건설에서의 복합재료 : 파괴강도에 대한 치수효과

김덕현*. 김두환**. 오상섭**. 임태호**

COMPOSITES IN CONSTRUCTION : Size/Scale Effects in Failure Theory

Duk-Hyun Kim*, Du-Hwan Kim**, Sang-Sub Oh** and Tae-Ho Lim**

ABSTRACT

Almost all buildings/infrastructures made of composite materials are fabricated without proper design. Unlike airplane or automobile parts, prototype test is impossible. One cannot destroy 10 story buildings or 100-meter long bridges. People try to build 100-story buildings or several thousand meter long bridges. In order to realize "composites in construction", the following subjects must be studied in detail, for his design: Concept optimization, Simple method of analysis, Folded plate theory, Size effects in failure, and Critical frequency. Unlike the design procedure with conventional materials, his design should include material design, selection of manufacturing methods, and quality control methods, in addition to the fabrication method.

Key Words : size/scale effects, failure analysis, natural frequency.

1. Introduction

Size effects influence the material properties of quasi-brittle materials (e.g. concrete and rocks). In case of any material, the larger the volume the greater is the probability of larger flaws. More recently, the mechanics of materials were studied at various scales ranging from atomic scale to microns to large macro or structural behavior. It has been known that linear elastic fracture mechanics (LEFM) applied to laboratory size quasi-brittle materials underestimates fracture toughness.

Classical LEFM technique may underestimate the true toughness of certain quasi-brittle materials such as geomaterials by as much as an order of magnitude, especially for those with large scale heterogeneities, and using typical laboratory size specimens.

The question remains as to how laboratory tests could produce a toughness value closer to the in-situ true fracture toughness. We can either build a huge laboratory and test huge specimens: or we can abandon the concept of LEFM.

* Korea Composites
** Seoul National University of Technology

In composite structures reasonable theory of size/scale effects on the failure mechanism is still lacking. Reduction in fiber strength is experienced when the size of the structures fiber bundle increases.

An efficient method to characterize the relationship between strength distribution and size in composites is not complete yet. It has been known that large composites are generally weaker than small composites. There could be several reasons for such phenomenon. One of the most important causes is the scale effect in brittle reinforcing fibers. Brittle fibers are generally strong and uniform in diameter but have the possibility of containing flaws with different strength. A longer fiber may have more of such possibility than a short fiber.

2.The Rate of Decrease of Fiber Strength

Based on the experience of a composite manufacturing specialist, the rate of decrease of tensile strength of glass fibers used for filament wound tubes as the mass of fibers increases is as shown in Fig. 1.From the test result reported by Crasto and Kim [2], an approximate relation between 90° tensile strength reduction rate, Y, and the volume (proportional to the mass), for the unidirectional composites of AS4/3501-6, can be expressed as Fig.2. Unless there is the test result for the same matrix to be used, this equation for epoxy can be used to estimate the rate of the decrease of 90° *tensile strength.*

For each of the constituent materials, both fibers and matrices, the rates of decrease of strengths, X, X', Y, Y', and S, as the mass increases, must be obtained in the future. The manufacturing method and other possible factors also have to be considered.

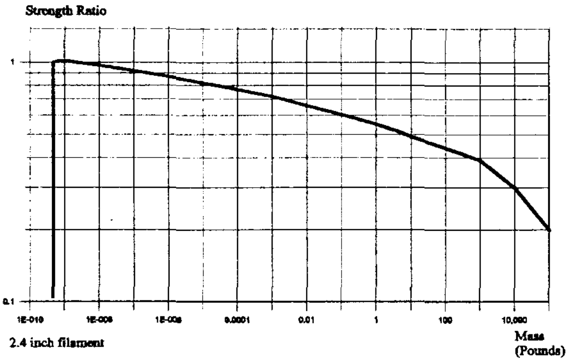

Fig. 1 Rate of decrease of glass fiber tensile strength based on mass

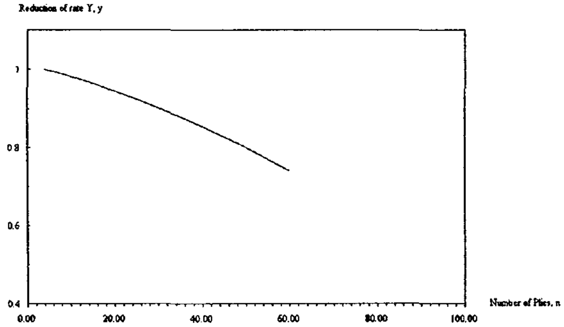

Fig. 2 Tensile strength reduction rate of epoxy matrix based on mass

Any strength theory can be used with "reduced" strength as given above.

3. Comments on Strength Criteria

Both the maximum stress and maximum strain criteria assume no interactions among the possible five modes. Since the Poisson's ratio is not zero, there is always coupling between the normal components, and this leads to disagreement between these two criteria regarding the magnitude of the load and the mode for the failure.

The result of two criteria agrees only on the shear plane and along the four lines of constant failures due to uniaxial stresses. Just as the deformation of a body is always coupled by the nonzero Poisson's ratio, failure of a body is also coupled. Because the micromechanics of failure is highly coupled, we should not extend the simple failure modes based on maximum stress or maximum strain components to fiber, matrix, and interfacial failure modes.

1) From the maximum stress theory,

$$\sigma = \frac{X}{\cos^2\theta},$$

$$\sigma = \frac{Y}{\sin^2\theta}, \qquad \text{or}$$

$$\sigma = \frac{S}{\sin\theta\cos\theta}. \tag{1}$$

2) From the maximum strain theory,

$$\sigma = \frac{X}{\cos^2\theta - \nu_{12}\sin^2\theta},$$

$$\sigma = \frac{Y}{\sin^2\theta - \nu_{21}\cos^2\theta}, \quad \text{or}$$

$$\sigma = \frac{S}{\sin\theta\cos\theta}. \tag{2}$$

The result of two criteria agrees only on the shear plane and along the four lines of constant failures due to uniaxial stresses. Just as the deformation of a body is always coupled by the nonzero Poisson's ratio, failure of a body is also coupled. Because the micromechanics of failure is highly coupled, we should not extend the *simple failure modes based on maximum stress or* maximum strain components to fiber, matrix, and Interfacial failure modes.

4. Recommended Strength-Failure Analysis Procedure

With available information at present, the following strength-failure analysis procedure is recommended for glass fiber reinforced composites with epoxy matrix.

1. Obtain reduced X by Fig. 1.
2. Assume the scale effect is the same for both tension and compression. (This assumption may be corrected when detailed research result is available).
3. Obtain Y=Y(Coupon) x by Fig. 2.
4. Obtain Y'=Y'(Coupon) x by Fig. 2.

(Again, this may be corrected when accurate study result is available).

5. Assume S=S (Coupon).
6. Use Tsai-Wu failure criteria for stress space. Since the rates of decrease of the moduii are not known, use of the criteria for strain space is complicated.

5. Conclusion

For composite structures, reasonable theory of size/scale effects on the failure mechanism is not complete yet. Based on the experience of a composite manufacturing specialist, an equation expressing the rate of decrease of the tensile strength of glass fibers used for filament wound tubes is derived. Similar equation for 90° tensile strength of epoxy is obtained by the result of Crasto and Kim study. From these equations, one can estimate the rate of the tensile strength reduction due to increased size.

Recommended strength-failure analysis procedure, using these reduced tensile strength, is presented. Numerical study is made for these cases.

A) Strength reduction is made for both tensile and compression.

B) Reduction is made for tensile strength only.

C) No strength reduction is made.

The Tsai-Wu failure criterion for stress space is used since the rates of decrease of moduli are not known, if strain space is used. Both modified Hill's criterion (Fxy*=0) and generalized. Non Mises criterion (Fxy*= -1/2) are considered, for each case. The result shows that the case C) is always on unsafe side. That is, strength reduction is necessary for safe design of a structure. It can be concluded that both cases, A) and B), have to be studied for each combination of stresses. Two criteria should be used for each case. The strength ratio R, is a function of five factors : two cases of test coupon strength, A) and B), two failure criteria, Fxy*=0 and Fxy*= -1/2, and the status of applied stresses. The proposed procedure in this paper is based on glass fibers and epoxy matrix. This procedure can be used for composites with other constituent materials.

The strength obtained by the above steps may not be "exact" for the composite with a given "increased" size. However, the result should not be too far off. Something is always better than nothing. Using strength theory with reduced tensile strength value alone is far better than designing the structure with the coupon test values. The recommended procedure will result in safer structures and will accelerate further studies for the exact failure-strength theories for composite structures with different scales-sizes, and with various constituent materials. When materials other than glass fibers and epoxy are used, only Fig. 1 and Fig. 2 may be modified.

When detailed information on size effect is not known, one can use Fig. 1 and Fig. 2 given above.

REFERENCES

1) Duk-Hyun Kim, " The Importance of Concept Optimization in Design and Scale/Size Effects in the Failure of Composite Structures", Proc. 3rd International Symposium on Textile Composites in Building Construction, 1996, PP327-339.

2) A.S. Crasto and R.Y. Kim, "The Influence of Specimum Volume on Matrix Dominated Composite Strength", Proc. 38th SAMPE Symposium, 1993.

3) Duk-Hyun Kim, et al, "The Importance of Size/Scale Effects in the Failure of Composite Structures", Proc. 4th Japan International SAMPE Symposium, 1995,pp837~843.

4) Duk-Hyun Kim, "Composite Materials for Repair and Rehabilitation of Buildings and Infrastructures", Plenary Lecture, Proc. of 3rd International Symposium of TCIBC, 1996, pp15~29.