*Fracture 1977, Volume 3, ICF4, Waterloo, Canada, June 19 - 24, 1977*

# TENSILE FRACTURE BEHAVIOUR OF VASCULAR SUBSTITUTES

A. T. Yokobori, Jr*, H. Ouchi,** T. Yokobori* and H. Sasaki**

## INTRODUCTION

Vascular substitutes in the living situation are subjected to alternating stress in terms of blood pressure. Therefore, for the study on the behaviour of them, it is much more relevant to make studies under hydrodynamical pressure, especially under alternating hydrodynamical stress than under usual tensile testing. Thus we are carrying out such experiments [1]. On the other hand, such experiments need long time and have many complexities.

In the present article as a method of rapid testing for comparison among vascular substitutes of different kinds, studies of tensile fracture have been carried out on two kinds of materials: Tetron and Dacron. Also the testing of this type may be of use to fundamental and quantitative knowledge on the crimped sheet itself of vascular substitutes.

## MATERIALS USED AND SPECIMENS

Materials for clinical use are vascular substitutes of two kinds, woven of Tetron and of Dacron. The former is domestic and the latter is imported. Both kinds were supplied in the crimped form for clinical use. The shape, size and other data are shown in Table 1. Test specimens were taken from the bulk substitutes as shown in Figure 1 in such a manner that the direction of tensile axis of the specimen was parallel to the central axis of the tube (the direction of blood flow) and the circumferential direction of the wall of the tube for each Tetron and Dacron substitute, respecitvely. The materials for specimen were in the form of straightened sheet from the crimped form. The dimensions of the specimen is as shown in Figure 2.

Four and eight specimens were used for each series of the tests on axial and circumferential behaviour of Dacron and Tetron substitutes respectively.

## EXPERIMENTAL RESULTS AND DISCUSSION

Typical examples of load versus elongation diagram are shown in Figure 3(a), (b) and Figure 4(a),(b) respectively. All of the series of tests show the common features in that load increases approximately linearly with increase of elongation and then rapidly decreases to fracture. However, it is to be noted that for the axial specimen many tiny staircases appeared between A and B on the load versus elongation diagram. It is interesting that this feature is similar to the case of fibre reinforced composite materials [2].

*Department of Mechanical Engineering II, Tohoku University, Sendai, Japan.
**The Second Department of Surgery, Tohoku University, Sendai, Japan.

The results are shown in Table 2. From Table 2 it can be seen that tensile strength and total elongation of both axial and circumferential specimen are smaller for Dacron substitute than for Tetron substitute.

For the case of axial specimen of Tetron substitute longitudinal thread bundles were observed to slip off from the constraint of the thread bundles located in the circumferential direction of tube as shown in Figures 5 and 6. This feature may be considered as corresponding to many tiny staircases appearing between A and B in Figure 3(a). After being subjected to the considerable overall elongation near the point B in Figure 3(a), most of constraints by lateral thread bundles may be relieved and catastrophic fracture of the specimen will occur. On the other hand, under tensile stress applied in the circumferential direction of the Tetron substitute tube, there is no trend of slipping off of the lateral threads bundles (situated in the circumferential direction of the tube) as shown in Figures 7 and 8 and fracture occurs without the trend of slipping, and thus the total elongation to fracture is smaller than in the axial direction. The reason of this may be that in this Tetron substitute the number of thread bundle and the diameter of the bundle are larger [3] in the axies direction than in the circumferential direction.

Also, there is some tendency of slipping off of the longtitudinal thread bundles under tensile stress applied in the axial direction of the Dacron substitute tube. However, this trend is not so conspicuous as for the Tetron substitute as shown in Figures 9 and 10. Under tensile stress applied in the circumferential direction of the Dacron substitute the behaviour is similar to the corresponding case of the Tetron substitute as shown in Figures 11 and 12.

The anisotropy of tensile strength and total elongation to fracture of the axial and circumferential specimen is shown in Table 3. It can be seen from Table 3 that the anisotropy is smaller in the Dacron substitute than in the Tetron substitute.

The circumferential (or hoop) fracture tensile strength of these substitutes are $4 \times 10^7 \sim 6 \times 10^7$ Pa, and, on the other hand, the hoop tensile stress clinically induced by blood pressure is at most about $8.6 \times 10^5$ Pa. Thus the former is far much larger, say, larger than fifty or seventy times of the latter. However, when the anisotropy is remarkable especially in cardiovascular applications, crack might initiate in the weaker direction resulting in leakage of the blood, or sudden brittle fracture with only slight deformation as mentioned above might occur. Therefore, at least, it may not be necessary to strengthen the axial direction more than the circumferential direction which is much more critical as far as blood pressure is concerned.

The ratio of the standard deviation $\sigma$ to the mean value $\mu$, that is, the coefficient of variation of the observed data is shown in Table 4. It can be seen from Table 4 that the coefficient of variation is in most cases smaller, that is, the scatter of mehanical properties is smaller in Dacron Substitute than Tetron substitute.





## CONCLUSIONS

(1) Both tensile strength and total elongation to fracture in the axial and the circumferential direction are smaller in Dacron substitute than in Tetron substitute except the value of total elongation based on the length of bellows.

(2) Since stress clinically induced by blood pressure is far smaller, say, one fiftieth or one seventieth smaller than the catastrophic value obtained herein, the characteristics of Dacron substitute mentioned in (1) is still satisfactory as far as mechanical safety of the virgin state is concerned, and, in addition, from the results of the total elongation based on the length of bellows, the Dacron substitute may be more suitable from the standpoint of softness than Tetron substitute.

(3) The anisotropy of mechanical properties is smaller in the Dacron substitute than in the Tetron substitute.

(4) The scatter of tensile strength and elongation to fracture is smaller in the Dacron substitute than in the Tetron substitute.

(5) From the characteristics mentioned in (1) to (4) it may be concluded that Dacron substitute is more suitable for clinical use than Tetron substitute as far as mechanical behaviour of the virgin state is concerned.

## ACKNOWLEDGEMENTS

The authors wish to express thanks to Mrs. Y. Ogawara and K. Shishido for their help in carrying out experiments. Appreciation should also be made to Mr. Y. Miyasaka for useful discussion.

## REFERENCES

[1] YOKOBORI, A. T., Jr., YOKOBORI, T., OUCHI, H. and SASAKI, H., International Conference on Fracture Mechanics and Technology, Univ. Hong Kong, 1977. To be published.

[2] TAKAKU, A. and ARRIDGE, R. G. C., J. Phys. D : Appl. Phys., 6, 1973, 2038.

[3] KAMIYA, K., BAN, I., NAKADA, Y. and NAKAO, Y., J. Gekachiryo, 21, 1969, 334.

Table 1 The dimension of vascular substitutes tube and some data related

| material | diameter mm | thickness μ | number of bundles / m of width: axial direction | number of bundles / m of width: circumferential direction | bundles of fibre: axial direction | bundles of fibre: circumferential direction | leakage rate of water ($1.6 \times 10^{[illegible]}$ Pa mmHg) $cc/cm^2/min$ |
|---|---|---|---|---|---|---|---|
| Tetron | 20 | 310 | $5.512 \times 10^3$ | $3.15 \times 10^3$ | 40 denier #4<br>140 μ | 100 denier #1<br>100 μ | 26.69 |
| Dacron | 18 | 222 | —— | —— | —— | —— | —— |

Table 2 Tensile strength and elongation to fracture obtained

| material | direction | tensile strength (nominal) Pa | elongation to fracture % plastic | elongation to fracture % total |
|---|---|---|---|---|
| Tetron | axial | $1.257 \times 10^8$ | —— | 132<br>316* |
| | circumferential | $5.864 \times 10^7$ | 25.1 | 56.8 |
| Dacron | axial | $7.03 \times 10^7$ | —— | 68.7<br>398* |
| | circumferential | $4.06 \times 10^7$ | 26.4 | 51.97 |

* Based on the length of bellows





Table 3 Anisotorpy of tensile strength and total elongation to fracture

| material | the ratio of tensile strength of the circumferential specimen to that of the axial one | the ratio of total elongation of the circumferential specimen to that of the axial one |
|---|---|---|
| Tetron | 0.466 | 0.430 |
| Dacron | 0.577 | 0.756 |

Table 4 The coefficient of variation of tensile strength and elongation to fracture. (per cent)

| material | tensile strength (nominal) \|σ/μ\| in per cent: axial direction | tensile strength (nominal) \|σ/μ\| in per cent: circumferential direction | elongation \|σ/μ\| in per cent: axial direction: plastic elongation | elongation: axial direction: total elongation | elongation: circumferential direction: total elongation* | elongation: circumferential direction: total elongation |
|---|---|---|---|---|---|---|
| Tetron | 10.5 | 10.9 | 22.4 | 5.6 | 11.1 | 11.3 |
| Dacron | 4.0 | 7.0 | 13.4 | 8.8 | 4.3 | 4.5 |

* based on the length of bellows

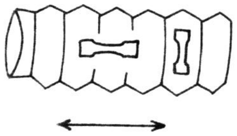
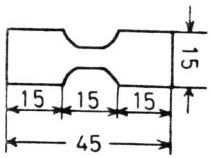


Figure 1 Schematic illustration of taking the axial and the circumferential specimens out of the vascular substitute tube. Arrow shows the blood flow direction.




in mm

Figure 2 Dimension of the specimen





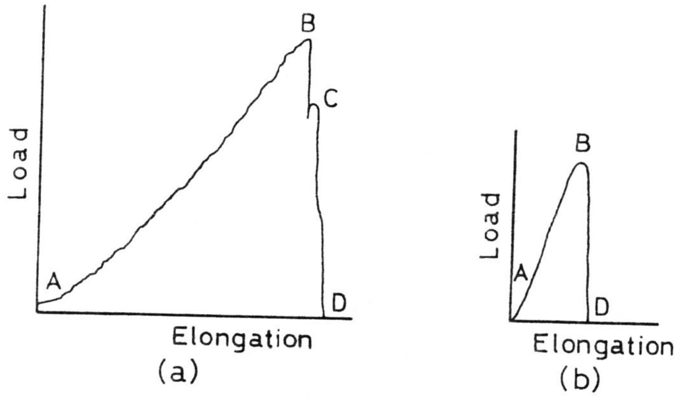



Figure 3 A typical example of load versus elongation diagram experimentally obtained for Tetron substitute.

(a) axial specimen

(b) circumferential specimen

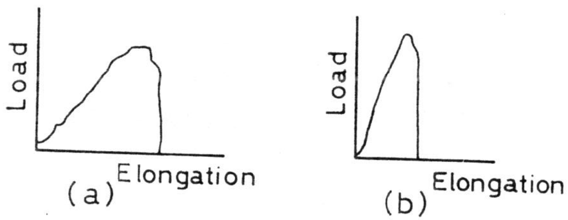



Figure 4 A typical example of load versus elongation diagram experimentally obtained for Dacron substitute.

(a) axial specimen

(b) circumferential specimen

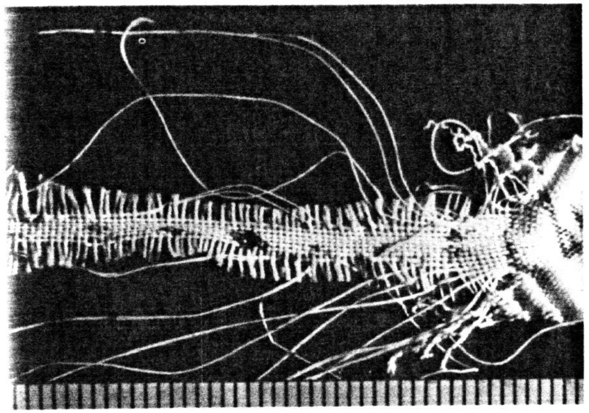


Figure 5  Tensile fracture appearance of Tetron substitute. (axial direction) scale is 1 mm units in Figures 5, 7, 9 and 11.

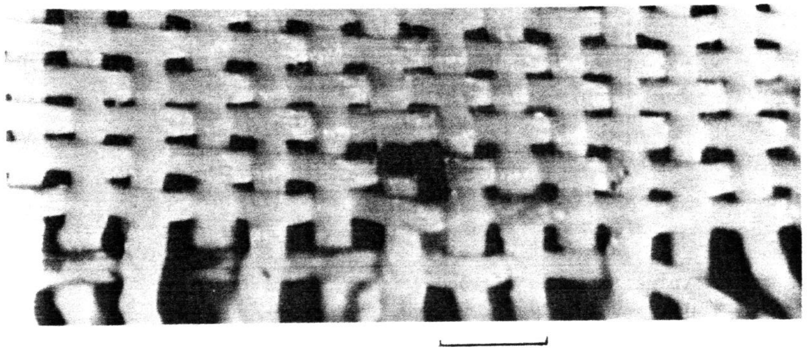



Figure 6  Magnification of fractured part of Figure 5





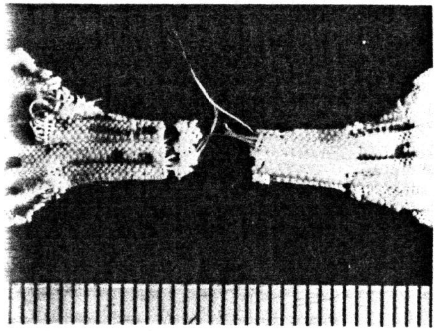


Figure 7  Tensile fracture appearance of Tetron substitute. (circumferential direction)

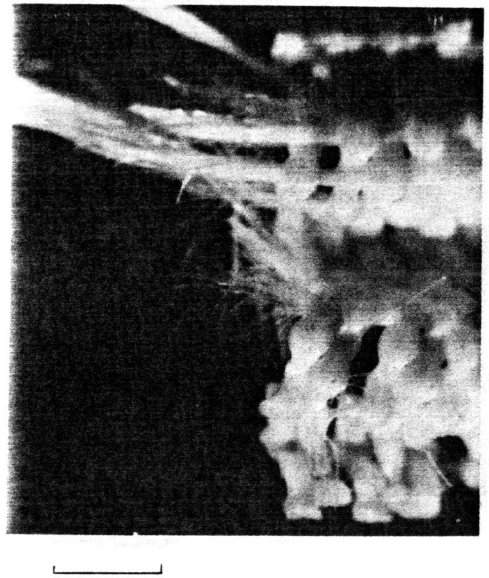



Figure 8  Magnification of fractured part of Figure 7

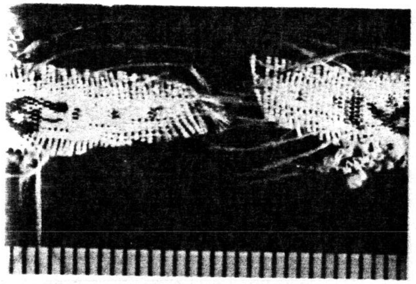
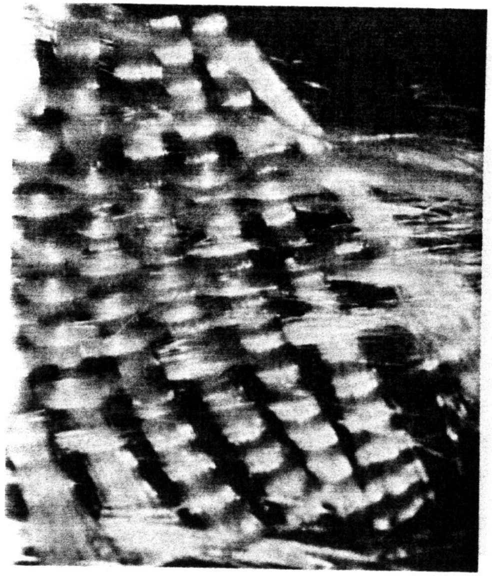


Figure 9 Tensile fracture appearance of Dacron substitute. (axial direction)



1 mm

Figure 10 Magnification of fractured part of Figure 9





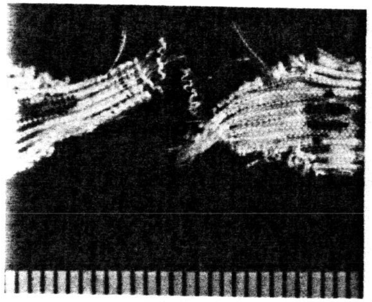
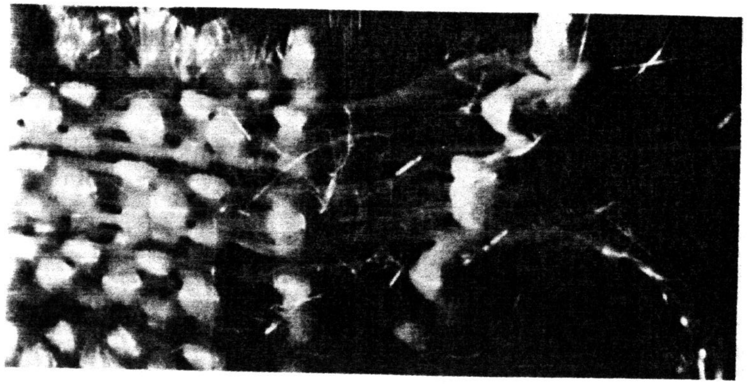


Figure 11 Tensile fracture appearance of Dacron substitute. (circumferential direction)



1 mm

Figure 12 Magnification of fractured part of Figure 11