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# Morphological and Mechanical Properties of Two Alcyonaceans, *Sinularia flexibilis* and *S. capillosa*

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**Ming-Chao Lin and Chang-Feng Dai (1997)** Morphological and mechanical properties of two alcyonaceans, *Sinularia flexibilis* and *S. capillosa*. *Zoological Studies* **36**(1): 58-63. Drag and changes of colony morphology under various flow velocities of 2 sympatric alcyonaceans, *Sinularia flexibilis* and *S. capillosa*, were studied. The mechanical properties of tissues from these 2 species were also investigated. Colonies of the 2 species have similar mophological and mechanical properties. Flexibility of the colonies enables them to bend into a drag-reducing orientation at higher flow velocities by collapsing the colony, thus bringing it nearer the substratum. In addition, the 2 species also have a similar volume fraction of sclerites and similar stiffness of intact colony tissue. However, the 2 species differ in sclerite size, and the stiffness of *S. flexibilis* after decalcification is higher than that of *S. capillosa*. These facts indicate that sclerites may not be the only factor affecting the stiffness of *S. flexibilis* and *S. capillosa*; the stiffness of the mesoglea may also play an important role. The results show that these 2 sympatric species possess similar morphological and mechanical properties to reduce drag, but they achieve this through different skeletal constitutions.

**Key words:** Biomechanics, Drag, Sclerite, Water flow.

Flow in the environment has important mechanical consequences for sessile organisms, which can be broken or dislodged by flow-induced drag. These forces not only depend on the strength of flow but also on attributes of organisms, which are adapted to resist or reduce drag (Denny et al. 1985). Whether a sessile organism will be dislodged from its substratum depends not only on the magnitude of the stresses it encounters, but also on the morphology and strength of its support system (Koehl 1982a). The morphological and mechanical features of sessile organisms which enable them to withstand drag include high flexibility (Charters et al. 1969, Vogel 1984, Denny et al. 1985, Harvell and LaBarbera 1985, Lin and Dai 1996), streamlined shape (Koehl 1977, Holbrook et al. 1991, Dudgeon and Johnson 1992, Lin and Dai 1996), and high stiffness (Delf 1932, Koehl 1982a, Dudgeon and Johnson 1992, Lin and Dai 1996).

Alcyonaceans vary in shape from thin encrusting forms to ornate upright structures, and in biomaterial properties from rubber-like rigidity to extreme flexibility. Colony morphology and mechanical properties of anthozoans are adapted to the hydrological conditions of their environment (Jokiel 1978, Koehl 1982a, Tunnicliffe 1982, Dai 1991). The colony morphology and mechanical properties of these organisms as a function of water movement have been little investigated.

Vosburgh (1977) noted that the resistance to breakage of colonies is dependent on the organization of their support systems. Alcyonaceans are supported by sclerite-containing tissues (Bayer 1973). Koehl (1982b) compared the moduli of elasticity of artificial tissues and showed that the colony tissues containing a greater volume fraction of sclerites have higher reinforcements than similar tissues with fewer sclerites. However, the stiffening effects of the mesoglea of alcyonaceans

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are still poorly understood.

*Sinularia flexibilis* (Quoy and Gaimard) and *S. capillosa* Tixier-Durivault coexist on reefs in southern Taiwan. The 2 species have flexible stalks and digitate lobes, and are difficult to distinguish by colony morphology. In this study, we investigated drag and changes of colony morphology for these 2 sympatric alcyonaceans under various flow velocities. The mechanical properties of tissues from the 2 species were also studied. Here, we explore how the 2 sympatric alcyonaceans, *S. flexibilis* and *S. capillosa*, interact with drag. Flume experiments we designed to measure the magnitude of the forces on the alcyonaceans in various flow velocities. The stiffening effects of sclerites and mesoglea of the 2 species are then compared in accordance with the measurements of the strength of sclerite-containing and scleriteless tissues.

## MATERIALS AND METHODS

### Specimen collection and acclimation

Colonies of *Sinularia flexibilis* and *S. capillosa* 12-15 cm in height were collected with substrata from a reef in Nanwan Bay, southern Taiwan (120°44'E, 21°57'N). Identifications followed Verseveldt (1980). The colonies were transferred to an acclimation tank in which the temperature was maintained at 24 °C. Invertebrate feeding blocks (Reef Care, No. 134, Aquarium Pharmaceuticals Inc.) were used to feed the alcyonaceans. Three days were allowed for acclimation before the experiments.

A recirculating flow tank of 75-l capacity, (320 cm long, 15 cm wide, 20 cm high) was made according to Leversee (1976). The tank was filled with 70 l filtered seawater, and a laboratory stirrer (Her-Cheng SC-VS35W) with a propeller (14 cm in diameter) was used to generate water flow. Upstream 30 cm from the alcyonacean colony, the flow tank was furnished with an acrylic sieve-tunnel which creates laminar flow. The flow velocity was controlled by a solid state motor control and measured by an electromagnetic current meter (Kenek, VM-401H). The sensor of the current meter was placed 15 cm upstream from the alcyonacean colony.

### Flume experiments

During the experiment, a colony was transferred into the flow tank and fastened on an acrylic base by inlaying the substratum of the colony into a groove on the base. The base was supported by a tray filled with stainless steel balls to reduce friction. The acrylic base was connected to a suspended electronic balance (Yong-Ten HA-02) by a nylon line. When the coral colony experienced stress from the water flow, the acrylic base moved on the tray and transmitted the force to the suspended electronic balance via the nylon line. Drag induced by a colony at various flow velocities was measured with the balance. The drag was standardized by dividing values at various velocities by the initial projected colony area at 0 cm $s^{-1}$ and is expressed in dyne $cm^{-2}$.

After 6 h of further acclimation, during which time the polyps fully expanded, 5 colonies of each species were tested at flow velocities ranging from 0 to 35 cm $s^{-1}$ at intervals of 5 cm $s^{-1}$. Colony profiles at various flow velocities were photographed through a window in the tank.

Projected colony areas perpendicular to the flow at various velocities were photographed using an underwater camera (Nikonos-V) with a 20-mm lens. The photographs of projected colony area were traced and measured using a digitizer (Lab Visions LV-1) connected to a computer. Variations of colony area under various flow velocities were standardized by dividing the measured projected area by the initial projected colony area.

Drag coefficients of the 2 species were calculated from the drag measurements and projected colony areas, using the equation:

$$C_D = \frac{2D}{\rho S U^2}$$

where $C_D$ is drag coefficient, $D$ is drag, $\rho$ is density of seawater, $S$ is projected colony area, and $U$ is velocity (Vogel 1981 1988).

### Mechanical testing

Sclerite-containing and decalcified strips were prepared for mechanical tests. The colonies were anaesthetized overnight in a solution of 20% $MgSO_4 \cdot 7H_2O$ in a 1:1 mixture with sea water until polyps pinched with a forceps did not contract (Koehl 1982b). Six strips of sclerite-containing tissue were cut from the stalk of a colony with a slicing machine (Omas VS250). Half of these strips were decalcified using a method similar to that described in Pennington and Hadfield (1989), using a saturated solution of MES [2-(N-morpholino) ethanesulfonic acid; Sigma Cat. No. M-8250] in filtered sea water. Decalcification took 1-2 wk, with the solution being renewed every 3 d, depending on the density and size of sclerites present.

The cross-sectional area of each strip was measured. Strips of tissue were stretched in a Mechanical Test System (MTS 810) that simultaneously printed the force-extension diagram on a plotter (X-Y recorder, Yokogawa 3025). The strain rate was controlled in $\varepsilon$ = 0.01 $s^{-1}$ (where $\varepsilon = \Delta L/L_0 \cdot t$, $\Delta L$ is the change in length of the specimen at time $t$, and $L_0$ is the original length of the specimen).

Stress ($\sigma$) was calculated as the force exerted per unit cross-sectional area of the specimen ($F/A$). Strain ($\lambda$) was calculated as percent extension of the original length ($\Delta L/L_0$). Plots of stress versus strain were made. From the resulting stress-strain curves, the moduli of elasticity that characterizes stiffness were calculated as the slope of the linear portion of the curves for sclerite-containing ($E$) and decalcified ($E'$) specimens. Reinforcement of sclerites was calculated by the equation:

$$e = \frac{E - E'}{E} = \frac{\Delta E}{E}$$

where $e$ is reinforcement of sclerites in tissue, $E$ is modulus of elasticity of sclerite-containing tissue, $E'$ is modulus of elasticity of decalcified tissue, and $\Delta E$ is reduction of modulus of elasticity after decalcification.

### Volume fraction of sclerites

The volume of a piece of tissue was determined by measuring the volume of water displaced by the tissue when put into a filled volumetric flask. Five pieces of stalk tissue were tested from each colony, and 5 colonies were tested for each species. According to the method used by West et al. (1993), the tissue was dissolved in bleach for 1 to 3 h and cleaned with an ultrasonic cleaner (Branson 5 200) for 2 to 5 s. The sclerites were then rinsed with distilled water and dried in an oven at 110 °C for 3 h. The dry weight of sclerites was measured by an electronic balance (Ohaus GT410) and the volume of sclerites was calculated by adopting a density of 2.6 g $cm^{-3}$ for calcareous sclerites (Koehl 1982b). The volume fraction of sclerites in stalk tissue was calculated using the formula,

$$\gamma = \frac{W}{\rho V}$$

where $\gamma$ is the volume fraction of sclerites in tissue, $W$ (g) is the dried weight of sclerites, $\rho$ (g $cm^{-3}$) is the density of sclerites, and $V$ ($cm^3$) is the volume of tissue.

In addition, sclerite length was analyzed. To estimate the mean length of sclerites ($l$), 30 sclerites from the stalk of each coral colony were randomly selected and measured.

## RESULTS

### Drag

Drag encountered by the colonies of *Sinularia flexibilis* and *S. capillosa* increased with flow velocity (Fig. 1). The projected colony areas of the 2 species declined with increasing flow velocity (Fig. 2). The flexible stalks and clumped lobes

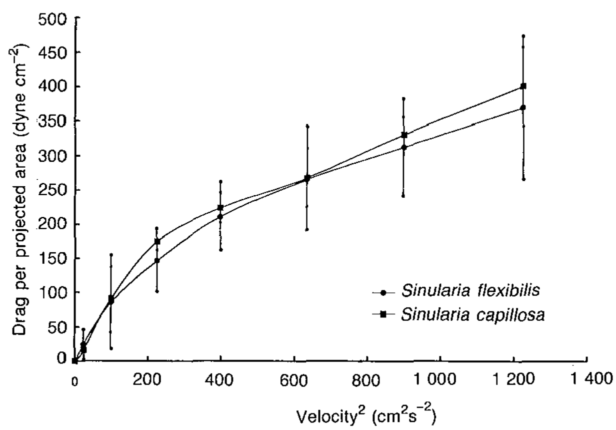


**Fig. 1.** Drag per projected colony area ($X \pm$ SE, $n$ = 5) as a function of flow velocity for *Sinularia flexibilis* and *S. capillosa*.

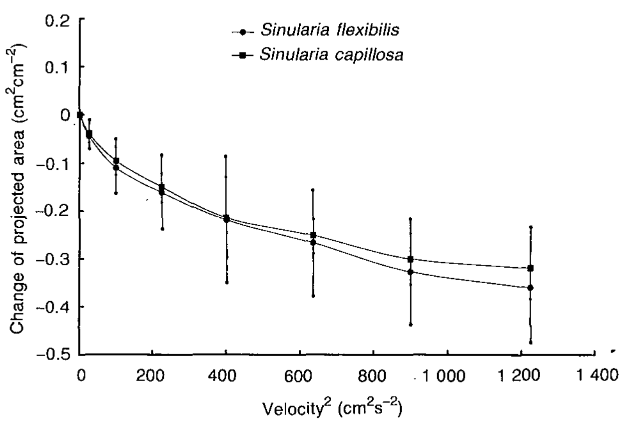


**Fig. 2.** Variation of projected colony area ($X \pm$ SE, $n$ = 5) as a function of flow velocity for *Sinularia flexibilis* and *S. capillosa*.

of both alcyonaceans tended to orient parallel to the flow, which also resulted in a reduction of projected colony area.

The drag coefficients of *S. flexibilis* and *S. capillosa* declined with increasing flow velocity (Fig. 3). Reconfiguration of the lobes and bending of the stalks, which made the colony more streamlined, resulted in creating a lower drag coefficient and reducing the projected colony area. Analysis of variance revealed that all main effects and interactions of the drag coefficients under various flow velocities do not differ between the 2 species (Table 1, $F = 0.75$, $n = 48$, $p > 0.05$).

### Tensile strength

The moduli of elasticity of sclerite-containing tissues of *S. flexibilis* and *S. capillosa* do not significantly differ (Table 2, $t = 0.687$, $n = 10$, $p > 0.05$). The moduli of elasticity of decalcified tissues of *S. flexibilis* are higher than these of *S. capillosa* (Table 2, $t = 0.999$, $n = 10$, $p < 0.05$).

There is no significant difference between the volume fraction of sclerites of *S. flexibilis* and that of *S. capillosa* (Table 2, $t = 0.394$, $n = 10$, $p > 0.05$). However, the reinforcement of sclerites of *S. capillosa* is higher than that of *S. flexibilis* (Table 2, $t = 0.969$, $n = 10$, $p < 0.05$).

The sclerites of the 2 species are densely packed in the mesoglea, and appear randomly oriented (Fig. 4). Although sclerites in both species are similarly spindle-shaped, the mean length of sclerites from *S. flexibilis* is less than that from *S. capillosa* (Table 2, $t = 0.999$, $n = 10$, $p < 0.005$).

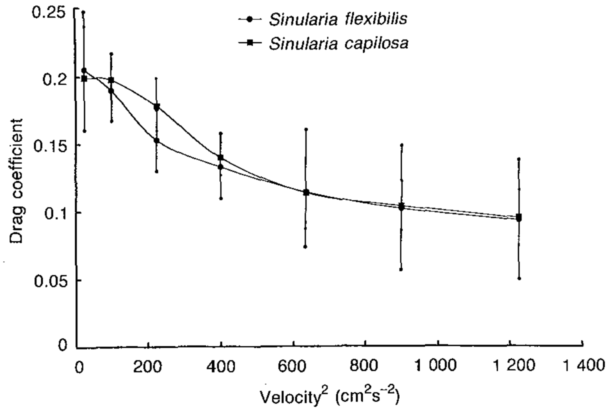


**Fig. 3.** Drag coefficient ( $\overline{X} \pm$ SE, $n = 5$) as a function of flow velocity for *Sinularia flexibilis* and *S. capillosa*.

## DISCUSSION

*Sinularia flexibilis* and *S. capillosa* are similar in colony morphology and in their responses to flow. As flow velocity increases, they bend, collapsing the colony and bringing it nearer the substratum, which reduces drag. Flexibility is an effective characteristic for withstanding drag by changing morphology (Harvell and LaBarbera 1985).

With their characteristic dense packing in the mesoglea, sclerites must interact with any bending or twisting of the colony and consequently affect the mechanics of the whole colony. Koehl (1982b) claimed that size and clustering density of sclerites affect the stiffness of the colony; the reinforcement of sclerites increases with the surface area and volume fraction of sclerites per tissue volume. However, a colony of alcyonaceans is composed of calcareous sclerites and mesoglea (Bayer 1973); the siffness of the mesoglea may also play an important role.

Although the volume fraction of sclerites and the stiffness of intact colony tissue are similar in *S. flexibilis* and *S. capillosa*, the stiffness of *S. flexibilis* after decalcification is higher than that of *S. capillosa*. Thus the volume fraction of sclerites is not the most important factor affecting the stiffness of the 2 species. *S. flexibilis* has smaller sclerites and a greater total surface area of sclerites per tissue volume than does *S. capillosa*. However, the stiffening effect of the sclerites of *S. flexibilis* is lower than that of *S. capillosa*. These facts indicate that the colony stiffness of the 2 species is not only affected by sclerites, but also the stiffness of the mesoglea.

For sessile organisms, the morphology or physiology has to match hydrodynamic conditions

**Table 1.** The analyses of variance of drag coefficients under various flow velocities between *Sinularia flexibilis* and *S. capillosa*

| Source | *df* | SS | MS | *F*-value | *p* |
|---|---|---|---|---|---|
| Model 1 | 15 | 0.863 | 0.0575 | 28.01 | > 0.0005 |
| Species | 1 | 0.001 | 0.0015 | 0.75 | n.s. |
| Velocity | 7 | 0.859 | 0.1228 | 59.76 | > 0.0005 |
| Species x Velocity | 7 | 0.002 | 0.0003 | 0.15 | n.s. |
| Error | 32 | 0.066 | 0.0021 | | |
| Corrected Total | 47 | 0.929 | | | |

R-square = 0.929.
*df*: degree of freedom.
SS: sum of squares.
MS: mean square.
n.s.: not significant.

**Table 2.** Morphological and mechanical properties of *Sinularia flexibilis* and *S. capillosa*

| | $\gamma$ | $l$ | $E$ | $E'$ | $\Delta E$ | $e$ |
|---|---|---|---|---|---|---|
| *Sinularia flexibilis* | 0.207 ± 0.022 | 0.77 ± 0.19 | 8.82 ± 0.68 | 8.19 ± 0.60 | 0.63 ± 0.97 | 0.07 ± 0.11 |
| *Sinularia capillosa* | 0.206 ± 0.017 | 1.48 ± 0.42 | 9.02 ± 0.87 | 4.83 ± 0.51 | 4.19 ± 1.34 | 0.47 ± 0.26 |
| *t*-value | 0.394 | 0.999 | 0.687 | 0.999 | 0.985 | 0.969 |
| *p* | n.s. | < 0.005 | n.s. | < 0.005 | < 0.05 | < 0.05 |

Values are expressed as the mean ± standard error of mean ($n$ = 5).
$\gamma$: volume fraction of sclerites in tissue.
$l$: mean length of sclerites (mm).
$E$: modulus of elasticity of sclerite-containing tissue (dyne $cm^{-2}$).
$E'$: modulus of elasticity of decalcified tissue (dyne $cm^{-2}$).
$\Delta E$: reduction of modulus of elasticity after decalcification (dyne $cm^{-2}$).
$e$: reinforcement of sclerites.
n.s.: not significant.

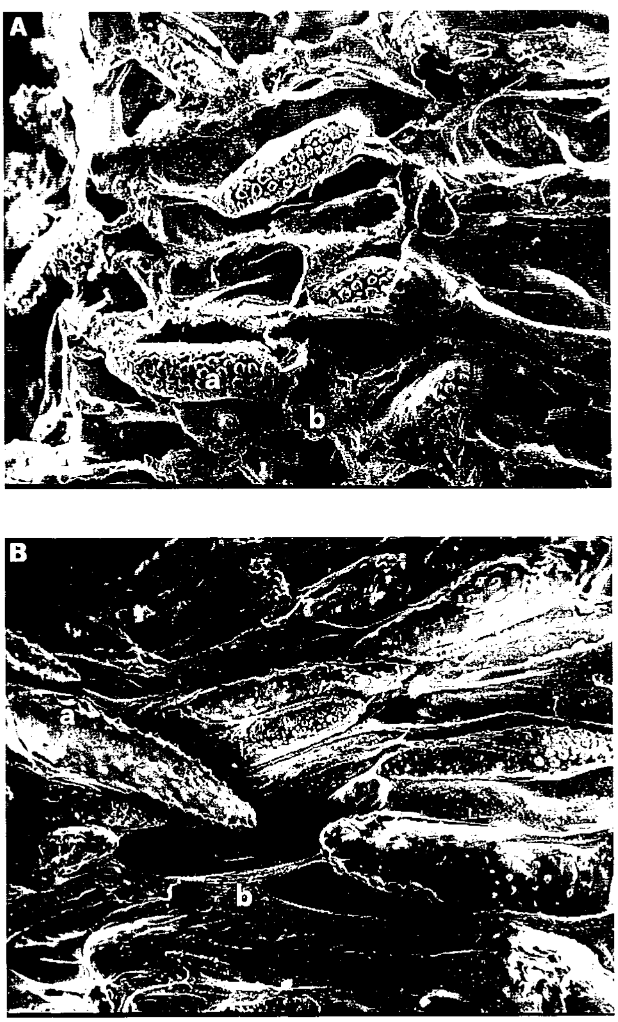


**Fig. 4.** The sclerites and mesogleas of *Sinularia flexibilis* and *S. capillosa*. (A: *Sinularia flexibilis*; B: *S. capillosa*; a: sclerite; b: mesoglea; Scale bar: 0.5 mm)

(Koehl 1984, Palumbi 1986). The morphology and skeletal materials of an organism can reflect adaptation to water movement (Peterson et al. 1982, Jeyasuria and Lewis 1987, Ricklefs and Miles 1994). *S. flexibilis* and *S. capillosa* coexist on reefs and experience similar wave stresses. They possess similar colony morphology and flexibility. However, they differ in the stiffness of the mesoglea and in sclerite size. Thus, these 2 sympatric species have similar morphological and mechanical properties to reduce drag. The properties are achieved through different skeletal constitutions.

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# 兩種指形軟珊瑚之形態和機械特性

林明炤[1]　　戴昌鳳[1]

本研究以生物力學的方法，分析柔軟指形軟珊瑚(*Sinularia flexibilis*)、條狀指形軟珊瑚(*S. capillosa*)的群體形態、機械特性和水流的關係。首先，以這兩種軟珊瑚的群體進行阻力實驗，於不同流速下，記錄珊瑚所承受的阻力和群體形態的改變，再取珊瑚的柱部組織，進行拉伸力試驗，測量應力和形變，推算珊瑚組織的彈性係數。結果顯示，這兩種軟珊瑚具有相似的形態和機械特性，其柔度使群體容易順應水流而變形，在較高的流速下，由於群體趨於流線形並倒向基底，可使阻力的作用減小。另外，這兩種軟珊瑚也具有相似的骨針含量和群體勁度，但它們的骨針大小和中膠層勁度卻不同，顯示骨針可能不是影響群體勁度的主要因子，中膠層勁度也許扮演著更重要的角色。因此，雖然這兩種軟珊瑚具有相似的形態和機械特性，但它們卻是藉著不同的支持構造減小阻力的作用。

**關鍵詞**：生物力學, 阻力, 骨針, 水流。

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