and bi-angular slit pattern UACS laminate with different L_x are shown in Table 2. Bi-angular slit pattern UACS with L_x equals 5mm and 12.5 mm display the highest Young's modulus and basically with the same level of conventional laminate without slits. Other types of UACS have slight decrease. Compared to conventional laminate without slits, UACS laminate with staggered slit pattern and bi-angular slit pattern in different slit

length have not shown significant change in Poisson's ratio.

3 Conclusions

UACS has bright future for the development in fabricating complex shaped composite structure as a new short fiber reinforced laminate. This paper investigates several UACS with different slit patterns. In all cases, UACS with bi-angular slit displays highest tensile mechanic properties. Young's modulus values of present UACS laminates appear a little decline compare to conventional laminate while Poisson's ratio have no obvious variation.

Slit micrographs of UACS laminate surfaces have pointed that slits are not straight exactly due to partial fiber bundles nearby slits have transformed after curing. Transformation of fiber bundles exhibits more obviously in UACS laminate with discontinuous slit patterns than that with continuous slit pattern. The difference of fracture modes will directly influence the final strength. Compared to previous UACS laminate, UACS with staggered slit and bi-angular slit shows more significant fiber breakage without decreasing the stiffness. Different slit patterns show different failure patterns, which results in the reduction of tensile strength at different levels.

Tensile strength is about to display no significant dependence on the slit length both in staggered slit pattern and in bi-angular slit pattern UACS laminate. The geometric parameter of width of chopped strands is not the decisive factor UACS laminate.

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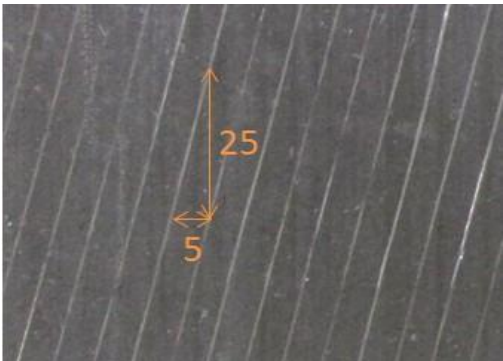
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Table1. Young’ modulus and Poisson’ ratio of conventional laminates and UACS with different slit patterns

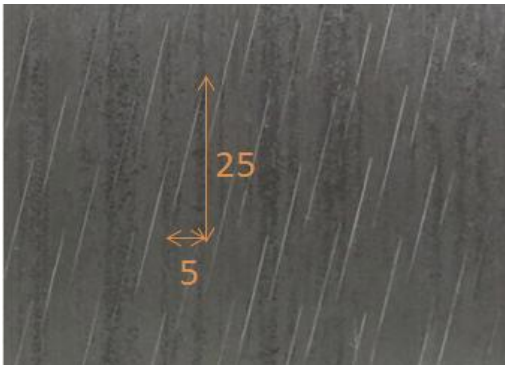
Specimen type	No slit	Continuous slit	Staggered slit	Bi-angular slit
Young’ modulus(MPa)	50.26	48.26	48.95	50.10
Poisson’ ratio	0.328	0.329	0.325	0.325

Table2. Young’s modulus and Poisson’s ratio of discontinuous slit UACS laminate with different L_x

Staggered slit pattern					
L_x (mm)	5	7.5	10	12.5	
Young’ modulus(MPa)	48.95	49.79	49.97	49.60	
Poisson’ ratio	0.325	0.322	0.321	0.303	
Bi-angular slit pattern					
L_x (mm)	5	7.5	10	12.5	
Young’ modulus(MPa)	50.10	49.40	49.36	50.46	
Poisson’ ratio	0.325	0.327	0.319	0.324	



(a) Continuous slit pattern



(b) Staggered slit pattern



(c) Bi-angular slit pattern

Fig.1. Schematic of prepreg with different slit patterns

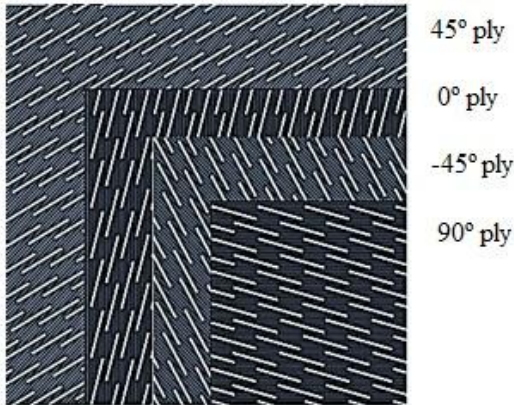


Fig.2. Schematic diagram of plies of UACS with staggered slit pattern

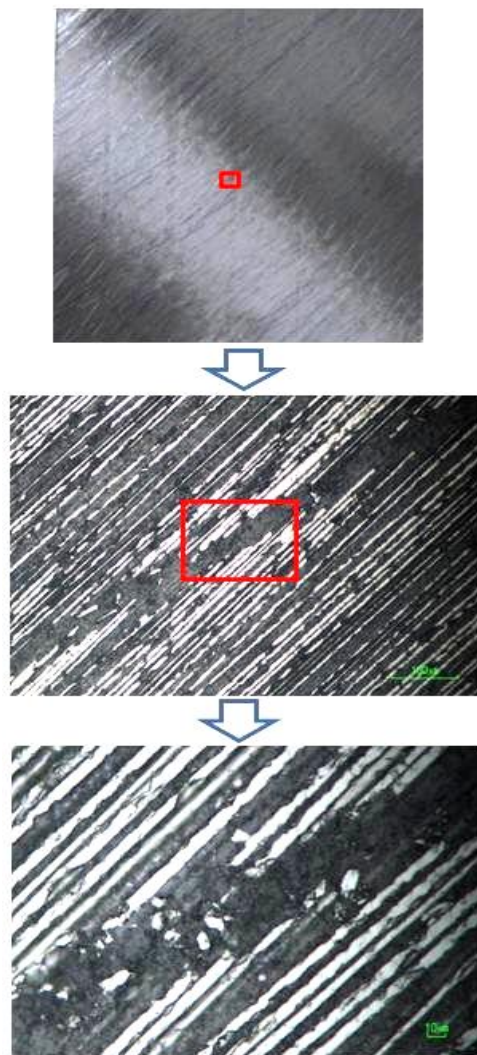


Fig.3 Slit micrograph of UACS with bi-angular slit pattern

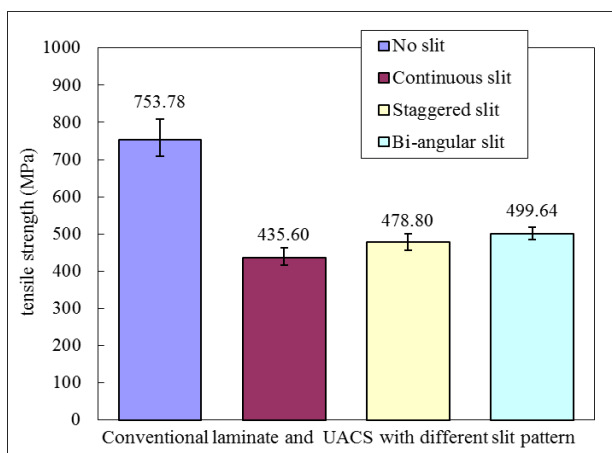


Fig.4 Tensile strength of conventional laminates and UACS with different slit patterns

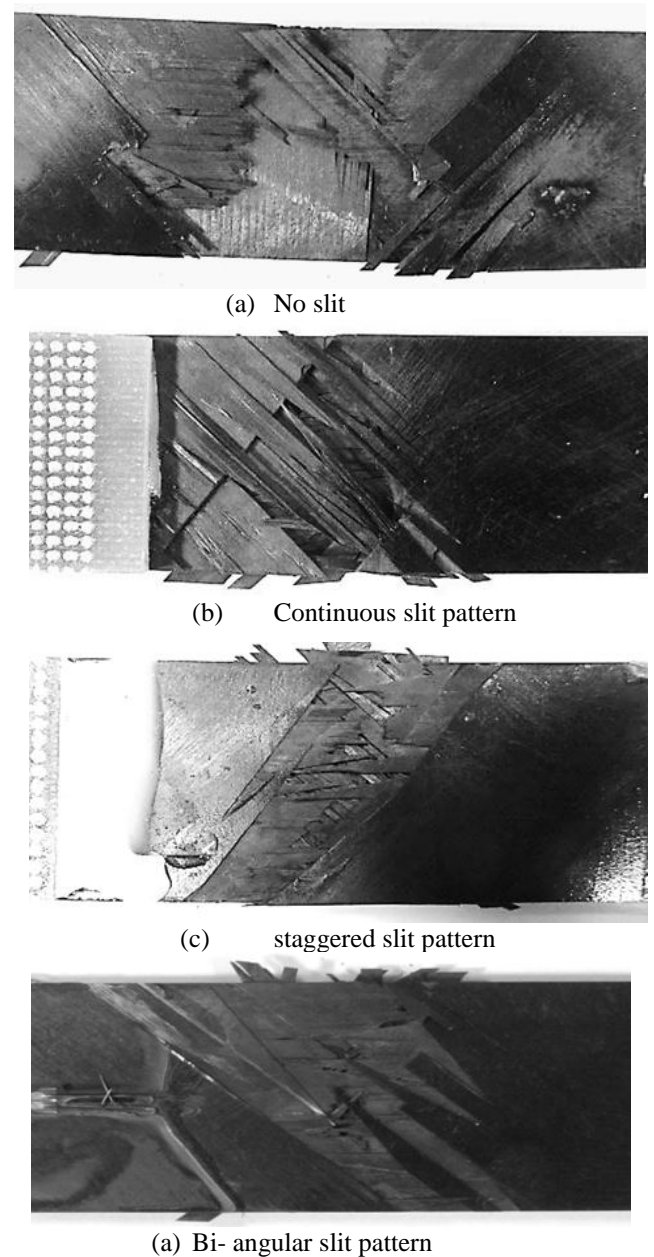
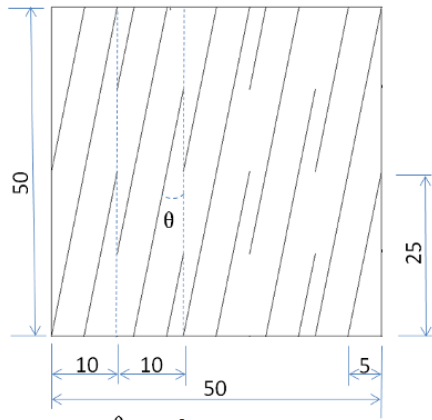
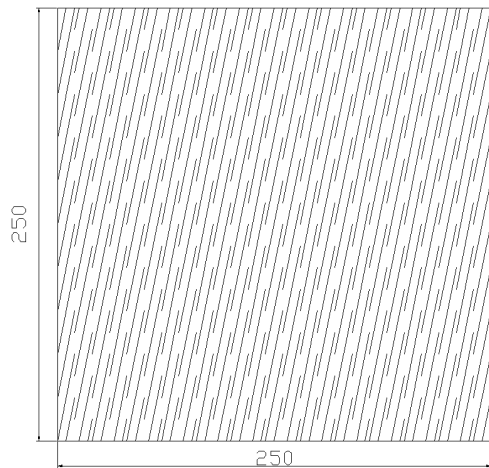
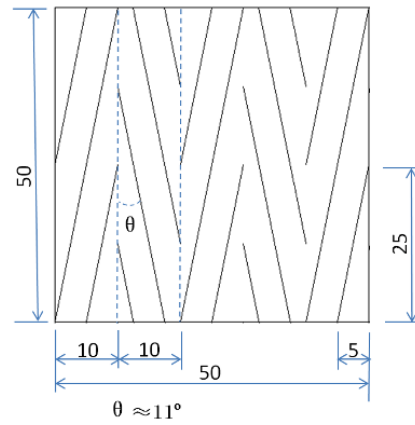
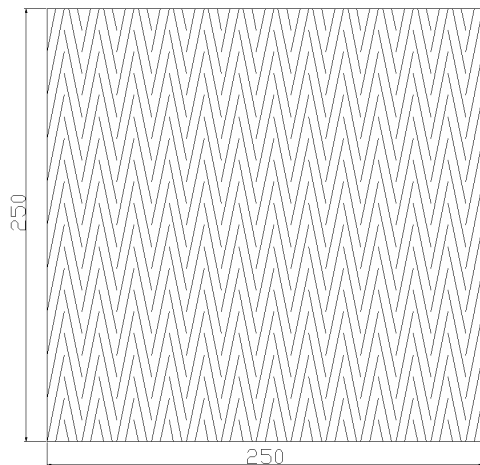


Fig. 5 Fracture surfaces of conventional laminate and UACS laminates with different slit patterns



(a) Staggered slit pattern



(b) Bi-angular slit pattern

Fig. 6 Schematic diagram of plies of UACS with discontinuous slit pattern ($L_x=10\text{mm}$)

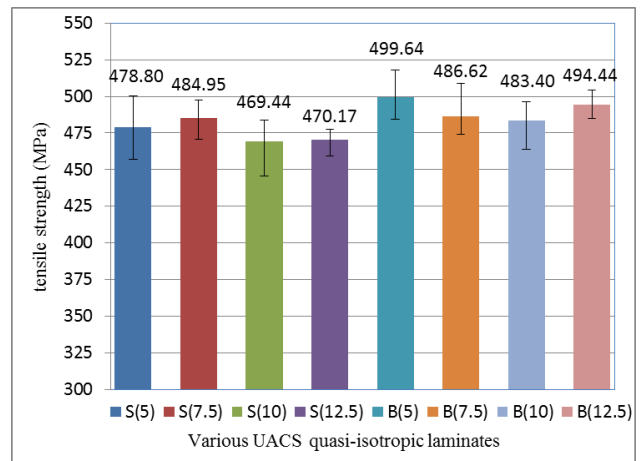


Fig. 7 Tensile strength of discontinuous slit UACS laminate with different L_x