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Geogrids and continuous filaments in earth reinforcement

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ABSTRACT: Earth reinforcement can take the form either of discrete layers such as polymer geogrids or randomly placed continuous filaments. The reinforcing mechanism for each of these types is different. Two types of geogrid used in different quantities and geometrical configurations were compared with continuous polyester filaments of two diameters and a range of reinforcement to weight ratios. The effectiveness of each reinforcement was measured by applying a vertical load to soil behind a model retaining wall and measuring the resulting vertical settlement and lateral force on the wall. The results indicated that soil reinforced with continuous filaments gave much reduced vertical settlements behind the wall together with considerably smaller lateral forces for the same proportion of reinforcement when compared to various types and geometries of geogrid reinforcement. The addition of random reinforcement is shown to provide a stress dependent cohesion to the soil considerably reducing lateral stress.

1 INTRODUCTION

Earth reinforcement can take the form of either discrete layers or less commonly random continuous filaments developed by Leflaive (1982), or mesh elements (Mercer et al, 1984); (McGown et al, 1985). The reinforcing mechanism for each of these types is different.

In order to compare the effectiveness of the two types of reinforcement, random and discrete; a series of tests have been carried out on reinforced soil behind a model retaining wall. Two types of polypropylene geogrid have been used in different quantities and geometrical configurations. The results were compared with continuous randomly placed polyester filaments at two diameters of 0.2mm and 0.6mm.

Vidal (1978) first noticed that random reinforcement increased the strength of a composite material. Early tests by Grey (1978) and Verma and Char (1988) on soil reinforced with short lengths of filament suggested there was little beneficial effect. It is important however for the reinforcement to have sufficient length for friction and hence tension to develop, and Leflaive (1985) showed that continuous filament reinforcement was beneficial in carrying tensile forces in soil. The mechanism suggested was that increasing strains pull the filament tightly around groups of soil particles increasing soil friction. In addition the random looping and cross-over of filaments results in an increasing tightening of slack sections as the soil is loaded, thus bringing further reinforcement into play. Leflaive (1988) successfully tested a 3m high retaining wall reinforced with polyester yarn and this technique is now widely used in both France and Japan.

Long et al (1972) and Hausmann (1976) introduced the concept of reinforcement providing a cohesion intercept to the Mohr-Coulomb failure envelope for the composite material. Hoare (1979) testing soil reinforced with random mesh elements found that an addition of 1% reinforcement by weight of soil increased the angle of shearing resistance by 2-3 degrees.

Tests on soil reinforced with random mesh elements by Mercer et al (1984) and Andrawes et al (1986) have shown that the introduction of up to 0.6% by weight of random reinforcement does not cause an increase in void ratio while CBR values increased by as much as 400% and in footing tests bearing pressures were much increased for a given settlement. Triaxial tests on the composite material also gave greater peak shear strengths together with enhanced ductility.

2 EQUIPMENT

The model retaining wall apparatus consisted of a strong three sided container lined with a low friction coating (PTFE). The internal dimensions of the box were 500mm high, 500mm wide and 500mm long. The model wall of dimensions

Table 1. Arrangement of reinforced soil tests

Type	Weight ratio	Layers	Position
SS35	1:1000 1:1000 1:1000 1.5:1000 2:1000	1 1 1 1.5 2	1/2h 1/3h 2/3h 1@2/3h; 1/2@1/3h 1/3h, 2/3h
SS3	0.5:1000 1:1000 1.5:1000 2:1000	1 2 3 4	1/3h 1/3h, 2/3h 1/4h, 1/2h 3/4h 1/5h, 2/5h 3/5h, 4/5h
0.2mm filament	1:1000 1.5:1000 2:1000	rando m	continuous
0.6mm filament	1:1000 1.5:1000 2:1000	rando m	continuous

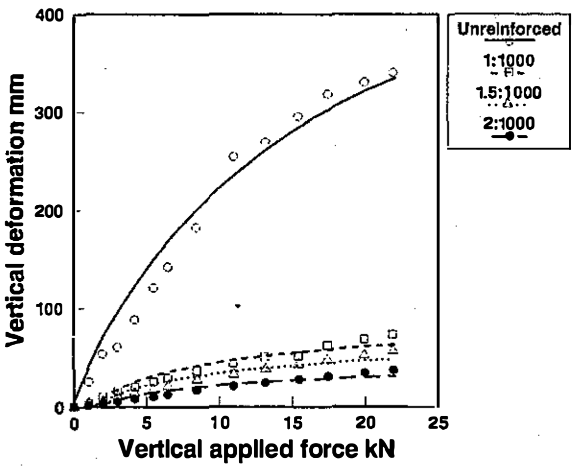

Figure 1 Vertical settlement against vertical load; 0.2mm filament.

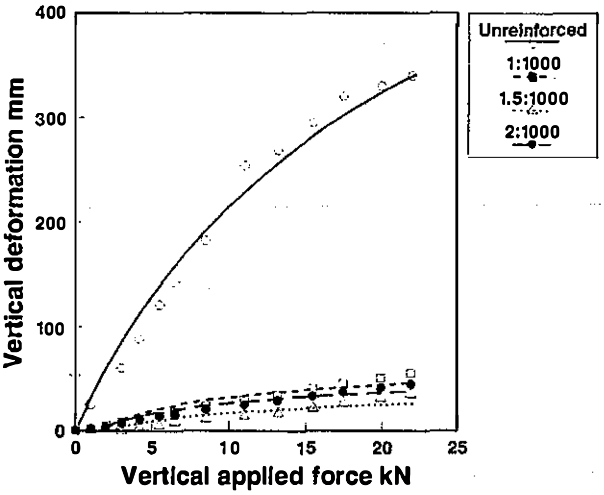

Figure 2 Vertical settlement against vertical load; 0.6mm filament.

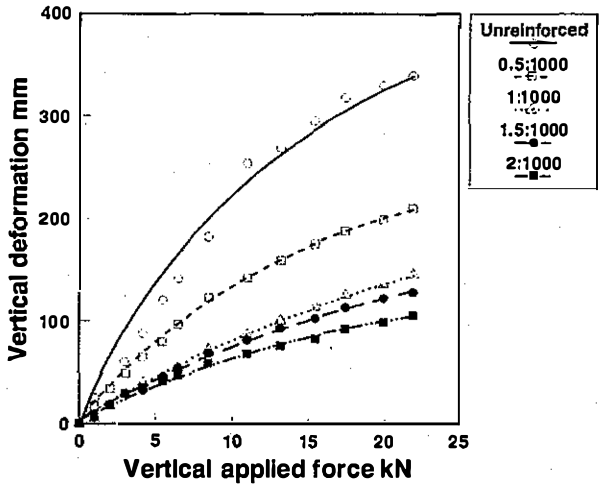

Figure 3 Vertical settlement against vertical load; SS3 Geogrid

500mm x 500mm formed the fourth side of the box. The wall was restrained from sliding at the toe but was free to rotate.

With the wall temporarily fixed in place the box was filled to the top and then loaded vertically using a hydraulic ram. Loads were determined by measuring the hydraulic pressure to the ram. The load was applied through a steel plate and was uniformly distributed over the surface of the sand. Readings were taken of both the vertical displacement behind the wall and also the rotation of the wall, using dial gauges. The horizontal force on the wall was monitored using a proving ring fixed at one third of the height of the wall.

The box was filled with a well graded sand with particle sizes of 5mm downwards. The friction angle of the sand was estimated from shear box and drained triaxial tests and was found to be 38° peak and 31° residual.

The sand was reinforced with four different materials. These were two types of "Tensar" biaxial geogrids, SS3 and SS35, and two types of continuous randomly oriented polyester filaments of 0.2mm and 0.6mm diameters.

The properties of the polypropylene geogrids were as follows:

SS3

weight:	0.24 kg/m2
strength:	transverse 27.4kN/m longitudinal 16.1kN/m

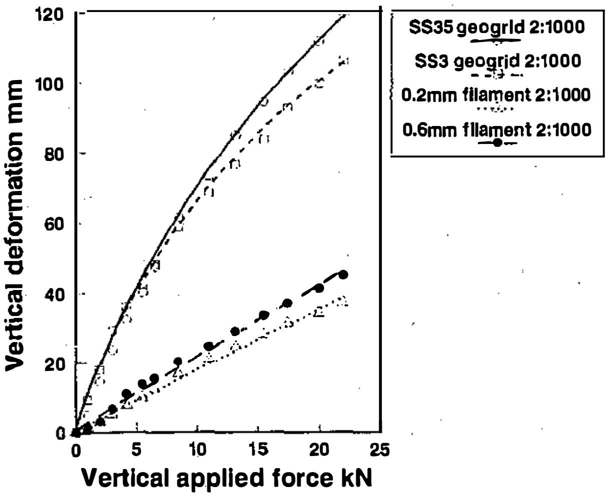

Figure 4 Vertical settlement against vertical load. Comparison between filament and geogrid

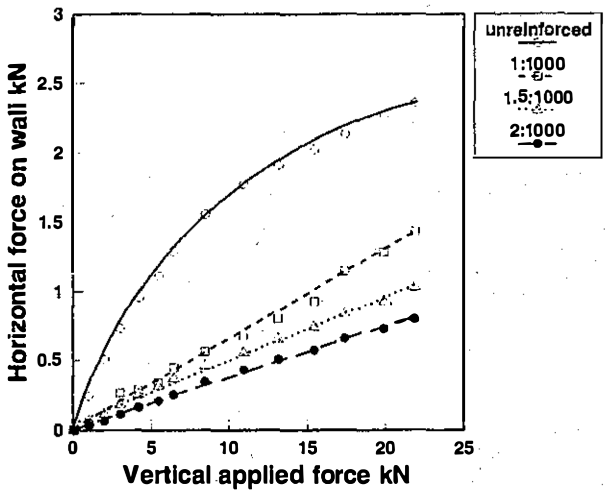

Figure 6 Horizontal force on wall against vertical load; 0.6mm filament

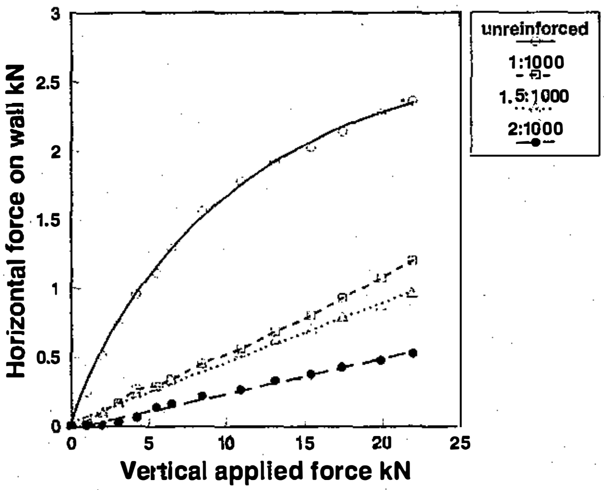

Figure 5 Horizontal force on wall against vertical load; 0.2mm filament

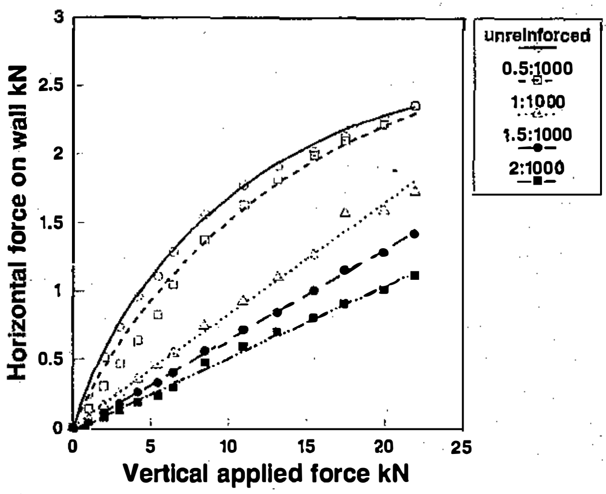

Figure 7 Horizontal force on wall against vertical load; SS3 geogrid.

SS35 weight 0.55 kg/m2
strength: transverse 42.0kN/m
longitudinal 34.0kN/m

Sand was placed behind the wall in three layers, compacting each layer with a heavy tamping bar. The soil was reinforced with either Tensar geogrids or continuous polyester filament. In the case of the geogrids these were placed at the appropriate height during the sand filling process with the transverse direction perpendicular to the wall. The quantity of filament to be used was first measured out and then some of the filament was unrolled in the box and sand poured in. The filament was then pulled out lightly by hand to create a uniform distribution before the sand was compacted this procedure was repeated until the box was filled.

3 TESTING PROGRAMME

The aim of the tests were to compare the effect of similar quantities of reinforcement by weight of sand on the vertical deformation and the lateral load transferred to the wall, with the ultimate aim of comparing the efficiency of the different soil reinforcement techniques.

Field tests by Andrawes et al (1986) on random meshes suggested that proportions of reinforcement:soil by weight of 1:1000 or 2:1000 were sufficient to achieve a beneficial effect. Reinforcement ratios were therefore chosen, varying from 0.5:1000 to 2:1000.

It was found that 1 sheet of SS35 geogrid which was enough to cover the fill had a weight of 120g and the sand fill was 120kg. This therefore gave a

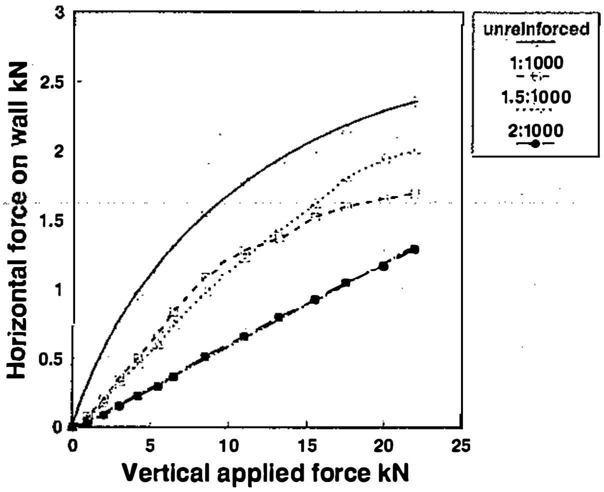

Figure 8 Horizontal force on wall against vertical load; SS35 geogrid.

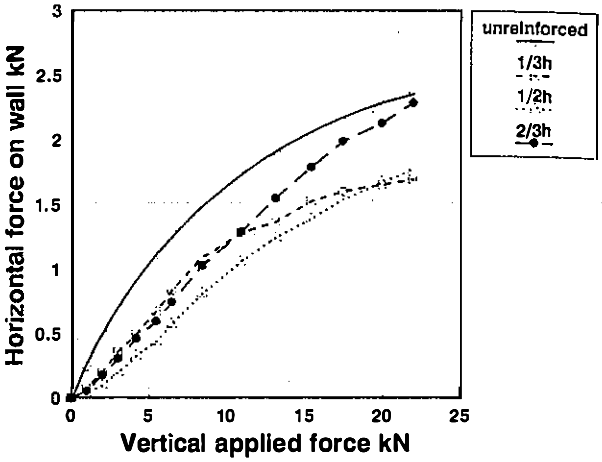

Figure 10 Horizontal force on wall against vertical load; effect of position of ss 35 geogrid. 1:1000

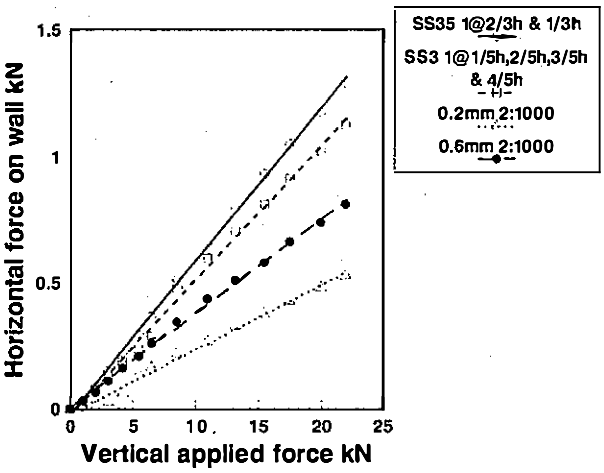

Figure 9 Horizontal force on wall against vertical load; comparison between geogrids and continuous filament 2:1000.

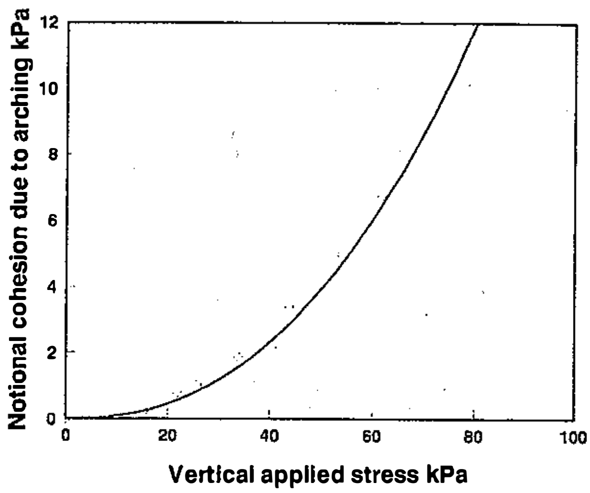

Figure 11 Notional cohesion due to arching; unreinforced soil

1:1000 reinforcement/soil weight ratio. "Tensar" SS3 grids had a weight of 60g per layer, thus each layer represented a 0.5:1000 ratio. The arrangements of grid and filament reinforcement are shown in Table 1.

4 RESULTS

Considering first the vertical deformation of the soil surface as the wall was loaded Figs 1 and 2 show the effect of 0.2mm and 0.6mm continuous filament reinforcement at the ratios by weight of soil of 1:1000, 1.5:1000 and 2:1000. The overall vertical deformation is dramatically reduced for reinforced soil compared with unreinforced. The deformation was dramatically reduced from a maximum of 340mm for unreinforced soil to maximum values ranging from 73mm down to as little as 37mm for 0.2mm filament at a ratio of 2:1000, with corresponding reductions at lower loads. Little benefit was gained by using a thicker filament of 0.6mm. In contrast the geogrids did not perform as well. Figure 3 shows the reduction in settlement for various ratios of SS3 geogrid from 0.5 to 2:1000. The vertical deformations were more than double those for continuous filaments. Figure 4 compares the action of the two types of geogrid and filaments at a constant ratio of 2:1000. The least efficient was the heavier geogrid SS35 while the least deformation was experienced by the 0.2mm and not the 0.6mm filament reinforced soil. It is clear that the length of filament introduced into the soil is more important than the tensile strength of the filament.

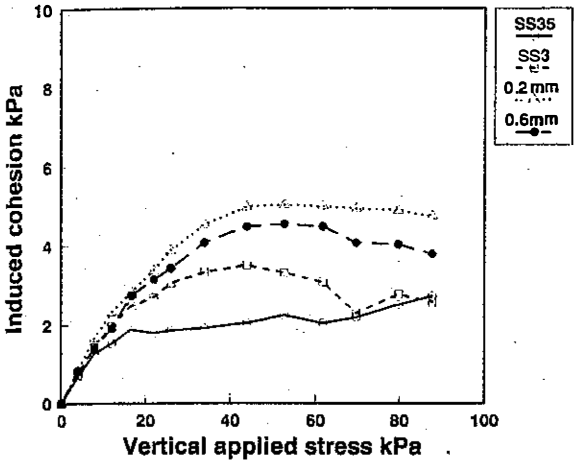

Figure 12 Induced cohesion against vertical stress; 1:1000

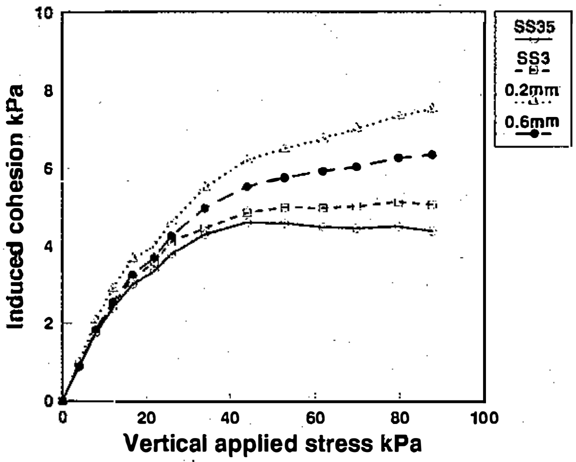

Figure 13 Induced cohesion against vertical stress; 2:1000

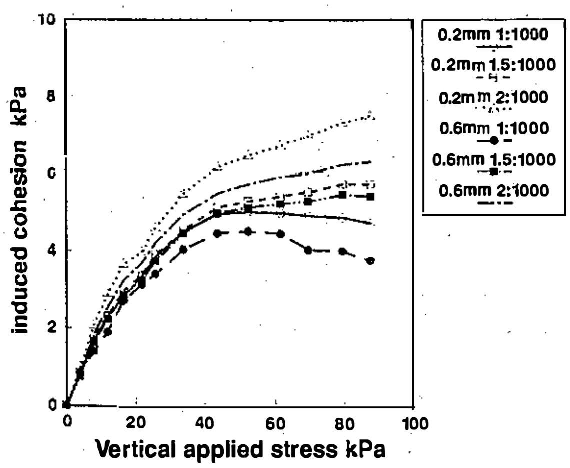

Figure 14 Induced cohesion against vertical stress; filament reinforced

Considering next the associated horizontal force measured at 1/3 of the height of the wall. Figures 5 and 6 show that the random reinforcement reduces lateral forces by between 50% and 75%. Similar benefits are not achieved by the geogrids (Figures 7 and 8). Little reduction was achieved by an SS3 geogrid ratio of 0.5:1000 which represented a single sheet placed at one third the height of the wall. In this case the composite behaved as though it was unreinforced. To achieve reductions in lateral stress of 50% ratios of 1.5:1000 for SS3 and 2:1000 for SS35 had to be introduced. Figure 9 illustrates the effect of each type of reinforcement at a ratio of 2:1000. This ratio was chosen for comparison since there were several sheets of geogrid reinforcement allowing a closer comparison with the randomly distributed filament. Even so, the filaments outperformed the geogrids in reducing the horizontal stresses.

It was suspected that the position of the geogrid reinforcement would affect the behaviour of the composite so tests were carried out on the SS35 geogrid placed at 1/3h, 1/2h and 2/3h. These tests (figure 10) showed that there was ultimately little difference at low stresses between the geogrid positions but that geogrids placed at the highest position of 2/3h were least efficient under ultimate conditions.

The concept introduced by Schlosser and Long (1973) and Hausmann (1976) that the reduction in lateral stress in a reinforced soil is equivalent to introducing or increasing a cohesion intercept in the Mohr-Coulomb failure envelope for the composite allows a comparison between the effect of the different types of reinforcement.

Assuming the soil friction angle $\phi' = 38°$ to be constant gives a single value for the active coefficient Ka = 0238.

Assuming the measured lateral stress on the wall:

$$\sigma_h = K_a \sigma_v - 2c\sqrt{K_a}$$

where σ_v is the applied vertical stress
and c is the "cohesion" intercept.

Then the cohesion

$$c = \frac{K_a \sigma_v - \sigma_h}{2\sqrt{K_a}}$$

It was noticed for the unreinforced sand that wall pressures were less than those expected from Rankine theory and it was assumed that this was caused by arching and scale effects of the sand and model container. The computed values for 'c' were therefore compensated by assuming that this effect introduced a notional 'c' value, Figure 11, which was subtracted from the values obtained for the reinforced soils. The resulting values were termed the "induced cohesion".

The induced cohesion values were not constant but increased with applied vertical stress which implies that the Mohr-Coulomb envelope for these composites is curved. At a reinforcement ratio of 1:1000, figure 12, the geogrid generated an induced cohesion of between 2 and 3kPa while the values for the filament increased to between 4 and 5 kPa. Similarly at a ratio of 2:1000, figure 13, the induced cohesion for the filament was correspondingly higher. The highest cohesions were obtained for the 0.2mm filament at a ratio of 2:1000. Examination of figure 14 reveals that at each ratio the 0.2mm gave higher ultimate induced cohesions compared with the 0.6mm filament. This shows once again that length of filament is a more important determinant of composite stiffness and strength than the tensile strength of the filament.

5 CONCLUSIONS

The results indicated that soil reinforced with continuous filaments gave much reduced vertical settlements behind a model retaining wall together with considerably smaller lateral forces for the same proportion of reinforcement by weight when compared to various types and geometries of geogrid reinforcement.

Values of induced cohesion in the soil composites when corrected for the arching effect were much higher for the continuous randomly placed filament than for the discrete layers of geogrid.

Increasingly the length of filament introduced into the composite had a more beneficial effect on settlement, lateral stress and induced cohesion than increasing the tensile strength of the filament. The induced cohesion increased with applied stress implying a curved Mohr-Coulomb failure envelope for the composite materials.

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