Journal of Engineering and Technology Vol. 4 No. 2, 2005 *ISSN 1684-4114*

ENERGY ABSORPTION BEHAVIOUR OF SHORT FIBRE COMPOSITE

A.K.M. Masud* A.K.M. Kais Bin Zaman*

ABSTRACT

Plastic composite material is one of the most suitable design materials in aircraft industries, due to its high specific strength. As unidirectional composites exhibit anisotropy, much effort has been drawn by the researchers to make isotropic plastic composite materials. One of their efforts is to make randomly oriented short fibre composites. Unfortunately, theoretical interpretation is highly case dependent. Energy absorption is an important property for structural design element especially for aircraft industries. Thus in this research a generalized model is developed to calculate energy absorption by the randomly oriented short fibre composite. Here, classical single- fibre pull-out process is considered for calculating the energy of the randomly oriented short fibre composite. Concept of single- fibre pull-out test is incorporated to the model, such that the fibres intersecting a fracture plane (where the fracture of composite occurs) would pull out or fracture like single- fibre pull-out test. The energy contribution of each fibre in the fracture plane is calculated for different embedded length and orientation to estimate the total fracture energy. According to the model, it is found that the energy absorption depends upon the intrinsic properties of the fibre and matrix, volume fraction, critical embedded length of the fibre (the critical embedded length is defined as the length at which the load required to pull out the fibre becomes almost equal to the fracturing load of the fibre, during the single-fibre pull-out test.), length of the short fibre and orientation of the fibres in matrix. The significance of the explicit formula for the energy absorption is that it can be used to estimate the amount of fibres and fibre length required to absorb certain amount of energy for composite to be used in structural design element before the material is made.

1. INTRODUCTION

Plastic composites have been in use for long due to their lightweight, high specific strength and improved performance under stringent physical, chemical and environmental conditions. From a technological point of view, short fibre composites are well established because they are easy to fabricate.

* *Department. of Industrial and Production Engineering, Bangladesh University of Engineering and Technology ,Dhaka – 1000, Bangladesh*

Prediction of the mechanical properties of the composites is a complex problem, due to many factors that play a considerable role in the properties of the composites. The energy absorbed by the composite depends upon the intrinsic properties of the fibre and the matrix and their interface. Fibre and matrix work together to develop internal energy to resist the external applied load. The load applied to the composite is transmitted along fibre and matrix as well as their interface. The classical single- fibre pull out test is a common means to determine the interfacial properties of fibre and matrix. Here, the critical embedded length is defined as the length at which the load required to pull out the fibre becomes almost equal to the fracturing load of the fibre, during the single- fibre pull-out test. This critical embedded length can easily be determined with the help of single fibre pull-out test. During fracture of short fibre composite, it can be assumed that some fibres are pulled out and some would fracture at the fracture plane of the composite. Whether a fibre in the fracture plane would pull out or fracture that depends on the critical embedded length. In this model contribution of energy by each fibre and matrix itself is calculated to estimate the total fracture energy of the composite.

2. MODELING OF ENERGY ABSORPTION

2.1. Single-fibre pull-out process

Single- fibre pull-out test is a very easy and common process of estimating interfacial properties of fibre and matrix. Many researchers have found that load required to pull out from embeddedment increases with the embedded length until the fibre fracture load attains. Although this increment has little deviation from linearity, it is assumed to be linear for simplicity. Load response for single-fibre pull-out test is shown in Figure 1[1].

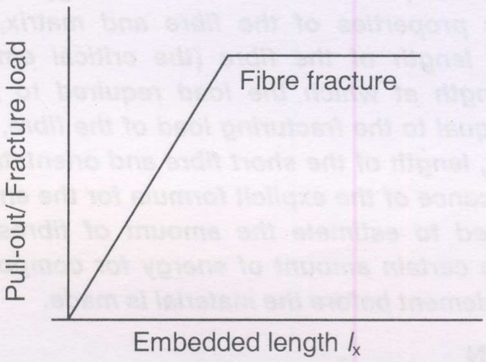

Figure. 1 Representation of load required to pull-out and fracture of fibre during pull out process.

2.2. Mathematical modeling of energy absorption

It is considered for randomly oriented short fibre composite that applied force is distributed three dimensionally in the matrix and the fibres. To resist the applied external energy, there would develop an internal energy inside the body of the composite. Both the matrix and the fibre would contribute in this development of internal energy. The sum of energy absorption by matrix and the fibre would be the total energy absorbed by the composite during fracture process. It is considered that ultimate failure would occur in an imaginary plane *S* that is perpendicular to the axis of applied load.

The equation of the energy absorption by the composite W_c is assumed to be calculated by the following equation: [1, 2]

$$W_c = \sum_{i=1}^{N_f} W_i^* + \frac{(1-V_f)}{(1+AV_f)} W_m$$

$$= N_f \; \overline{W_i^*} + \frac{(1-V_f)}{(1+AV_f)} W_m \qquad (1)$$

where, V_f is the fibre volume fraction and W_m is the fracture energy of the matrix. N_f is the number of the fibres per unit area those intersect plane *S*, W_i^* is the energy contributed by the individual fibre on the fracture plane, $\overline{W_i^*}$ is the expectation of the energy W_i^*, *A* is the shape parameter [2] which is related to the packing condition of the fibre. First part of Eq. (2.1) is the contribution of fibre and the second part defines the contribution of matrix in the composite.

From statistical metallography [3], it is found that in case of randomly oriented short fibre composite, the number of fibre intersecting any plane in a unit volume is:

$N_f = (N_v \, l_f) / 2$

where, N_v and l_f are the number and length of the short fibres in a unit volume, respectively.

$$N_f = \frac{N_v l_f}{2} = \frac{V_f}{2A_f} \qquad (2)$$

where, A_f is the cross-sectional area of the short fibre.

2.3. Estimation of individual energy contribution by each fibre w_i^*

Figure 2 shows a typical situation of forces that would occur in the composite during loading. It is assumed that a fibre AOB would intersect an imaginary plane *S* along which the composite is expected to fracture. *F* is the force that is developed along the axis of the fibre during the loading process.

Here, ϕ is the angle between loading direction and fibre axis. When plane S intersects the fibre at point O, it has two parts. The shorter length l_x would act as embedded length and this will determine whether the fibre would be fractured or pulled out. Maximum length of l_x would be half of the total length of the fibre [4].

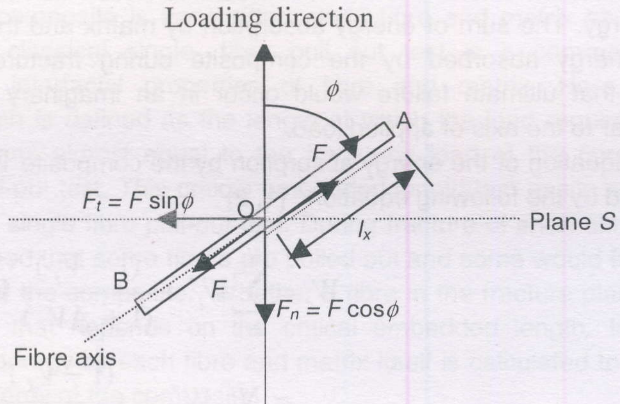

Figure. 2 Condition of the force acting along the fibre axis that appears in the fracture plane.

To assign the contribution of fibre orientation angle and the embedded length in the energy absorbed by the fibre, it is assumed that the energy contributed by a single fibre Wi^* is a functional product of the function of embedded length $u(x)$ and the angular position of the fibre $v(\phi)$, because these two variables are varying simultaneously.

$$W_i^* = W_i^*(x, \phi) = u(x)v(\phi) \tag{3}$$

It is evident from the pull-out test and its results (Figure 1) that when the embedded length is less than the critical length l_c, the fibres will be pulled out and the load required to pull out the fibre would increases linearly with the embedded length. Again it is evident from Fig. 1 that when the embedded length is greater than the critical one, the fibres will be fractured out but this fracture load does not depend further on the embedded length.

When the embedded length is less than the critical one, it is assumed that interfacial property would only contribute to the energy absorption. Thus, when the embedded length is less than the critical one, then energy contribution due to the embedded length $u(x)$ would be calculated from Figure 1 as ½ $(A_f \sigma_f / l_c) \cdot x^2$. On the other hand, when the embedded length is greater than the critical one,

then energy contribution due to embedded length would depend on the energy of fibre fracture and would be calculated from Figure 1 as ½ $A_f\ \sigma_f\ \delta$. Here, it is also assumed that the fibre would shear internally when the embedded length is greater than the critical one and would be calculated as $\tau_y\ A_f\ \phi x$. This idea of shearing the fibre itself and the calculation of energy have been taken from Ref. 3.
Therefore, the energy contribution by each fibre for different embedded length is represented as follows:

$$u(x)=\begin{cases}\dfrac{1}{2}\dfrac{A_f\,\sigma_f}{l_c}x^2 & l_f\le 2l_c\\[2ex] \dfrac{1}{2}A_f\,\sigma_f\,\delta\ +\ \tau_y\,A_f\,\phi x & l_f>2l_c\end{cases}\tag{4}$$

where, σ_f is the strength of the fibre, A_f is the cross-sectional area of the short fibre, x is the arbitrary length of the fibre, δ is the fracture deformation of the fibre and τ_y is the inter-laminar shear stress of the fibre itself.
It is assumed that tangential component F_t in Figure 2 has no contribution in the energy absorption of the composite. Thus, the energy absorption by a single fibre mainly depends upon the angular position of the fibre with respect to the loading direction. Therefore, the function of orientation angle is equal to cosϕ, i.e.

$$v(\phi)\ =\ \cos\ \phi\tag{5}$$

.
From Eq. (2.5) it is evident that among the fibres in the fracture plane S, those that have a small inclination would hold extra energy compared to those with large orientation angle but along the fracture plane (ϕ = 90º), the fibre would have no contribution in the energy absorption.
The applied load would be distributed among all the fibres at the fracture plane. The whole combination of the fibres in the fracture plane would not fail until all the fibres in that fracture plane S are peeled. When all the fibres are peeled, the specimen would gain the maximum internal energy contributed by the fibres and after this point fracture of the composite would occur through out the plane S.

2.4. Distribution of x and ϕ

To calculate the expected value of individual energy contributed by a single fibre , W_i^*, the probability distributions of x and ϕ should be calculated. A hemisphere is considered with radius l_f as shown in Figure 3, where l_f is the length of the short fibre [1]. Here, all the intersecting fibres in the fracture plane S of the composite are assumed to be accumulated at the center of the hemisphere. Thus, these fibres would be distributed randomly in three dimensions at the center of the hemisphere.

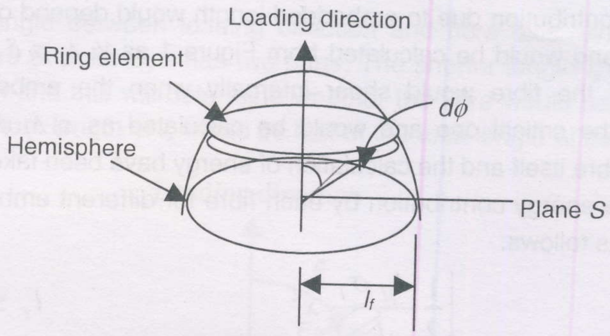

Figure. 3 Schematic diagram of a hemisphere where the fibres are homogeneously distributed.

To calculate P_f , the probability that the fibre would have the required embedded length l_f and it would have the required orientation in between ϕ and $\phi+d\phi$, is assumed to be the ratio of the area of the ring element (Figure 3) made by angle $d\phi$ to the area of the hemisphere [1].

$$P_f = \frac{2\pi l_f \times l_f \sin\phi \; d\phi}{\frac{1}{2}\times 4\pi\, l_f^2} \qquad (6)$$

$$= \sin\phi \;\; d\phi$$

The probability of locating the fibre that intersects plane S (Fig. 3) with an angle ϕ is defined by P_s and can be obtained by the following equation:

$$P_s \propto \cos\phi$$

$$\Rightarrow P_s = K_\phi \cos\phi \qquad (7)$$

where, K_ϕ is the proportionality constant.

For total probability,

$$\int_0^{\pi/2} K_\phi \cos\phi \, d\phi = K_\phi = 1$$

$$\Rightarrow P_s = \cos\phi \qquad (8)$$

Further, the probability of locating the embedded length l_x in the length between x and $x+dx$ is defined by P_x and can be obtained by the equation:
where, K_x is the proportionality constant.

$$P_x \propto dx$$

$$\Rightarrow P_x = K_x\, dx \qquad (9)$$

For total probability,

$$\int_0^{l_f/2} K_x\, dx = 1$$

$$\Rightarrow K_x = \frac{2}{l_f} \qquad (10)$$

2.5. Calculation of the expected value of the energy contribution:

It is mentioned earlier that the individual contribution of fibre in energy W_i^* depends on:

(a) Embedded length of the fibre, l_x

(b) Angle of orientation ϕ with respect to the loading direction

(c) P_f, the probability that the fibre would have the required embedded length l_f and would have the required orientation in between ϕ and $\phi + d\phi$

(d) P_s, the probability that the fibre would intersect the fracture surface as well as would have a small orientation ϕ with the loading direction

(e) P_x, the probability of locating the embedded length of the fibre in the length ranges between x and $x+dx$.

To have the contribution of short fibre in the energy of the composite, the above-mentioned factors should occur simultaneously and hence W_i^* shall be the product of all the factors from (a) to (e).The differential values for the energy contribution by the i-th fibre can be written as follows:

$$dW_i^* = W_i^*(x,\phi)\, K_x\, dx\, K_\phi \cos\phi \sin\phi\, d\phi \qquad (11)$$

Thus, the expected energy absorption in the fracture plane by a single fibre $\overline{W_i^*}$ would be the integration of dW_i^*.

$$\overline{W_i^*} = \int_0^{L_f/2} \int_0^{\pi/2} W_i^*(x,\phi)\ K_x\, dx\ K_\phi \cos\phi\ \sin\phi\ d\phi$$

$$= K_x\, K_\phi \int_0^{L_f/2} u(x) \int_0^{\pi/2} \cos\phi^2 \sin\phi\, d\phi$$

$$= \frac{K_x K_\phi}{3} \int_0^{L_f/2} u\,(x)\, dx \tag{12}$$

Here, the embedded length is varied from 0 to $l_f/2$, each fibre would be divided into two parts and $l_f/2$ would be the maximum length that can participate in the energy absorption. Again, the orientation angle ϕ is varied from 0 to $\pi/2$ as fibres along the loading direction ($\phi = 0^{\circ}$) have more contribution and along the fracture plane ($\phi = 90^{\circ}$) it would have no contribution.

In case of composite, made of short fibres having a fibre length of less than $2l_c$, all the fibres would pull out. Thus the equation of energy contributed by pull-out process by each fibre is as follows:

$$\overline{W_i^*} = \frac{K_x K_\phi}{3} \int_0^{l_f/2} \frac{1}{2} \frac{A_f\, \sigma_f}{l_c} x^2 dx$$

$$= \frac{A_f\, \sigma_f\, l^2{}_f}{72\, l_c} \tag{13}$$

In case of composite made of short fibres having a fibre length greater than $2l_c$, the energy absorbed would depend upon three phenomenon. In this composite, some of the fibres intersect the plane S with embedded length less than critical length and some would be greater than the critical length and accordingly some fibres would pull out and some would fracture out. Thus, energy would absorb during pull-out and fracturing of the fibres in the fracture plane. Further we assume that certain energy would absorb during internal shearing of the fibres.

$\overline{W_i^*}$ = pull-out energy + fracture energy + shear energy

$$\overline{W_i^*} = K_x K_\phi \int_0^{l_c} \int_0^{\pi/2} \frac{1}{2} \cdot \frac{A_f \sigma_f}{l_c} x^2 dx \cdot \cos^2\phi \, \sin\phi \, d\phi$$

$$+ K_x K_\phi \int_{l_c}^{L_f/2} \int_0^{\pi/2} \frac{1}{2} \, \sigma_f A_f \, \delta \, dx \cdot \cos^2\phi \, \sin\phi \, d\phi$$

$$+ K_x K_\phi \int_{l_c}^{L_f/2} \int_0^{\pi/4} \tau_y A_f \, \phi \, x \, dx \cdot \cos^2\phi \, \sin\phi \, d\phi \tag{14}$$

Now, from Eq. (2.14),

Pullout energy:

$$(\overline{W_i^*})' = K_x K_\phi \int_0^{l_c} \int_0^{\pi/2} \frac{1}{2} \cdot \frac{A_f \sigma_f}{l_c} x^2 dx \cdot \cos^2\phi \sin\phi d\phi$$

$$= \frac{A_f \sigma_f l_c^2}{9 l_f} \tag{14a}$$

Fracture energy:

$$(\overline{W_i^*})'' = K_x \, K_\phi \int_{L_c}^{l_f/2} \int_0^{\pi/2} \frac{1}{2} \, \sigma_f \, A_f \, \delta \, dx \cos^2\phi \sin\phi \, d\phi$$

$$= \frac{A_f \, \sigma_f \, \delta}{3 l_f} \left(\frac{l_f}{2} - l_c \right) \tag{14b}$$

Shear energy:

$$(\overline{W_i^*})''' = K_x K_\phi \int_{l_c}^{L_f/2} \int_0^{\pi/4} \tau_y A_f \, \phi \, x \, dx \cdot \cos^2\phi \sin\phi \, d\phi$$

$$= 0.0517 \, \frac{A_f \sigma_f}{l_f} \left(\frac{l_f^2}{4} - l_c^2 \right) \tag{14c}$$

Now putting the individual contribution by the pull-out, fracture and shear from Eqs. (2.14.a), (2.14.b) and (2.14.c) in Eq. (2.14), the expected value of the energy absorbed by single fibre is written as follows:

$$\overline{W_i^*} = \frac{\sigma_f A_f l_c^2}{9 l_f} + \frac{\sigma_f A_f \delta}{3 l_f}\left(\frac{l_f}{2} - l_c\right) + 0.0517 \frac{\sigma_f A_f}{l_f}\left(\frac{l_f^2}{4} - l_c^2\right)$$

$$(2.15) \qquad = 0.0594 \frac{\sigma_f A_f l_c^2}{l_f} + \frac{\sigma_f A_f \delta}{3 l_f}\left(\frac{l_f}{2} - l_c\right) + 0.0129\, \sigma_f A_f l_f \quad (15)$$

For composite reinforced with fibres of length $l_f \leq 2l_c$, the energy absorption of the composite is obtained by putting the value of Eq. (2.13) and Eq. (2.2) in Eq. (2.1):

$$(2.16) \qquad (W_c)_{l_f \leq 2l_c} = \frac{\sigma_f V_f l_f^2}{144\, l_c} + \frac{(1 - V_f)}{(1 + A V_f)} W_m \quad (16)$$

For composite reinforced with fibres of length $l_f > 2l_c$, the energy absorption of the composite is obtained by putting the value of Eq. (2.15) and Eq. (2.2) in Eq. (2.1):

$$(W_c)_{l_f > 2l_c} = \frac{\sigma_f V_f}{2}\left[\, 0.0594 \frac{l_c^2}{l_f} + \frac{\delta}{3 l_f}\left(\frac{l_f}{2} - l_c\right) + 0.0129\, l_f \,\right]$$

$$(2.17) \qquad + \frac{(1 - V_f)}{(1 + A V_f)} W_m \quad (17)$$

3. EFFECTS OF FIBRE VOLUME FRACTION AND EMBEDDED LENGTH ON ENERGY ABSORPTION

Two sets of graphs have been plotted in Figure 4 and 5 using the Eqs. (2.16) and (2.17) and considering the data of Carbon fibre and Polyester resin. The energy absorbed by the matrix, W_m, the strength of the fibre, σ_f and the fracture deformation, δ are considered as 3 kJ/m^2, 2700×10^3 kN/ m^2 and 10 mμ, respectively [1,5]. Here, A is chosen as 2.5 as an approximate upper limit [2].

In Figure 4, the fibre length is taken as less than or equal to twice the critical embedded length. Here, graphs have been plotted for this case considering three different values of l_f/l_c ratio. When l_f/l_c is equal to 1, fibre length is equal to critical embedded length, i.e., fibre length is less than twice the critical embedded length. When l_f/l_c ratio is 1.5 or 2, fibre length is twice the critical embedded length.

Now putting the individual contribution by the pull-out, fracture and shear from Eqs. (2.14.a), (2.14.b) and (2.14.c) in Eq. (2.14), the expected value of the energy absorbed by single fibre is written as follows:

$$\overline{W_i^*} = \frac{\sigma_f A_f l_c^2}{9 l_f} + \frac{\sigma_f A_f \delta}{3 l_f}\left(\frac{l_f}{2} - l_c\right) + 0.0517 \frac{\sigma_f A_f}{l_f}\left(\frac{l_f^2}{4} - l_c^2\right)$$

(2.15)

$$= 0.0594 \frac{\sigma_f A_f l_c^2}{l_f} + \frac{\sigma_f A_f \delta}{3 l_f}\left(\frac{l_f}{2} - l_c\right) + 0.0129 \sigma_f A_f l_f \quad (15)$$

For composite reinforced with fibres of length $l_f \leq 2l_c$, the energy absorption of the composite is obtained by putting the value of Eq. (2.13) and Eq. (2.2) in Eq. (2.1):

(2.16)

$$(W_c)_{l_f \leq 2l_c} = \frac{\sigma_f V_f l_f^2}{144\, l_c} + \frac{(1 - V_f)}{(1 + A V_f)} W_m \quad (16)$$

For composite reinforced with fibres of length $l_f > 2l_c$, the energy absorption of the composite is obtained by putting the value of Eq. (2.15) and Eq. (2.2) in Eq. (2.1):

$$(W_c)_{l_f > 2l_c} = \frac{\sigma_f V_f}{2}\left[\, 0.0594 \frac{l_c^2}{l_f} + \frac{\delta}{3 l_f}\left(\frac{l_f}{2} - l_c\right) + 0.0129\, l_f \right]$$

(2.17)

$$+ \frac{(1 - V_f)}{(1 + A V_f)} W_m \quad (17)$$

3. EFFECTS OF FIBRE VOLUME FRACTION AND EMBEDDED LENGTH ON ENERGY ABSORPTION

Two sets of graphs have been plotted in Figure 4 and 5 using the Eqs. (2.16) and (2.17) and considering the data of Carbon fibre and Polyester resin. The energy absorbed by the matrix, W_m, the strength of the fibre, σ_f and the fracture deformation, δ are considered as 3 kJ/m^2, 2700×10^3 kN/ m^2 and 10 mμ, respectively [1,5]. Here, A is chosen as 2.5 as an approximate upper limit [2].

In Figure 4, the fibre length is taken as less than or equal to twice the critical embedded length. Here, graphs have been plotted for this case considering three different values of l_f/l_c ratio. When l_f/l_c is equal to 1, fibre length is equal to critical embedded length, i.e., fibre length is less than twice the critical embedded length. When l_f/l_c ratio is 1.5 or 2, fibre length is twice the critical embedded length.

Here, these conditions have been plotted using different fibre length of 1 mm, 2 mm, 3 mm, 4 mm and 5 mm and shown in Fig. 4 (a~e). It may be mentioned here that all the fibres will be pulled out because the length of the fibre is less than or equal to twice the critical embedded length. From fig. 4, it is evident that energy absorption increases with the increase in fibre volume fraction, fibre embedded length and the l_f / l_c ratio, when fibre embedded length is less than or equal to critical embedded length.

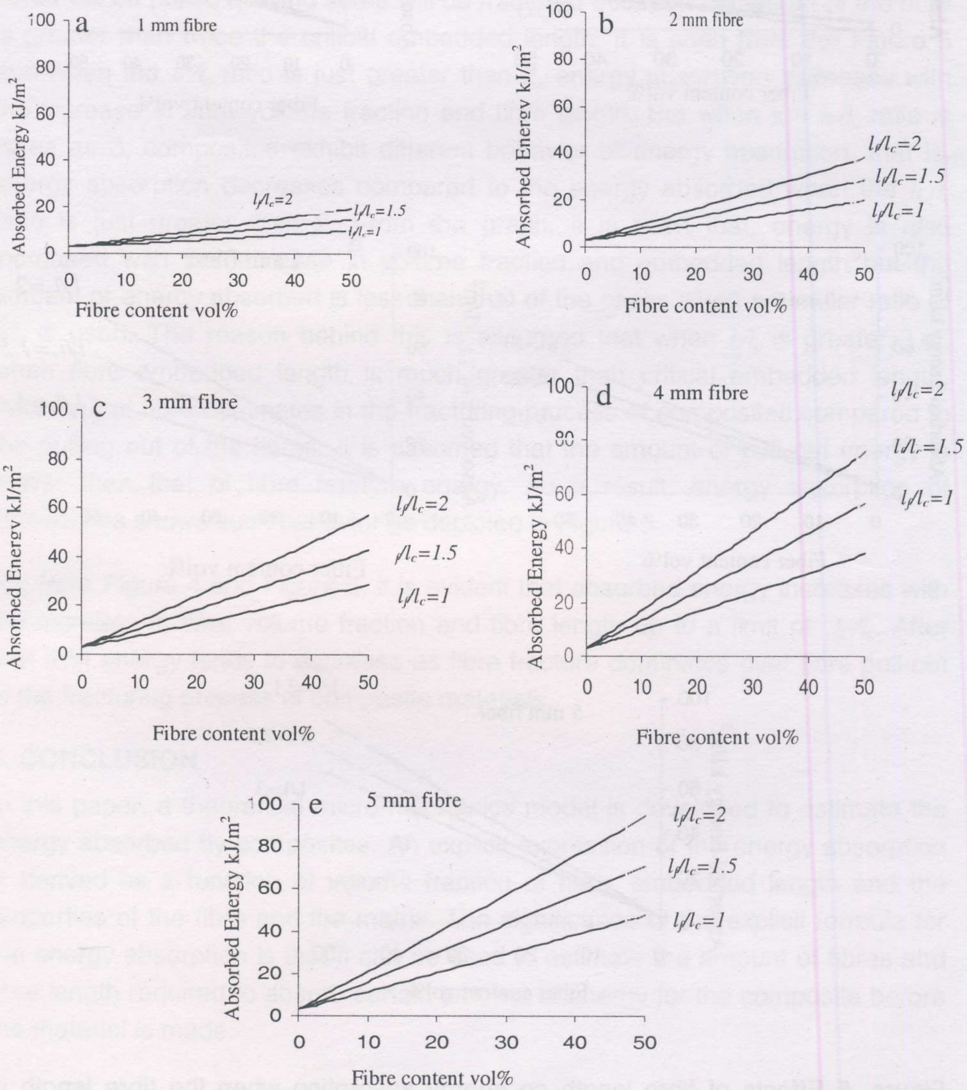

Figure. 4 Effects of fibre length on energy absorption when the fibre length is less than or equal to twice the critical embedded length

In Figure 5, the fibre length is greater than twice the critical embedded length. Here again, graphs have been plotted for this case considering three different values of l_f/l_c ratio, equal to 2.1, 2.5 and 3. For all conditions, fibre length is greater than twice the critical embedded length. Here, these conditions have also been plotted using different fibre length of 1 mm, 2 mm, 3 mm, 4 mm and 5 mm and shown in Figure 5 (a~e). It may also be mentioned here that some of the fibres will be pulled out and some will be fractured because the length of the fibre is greater than twice the critical embedded length. It is seen from the Figure 5 that when the l_f/l_c ratio is just greater than 2, energy absorption increases with the increase in fibre volume fraction and fibre length. But when the l_f/l_c ratio is takes as 3, composites exhibit different behavior of energy absorption, that is, energy absorption decreases compared to the energy absorbed when the l_f/l_c ratio is just greater than 2. From the graph, it is seen that, energy is also increased with the increase in volume fraction and embedded length but the amount of energy absorbed is less than that of the cases when a smaller ratio of l_f/l_c is used. The reason behind this is assumed that when l_f/l_c is greater, i.e., when fibre embedded length is much greater than critical embedded length, fracturing of fibre dominates in the fracturing process of composites compared to the pulling out of the fibres. It is assumed that the amount of pull out energy is higher than that of fibre fracture energy. As a result, energy absorption of composites shows such behavior as depicted in Figure 5.

So, from Figure 4 and Figure 5, it is evident that absorbed energy increases with the increase in fibre volume fraction and fibre length up to a limit of l_f/l_c. After that limit energy tends to decrease as fibre fracture dominates over fibre pull-out in the fracturing process of composite materials.

4. CONCLUSION

In this paper, a theoretical micro-mechanics model is developed to estimate the energy absorbed by composites. An explicit expression of the energy absorption is derived as a function of volume fraction of fibre, embedded length and the properties of the fibre and the matrix. The significance of the explicit formula for the energy absorption is that it can be used to estimate the amount of fibres and fibre length required to absorb certain amount of energy for the composite before the material is made.

REFERENCES

[1] Masud, A. K. M., Suzuki, J. and Isogimi, K., Bending properties of the Aramid short fibre composite and modeling of strength, JSME International Journal, Series A, Vol. 43 No. 1, pp. 94-102, 2000.

[2] Turcsanyi, B. Pukanszky , B. Tudos , F., Composite Dependence on Tensile Yield Stress in filled Polymers, J. Mater. Sci. Letters, Vol. 7, pp. 160 – 162, 1988.

[3] Underwood, E. E., Applications of Quantitative Metallography, Materials Handbook, Vol. 8, 8th Edition, ASM, , pp. 37 – 47, 1973.

[4] Rashed, E., Energy absorption of short fibre composite, Dissertation for the M. Engg. Degree, Department of Industrial and Production Engineering, Bangladesh University of Engineering and Technology, Bangladesh, December, 2001.

[5] Hull Derek, An Introduction to Composite Materials, 1st Edition, Cambridge University Press, 1981.

(Contd. from 2nd cover page)

8. SI units must be used in the manuscript However, other units may be used in parenthesis.

9. Tables should be referred to in consecutive Arabic numerical. Each table must have a table caption.

10. Line drawings must be in a form suitable for reproduction e.g., laser printout, drawn in Indian ink on white paper or on traching paper. Photographs should have a glossy finish. Each figure must have a number and a figure caption. Elecrtonic mode is preferred.

11. References should be set out in alphabetical order of the author's last name in a list at the end of the article. They should be given in standard form as in the following examples :

(a) Journal
Bloomer G. and Wright A., "Scheduling of Vehicles from Factory to Depot." Operations Research, Vol. 12, January, pp. 590-598, 1984.

(b) Book
Best, John., and Kahn, James V., Research in Education, Prentice-Hall, New Jersey, 1986.

(c) Monograph
Syedali, M.M. "Computer Controlled Car", Thesis, M.Sc. Engineering, Department of Mechanical Engineering, BUET, 1990

(d) Conference Paper
Hasan, M. and Ullah, M.S. "Tourism development in the Chittagong Hill Tracts of Bangladesh after the peace agreement of 1997", a paper submitted to the Regional Conference on physical mobility and development in the mountains", Tribhuvan University, 15-17, March, 2000 Kathmandu, Nepal, pp.12,

(e) Unpublished paper
Ahmadi, R and Tang : Production Allocation with Dual Provisioning, Working Paper, Anderson Graduate School of Management, UCLA (1991)

12. The University does not accept responsibility for loss or damage of manuscript while in mail.

13. The responsibility for opinions in the contributions rests entirely on their authors.

14. The author (s) must submit declaration that the paper was not published elsewhere.

15. In case of joint papers, communication will be made with the first author.

16. The University will reserve the copyright of the paper once it is accepted for publication in the Journal. The authors must obtain written permission from REASP, IUT for publication elsewhere.

Procedure for acceptance of papers and publications :

1. Papers submitted for publication will be referred to the listed reviewers for assessment. However, the editorial board will make initial screening of the papers.

2. After the assessment, the authors may be requested to modify/clarify certain points.

3. Accepted/modifed/corrected papers will be published in the next issue of the Journal.