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Angle Ply Laminates $(\pm 45°)_{2S}$ 에 있어서 매트릭스 점탄성의 기계적 행태와 Damage 발달에 대한 영향

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Effects of Matrix Viscoelasticity for the Mechanical Behavior and Damage Development in Angle Ply Laminates $(\pm 45°)_{2S}$

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요 약 : Angle ply laminates$(\pm 45°)_{2S}$ 의 인장실험에 있어서 **shear stress**에 의한 매트릭스 수지의 변형이 상기 구조의 기계적 행태를 좌우한다. 수지의 특성에 따른 변화를 살펴보기 위하여, brittle한 5208수지와 ductile한 914수지를 사용하여, 그 행태를 stress rate를 변화시켜가며 조사하였다. Stress rate에 의한 파괴시 최대 stress의 변화는 T300/5208의 경우 12%, T300/914의 경우는 10%였다. T300/914의 경우에 변형이 커짐에 따라 fiber rotation에 의한 영향이 나타남을 알 수 있었다. 상기구조에 대한 maximum failure criterion의 적용은 많은 문제점을 수반할 것으로 여겨진다.

Abstract : In $(\pm 45°)_{2S}$ angle-ply tensile specimens, the high shear stress acting on planes parallel to the fiber directions, the matrix characteristics controll the mechanical responses. To know these effects for the mechanical behavior and damage development, two different matrix systems, brittle matrix of 5208 and ductile matrix of 914, are investigated at several stress rates. The matrix nature changes the mechanical behavior and the damage development in these materials. The stress rates change the maximum stress at failure about 12% in T300/5208 and about 10% in T300/914. In T300/914 the fiber rotation displays an important role in large deformations. The maximum failure stress criterion is not very applicable for the systems with matrix controlled mechanical response.

INTRODUCTION

The complete mechanical behavior, including failure, of engineering materials are the most important properties that the designers have to know in order to design safe and efficient structure. Unfortunately, this property is very difficult to establish with fiber reinforced composites because of vast differences in properties between fiber and matrix. These differences may lead to fiber controlled and matrix controlled mechanical response along their stacking sequence.

The angle-ply laminate $(\pm 45^{\circ})_{2S}$ loaded in the axial direction shows mechanical response which is dominated by the matrix properties. However, like other plastics, epoxies are viscoelastic materials. In this case one of the important parameters that has to be considered is rate of loading. Since the mechanical response, damage accumulation and ultimate strength can be significantly influenced by strain or stress rate. Lifshitz[1] demonstrated that the strain rate changes the stress-strain reponse. And there are much deviations in this ultimate strength in the previous results.[2~9]

The damage development and the mechanical behaviour would be influenced by the resin characteristics and the experimental conditions. To know this effect we have chosen two types of matrix, brittle matrix narmco 5208 and ductile BSL 914. Two different stress rates are used to see the viscoelastic effect in the stress-strain reponse and for the ultimate strength. For damage development verification, acoustic emissions[10] and replication technics were applied.

EXPERIMENTS

The stacking sequence of $(\pm 45^{\circ})_{2S}$ structure is $+45^{\circ}/-45^{\circ}/+45^{\circ}/-45^{\circ}/-45^{\circ}/+45^{\circ}/-45^{\circ}/+45^{\circ}$. T300/5208 (Vf=0.67) was supplied by ONERA and T300/914 (Vf=0.63) was supplied by ETCA of France. Straight sided coupon specimens with 235 mm long and 25 mm wide were prepared and its gage length was 135 mm. The glass/epoxy tabs were used. The side edges of the specimens were ground with sand papers and polishing powders for microscopic observations. These specimens were stored in a conditionning cabinet with R. H. 65% at 23℃ before use.

Two stress rates are used for each resin system. For T300/5208, 0.022 MPa/sec($=\dot{S}_1$) and 22 MPa/sec($=\dot{S}_2$) are used and for T300/914, 0.024 ($=\dot{S}_3$), MPa/sec. and 24 MPa/sec($=\dot{S}_4$) are used. The test was done by hydraulic universal testing machine, Instron. The strain gages were used to detect the deformations of the specimens. The replicas of the specimen edge were taken in regular interval with acetone swollen acetate cellulose at the very low stress rate without arrest. For these two low stress rates ($\dot{S}_1$, $\dot{S}_3$), the endurance of one experience is about two hours.

Acoustic emissions are detected with the aid of a piezo-electric transducer (300KHz). Silicone grease is used for attachement of the transducer to the specimens. The transducer signal is pre-amplified 40 dB and filtered below 100 KHz. L'amplication is fixed at 70 dB with threshold of 0.5 V. The Dunegan 3000 is used for this purpose. The counting rate is registered on the recorder.

RESULTS AND DISCUSSION

The maximum stress failure criterion continues to be one of the most widely used for composite.[11] One apparent reason for the populatity of the maximum stress criterion is the ease with which it can be applied. But this is time independent and therefore is doubtful in applications for the viscoelastic matrix controlled mchanical behavior. Firstly this fact is verified in the brittle matrix system, T300/5208.

Two stress rates, 0.022-Mpa/sec. ($\dot{S}_1$) and 22 Mpa/sec. ($\dot{S}_2$) are used. The total loading times until the failure for $\dot{S}_1$ are about 2 hours and about 7 secondes for $\dot{S}_2$. The loading rate of $\dot{S}_2$ is 1000 times faster than that of $\dot{S}_1$. The stress-strain responses are shown in Fig. 1. The initial parts of two curvses are identical until the shear deformation of 0.2%. After this point these two curves start to diverge. Their differences continue to grow till the final rupture. For the same load level, the deformation with $\dot{S}_1$ is lower than that of $\dot{S}_2$. This facts demonstrates that there is additional deformation due to the creep for $\dot{S}_1$. From the results in Fig.1, one can see that the strains at the final rupture does not show the meaningful difference. But there are

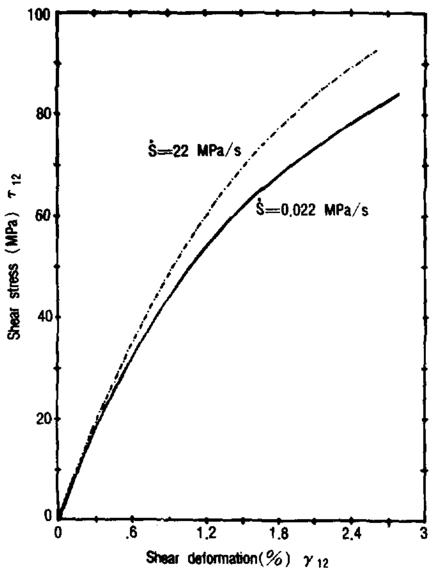

Fig. 1. Stress-deformation curve in monotonic tensile test (T300/5208).

Table 1. Failure Strength in Monotonic Tensile Test (T300/5208)

No.	$\dot{S}$(Mpa/sec.)	G_{12}(Gpa)	Sult(MPa)
1	0.022	–	165
2	0.022	–	168
3	0.022	–	169
4	0.022	5.42	168
5	0.022	5.99	166
6	0.022	6.10	151
7	0.022	6.97	161
8	22	6.90	190
9	22	6.25	180
10	22	5.71	191
11	22	5.58	183

Where $\dot{S}$ =stress rate
G_{12} =initial shear modulus
Sult =tensile strength

much difference in the maximum stress. The stress rate effect for the ultimate strength is summarized in Table 1. At average, the tensile strength with $\dot{S}_1$ is about 12% lower than that with $\dot{S}_2$. This fact shows in one aspect the impartance of stress rate effect and in other aspect the viscoelastic characteristics of matrix.

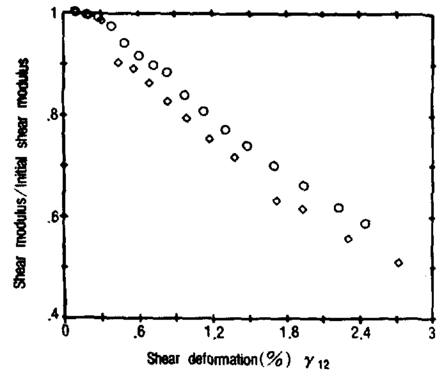

Fig. 2. Secant modulus variation in monotonic tensile test (T300/5208).

In various theoretical analysis[12~15] it has not been considered.

The stress-strain curve of T300/5208 shows an increasing nonlinearity in high load level. This nonlinearity is due to the damage development and the creep effect. It can be more quantitatively represented by the stiffness reduction. The variation of the secant shear modulus is presented in Fig. 2. There is no effect of stress rate until the 0.3% of shear deformation. After this point, the stiffness curves are quasi linear and their difference rest nearly same. The origin of this difference can be assumed as the following fact. After the stress values have grown to be equal to the shear strength value of the matrix, a conditional flow of the polymer matrix starts in the maximum stress concentration sites, and there is a redistribution of the stress field. In this brittle matrix resin, this redistribution of the stress requires a sufficient time.

The crack density variation with $\dot{S}_1$ is shown in Fig. 3. One can see that the total average crack density development is about quasi-linear such as the stiffness reduction. The acoustic emission results are presented in Fig.4. The acoustic emission activity is about continuous after the axial load of 90 MPa. These phenomena lead us to the following conclusion. In T300/5208 the nonlinearity of the stress-

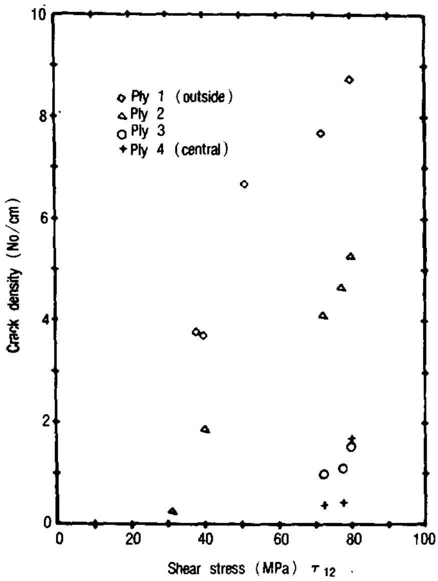

Fig. 3. Crack density variation in monotonic tensile test (T300/5208).

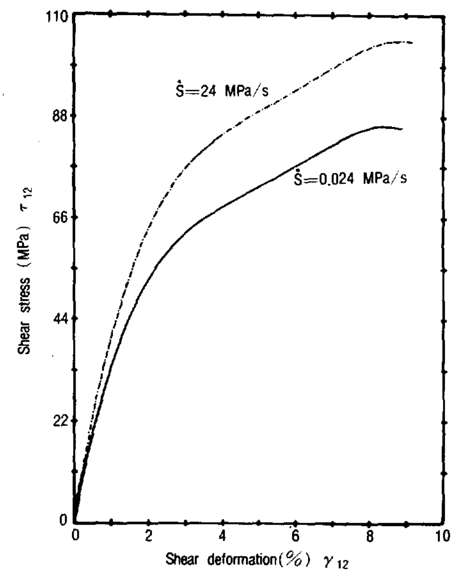

Fig. 5. Stress-deformation curve in monotonic tensile test (T300/914).

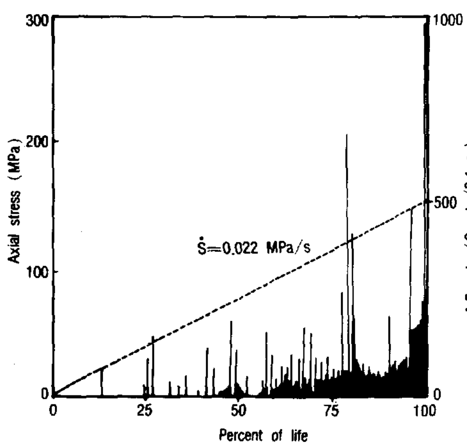

Fig. 4. Acoustic emission in monotonic tensile test (T300/5208).

strain is due to the viscoelasticity of the matrix and the matrix crackings.

Secondly the viscoelastic matrix controlled mechanical behavior is investigated in the ductile matrix system, T300/914. The stress-strain responses are shown in Fig.5. In this case two stress rates 0.024 MPa/sec. ($\dot{S}_3$) and 24 MPa/sec. ($\dot{S}_4$) are chosen. The loading time for $\dot{S}_3$ is about 2 hours and for $\dot{S}_4$ is about 7 secondes. In comparing with the results in Fig.1 one can see that the nonlinearity in this system is more pronounced. The curious phenomenon is the slight stiffening observed at the very high strain. Near final rupture this material shows unstability which has not been observed in T300/5208. The difference of the stress-strain curves in T300/914 is greater than that of T300/5208. It is due to the matrix ductility. This ductility and high fracture deformation permit the rotation of the reinforcing fibers.[8,16]

In T300/914 the stress rate changes also the tensile strength. The results are summarized in Table 2. The ductility, more pronounced visco-elasticity, of the matrix was assumed to show the greater influence in the tensile strength. But the different of the tensile strength is about the 10 %, which is slightly smaller than that of T300/5208. It shows again the fiber rotation effect for the mechanical behavior of T300/914.

The shear modulus variation with the deformation was investigated to further consider its

Table 2. Failure Strength in Monotonic Tensile Test (T300/914)

No.	$\dot{S}$(Mpa/sec.)	$G_{12}°$(Gpa)	Sult(MPa)
1	0.024	5.08	178
2	0.024	5.69	177
3	0.024	4.82	181
4	0.024	4.31	179
5	24	4.02	198
6	24	4.94	198
7	24	4.83	200
8	24	6.45	204

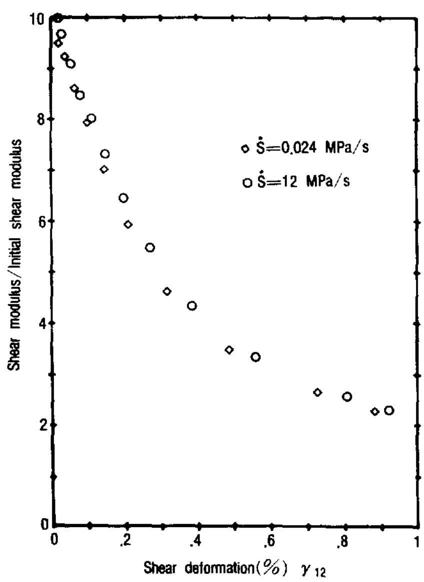

Fig. 6. Secant modulus variation in monotonic tensile test (T300/914).

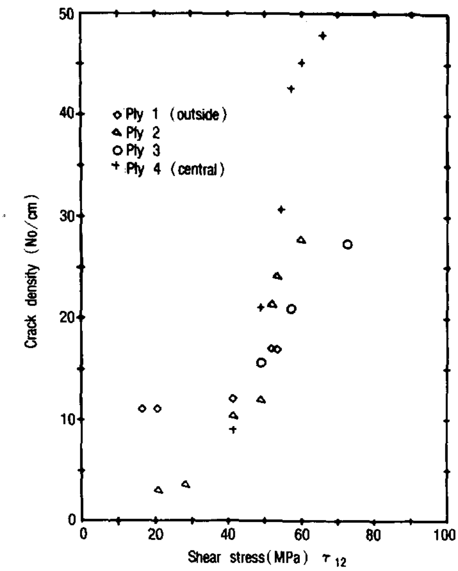

Fig. 7. Crack density variation in monotonic tensile test (T300/914).

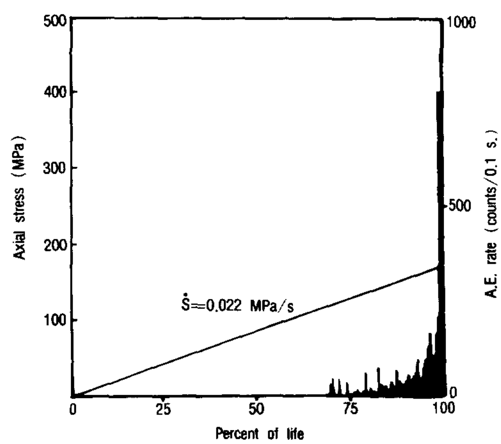

Fig. 8. Acoustic emission in monotonic tensile test (T300/914).

mechanical behavior. The results are shown in Fig.6. Curiously the two curves nearly coincide. It shows that the ductility of the matrix permits more strain and that this strain induces more fiber rotation. This fiber rotation compensates the additional stiffness reduction due to the creep effect of the matrix.

To know further the damage development effect for the mechanical behavior the replications of the free edge of the specimens and the acoustic emission technic are applied. The crack density variation is shown in Fig. 7. This matrix is attaked by the acetone which is used to soften the acetate cellulose films. After several replications the acetone damaged seriously edge surface. This fact reminds us the necessity for the mechanochemical degradation in polymer matrix. Acoustic emission results are presented in Fig. 8 to verify above observations.

One can see that there are few acoustic emissions for low stress levels. The active acoustic emissions start to be observed from the 70% of the tensile strength. The acoustic emissions are only very active near the final rupture. It shows that the ductility of the matrix does not induce the matrix cracking at the low stress levels. When there are crackings, their number is not great. The active acoustic emissions near the final rupture is attributed to the fiber rotation and induced interface and matrix damage. The characteristics of the matrix changes the mechanical behavior of this structure.

CONCLUSIONS

The viscoelastic characteristics of the matrix change the mechanical behavior and its damage development, The stress rates influence maximum tensile stress at the rupture. In ductile matrix system, the fiber reorientation with the great deformation should be considered for the analysis. The maximum stress failure criterion is not very successful for this systems, $(\pm 45^{\circ})_{2S}$, which the matrix controlls the mechanical responses.

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