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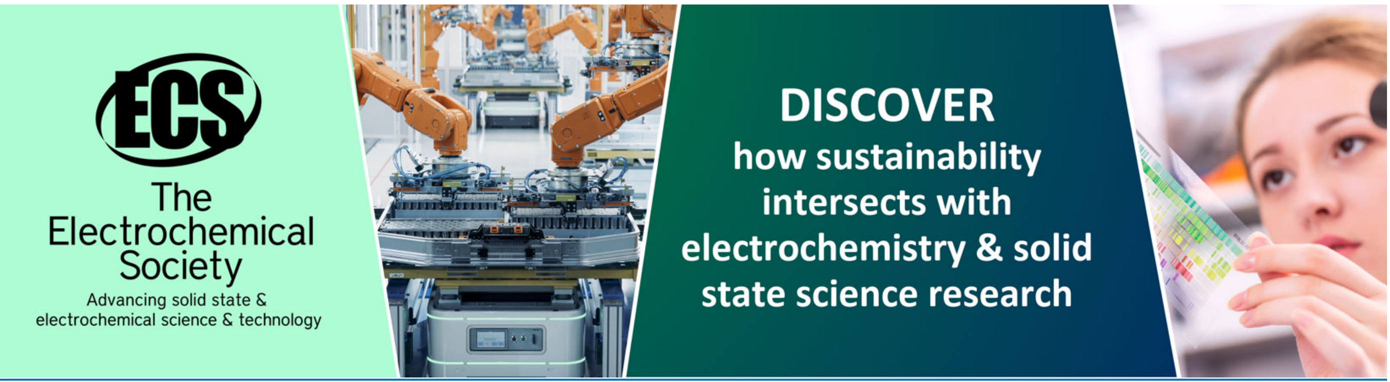

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Bending Properties of Fiber Composite Dilatant Compound

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Abstract. We have developed a viscoelastic-plastic dilatant compound, whose stiffness increases with increasing deformation rate, as a matrix material, and a "fiber composite dilatant compound" to which fibers have been added. In this study, three-point bending flexural tests were conducted to clarify the mechanical properties of the material. The results showed that the bending load increased when the fibers were oriented in the bending direction. It was also found that, under constant fiber content, lengthening the fibers and increasing the number of fibers by decreasing their diameter contributed to the increase in bending load.

1. Introduction

We have developed a fiber composite fluid, in which a dilatant fluid (Sear Thickening Fluid), having a characteristic of increasing viscosity with increasing shear rate, is used as a matrix material, and fibers are added. An anisotropic viscoelastic fin encapsulating the fiber composite fluid in a flexible urethane gel container was produced, and the dependence of its stiffness on bending rate was investigated [1]. This fin can be applied to various fields by taking advantage of the feature that the stiffness changes according to the deformation rate. However, in practical use, they require a container to seal the fluid, making them structurally complex. In related research, protective textiles in which the fiber is impregnated with dilatant fluid have also been developed, but the fluid content cannot be increased [2]. Thus, we developed a "fiber composite dilatant compound" using a viscoelastic-plastic dilatant compound as a matrix material instead of dilatant fluid. Since the viscoelastic-plastic dilatant compound is not a fluid, it does not require fins for encapsulation. For the viscoelastic-plastic dilatant compound, we selected Dow Corning 3179 Dilatant Compound [2]. This is an elastic silicone polymer that is also used in a toy called Silly Putty [3]. The mechanical properties of this material have been investigated [3-4], and its potential for sensor applications has also been studied [5].

In this study, three-point bending flexural tests were conducted to characterize the stiffness of fiber composite dilatant compounds as a mechanical property that increases with the deformation rate. This paper reports the results of the tests with varying fiber orientation and fiber specifications (length, diameter, and filling ratio).

2. Material and Methods

The matrix for the fiber composite dilatant compound was Dow Corning 3179 Dilatant Compound (henceforth referred to as compound), as described in the introduction. The fibers were nylon fibers regarding their strength balance with compound and availability.

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Figure 1 shows a test piece of three-point bending flexural test. The test piece was rectangular, and its dimensions was 90 × 20 × 9 mm. The diameter and length of the fiber (L and D), and fiber filling ratio (Fr, vol%) were varied. The test piece consists of three fiber layers and four compound layers (matrix layers). The method of the fabrication is as follows. (1) Forming the four compound layers (2) Placing the fibers in a certain direction on the top surface of the three compound layers (3) Overlapping the compound layers.

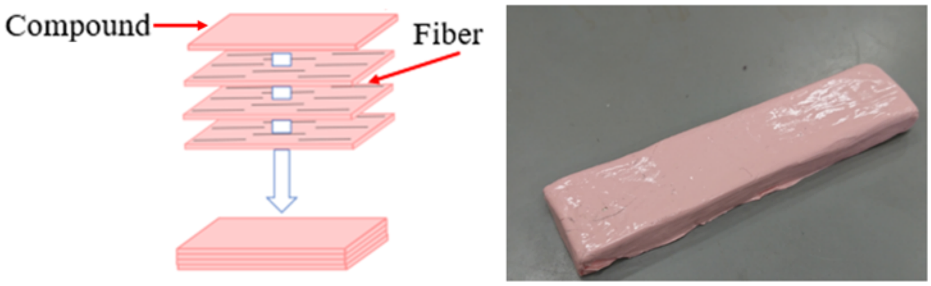
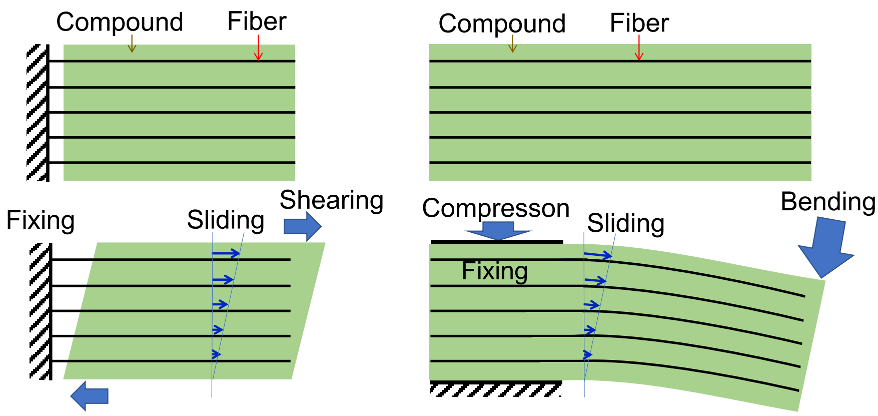


Figure 1. Test piece of three-point bending flexural test

Figure 2 shows a conceptual diagram of the effect of increased shear force obtained by composing fibers. (a) shows the shear deformation of the compound with one end of each fibers fixed. The shear deformation of the compound causes sliding between the fibers and the compound, resulting in a large shear force. (b) shows the state in which a part of the test piece is compressed and fixed, and the other tip is loaded to bent. From this figure, it can be seen that there is an area where the fiber is fixed and that the bending of the test piece creates the shear force due to sliding between the fiber and the compound. Therefore, a fixed region of fibers is necessary to generate sliding region between the fibers and the compound.



(a) Shearing (b) Bending

Figure 2. Concept of increasing shearing force and bending force by compositing fibers

Figure 3 shows a diagram of the three-point bending flexural test. The "parallel" fiber orientation means that the fiber direction and the direction of shear force due to bending are parallel. On the other hand, "perpendicular" means that the indenter's fiber direction and depth direction are parallel. The fiber direction and the direction of shear force due to bending are perpendicular. Indenter speed Ui was varied from 10 to 1000 mm/min from low to high speed. Indenter displacement was set to 0 mm when the indenter touched the test piece.

3. Results and discussion

3.1. Effect of fiber orientation and indenter speed on bending load

Figure 4 shows the results of a three-point bending flexural test at an indenter speed of 100 mm/min. As the displacement of the indenter increases, the bending load also increases, especially when the fiber orientation is parallel. In order to examine the effect of various test conditions on the bending load, the load at a displacement Zi of 8 mm (maximum value of the monotonically increasing load in the test) was measured three times and the average value was defined as the representative value of the bending load.

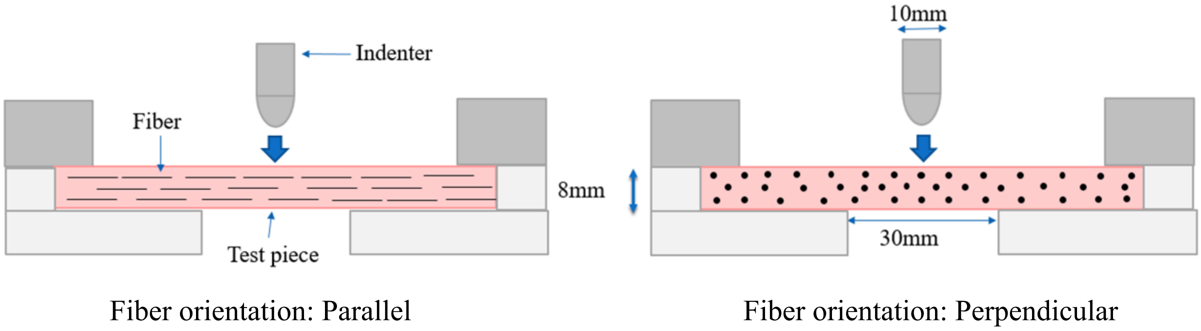


Figure 3. Three-point bending flexural test

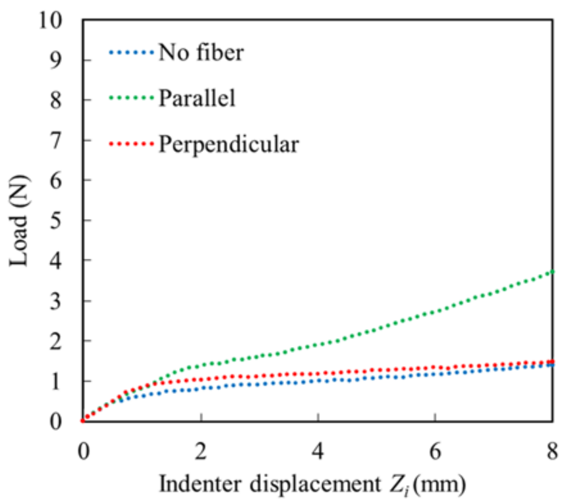


Figure 4. Three-point bending flexural test results.
Indenter speed = 100 mm/min, Fiber diameter D=0.165 mm, Fiber length, L=15mm, Number of fibers N=144, Filling ratio F_r=0.29 vol%

Figure 5 shows a schematic diagram of test piece deformation when the fiber orientation is parallel. The flow inside the compound due to the deformation produces a sliding region between the fibers and the compound. Thus, greater shear force is generated due to the shear rate of the compound. In a three-point bending flexural test, a fixation region or a region with relatively slow sliding velocity is considered to occur at the point where the compound is compressed by the indenter or support plate. As explained in Fig. 2, if there is no fixing region where the compound and fibers are fixed, a sliding region will not occur. In the three-point bending test, the fixing region is considered to occur at the point where the compound is compressed by the indenter or support plate. Thus, when the fiber orientation is parallel, a sliding region is generated and the load increases, while when the fiber orientation is perpendicular, no sliding region is generated and the load is as low as in the no-fiber condition.

Figure 6 shows the relationship between indenter speed and load at Zi=8mm. The load increases with increasing indenter speeds. These characteristics are due to the dilatancy property of the compound. The load is higher in the parallel orientation case than in the perpendicular orientation case for the

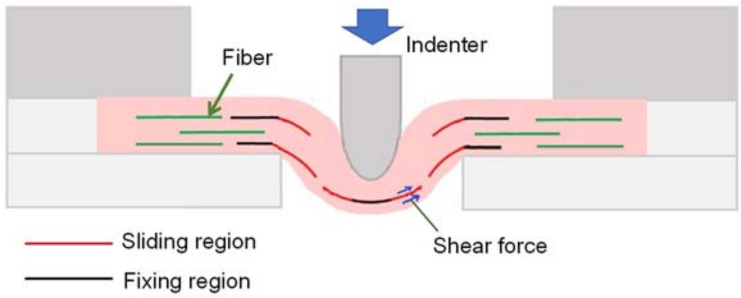


Figure 5. Schematic bending diagram of the test piece (Parallel fiber orientation)

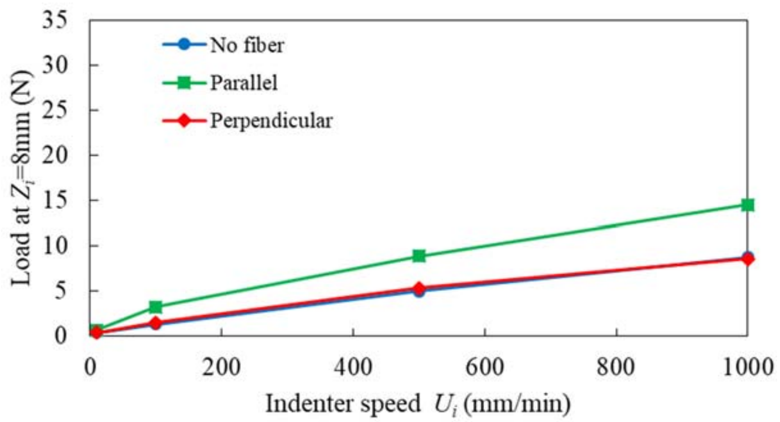


Figure 6. Relationship between indenter speed and load. Fiber diameter D=0.165 mm, Fiber length, L=15mm, Number of fibers N=144, Filling ratio F_r=0.29 vol%

fiber orientation. This is because, as already mentioned, parallel fiber orientation increases the shear force between the fibers and the compound. Also, as the indenter speed increases, it becomes even more significant due to the dilatancy of the compound.

3.2. Effect of fiber length on bending load under constant fiber diameter and fiber filling ratio (Parallel fiber orientation)

Figure 7 shows the relationship between fiber length L and load. The number of fibers varies because the fiber diameter and filling ratio are kept constant. A fiber length of 0 mm means no fiber. As L increases, the load also increases because the longer the fiber, the greater the length of the fixing and sliding regions. However, since the fiber diameter and filling ratio are kept constant, the total surface area of the fiber (excluding the area of the end faces) is constant, which means that the number of fibers is reduced when the fiber is longer. Nevertheless, the longer the fiber, the larger the load, which means that the length of the fiber is a significant factor in the load increase.

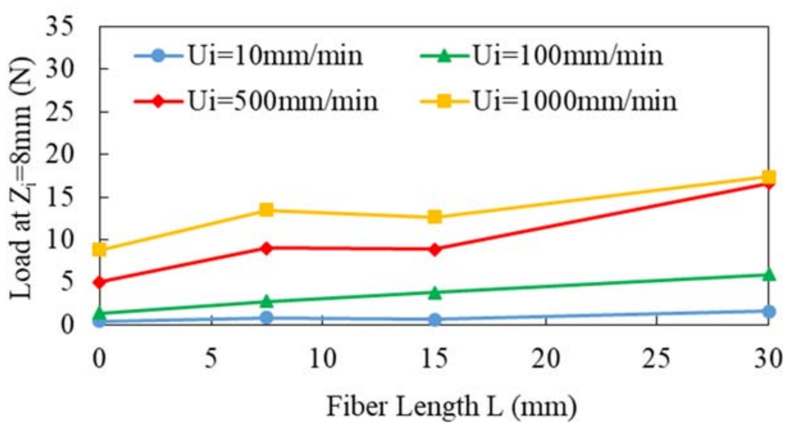


Figure 7. Relationship between fiber length L and load. Parallel orientation, Fiber diameter D=0.165 mm, Filling ratio F_r=0.29 vol %. Number of fibers N (72 - 288) were changed to keep constant Fr.

3.3. *Effect of fiber diameter on bending load under constant fiber length and fiber filling ratio (Parallel fiber orientation)*

Figure 8 shows a relationship between fiber diameter D and load. The number of fibers varies because the filling ratio and fiber length are kept constant. As in Fig. 7, a fiber length of 0 mm means no fibers, and the existence of parallel-oriented fibers increases the load. However, the load tends to decrease as the fiber diameter increases above 0.117 mm. This tendency is because since the fiber length and filling ratio is constant, the total surface area of the fibers decreases as the number of fibers decreases with increasing fiber diameter. Therefore, for the same filling ratio and fiber length, it is better to make the fiber diameter smaller to increase the number of fibers and surface area where the sliding region occurs. However, there is a limit to the smaller fiber diameter for the increase of load, and future tests with fibers with diameters smaller than 0.117 mm are needed to verify this.

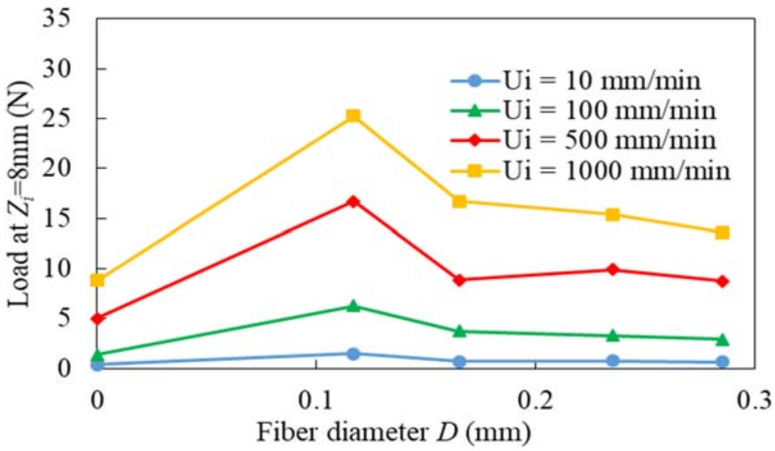


Figure 8. Relationship between fiber diameter *D* and load. Parallel orientation, Fiber length, *L*=15mm, Filling ratio F_r=0.29 vol %. Number of fibers *N* were changed from 288 (at *D*= 0.117 mm) to 48 (at *D*=0.285 mm) to keep constant *Fr*.

3.4. *Effect of filling ratio on load under constant fiber length and fiber diameter (Parallel fiber orientation)*

Figure 9 shows the relationship between fiber filling ratio Fr and load. Since the fiber length and diameter were kept constant, the filling ratio varied by changing the number of fibers. The load increased as the filling ratio increased because of the fibers' increased number and total surface area. However, the fibers' stiffness effect is negligible because this study's fiber-filling ratio is meager. From the above, the load depends on the sliding between the compound and the fibers and increasing the fibers' length, and number (surface area) is essential to increase the load.

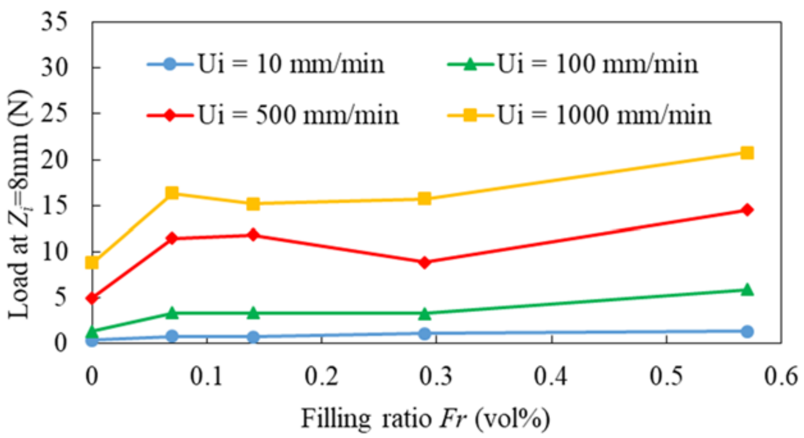


Figure 9. Relationship between fiber filling ratio *Fr* and load. Parallel orientation, Fiber length, *L*=15mm, Fiber diameter *D*=0.16: mm,Filling ratio F_r=0.29 vol % Number of fibers *N* was changed from 36 (at F_r = 0.07 vol %) to - 288 (at F_r = 0.57 vol %)

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4. Conclusion

In this study, we conducted the three-point bending flexural test to investigate the mechanical properties of "The Fiber Composite Dilatant Compound." The results showed that the large bending load could obtain by orienting the fibers parallel to the bending, increasing the number of fibers by thinning and lengthening their fibers. This large bending load attributes to the increased sliding region between the fibers and the compound.

Future issues for this study include increasing the filling ratio, fiber fineness, and the effects of fiber material (fiber surface: friction between fiber and compound, and fiber stiffness).

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