NEW COMPOSITE CONSTRUCTION MATERIAL WHICH SOLIDIFIES IN WATER

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A flexible water proof structural material which will solidify in water as well as in air has long been desired in civil engineering.[1,2] The authors have developed a new class of material, which we call Aquaphalt, collectively composed mainly of asphalt emulsion and cement which has this ability.
The components of this new material are liquid at ambient temperature, but when mixed, form a gel almost instantly.
The gel does not disperse in water, and gradually becomes hard, whether in water or air. Geling time and hardness are adjustable by changing the composition. The mixture is soft and sticky, similar to asphalt, and has the properties of excellent resistance to water, to fracture due to earthquakes,
and of good adhesion to other materials. Aquaphalt is anticipated to have practical applications in tunnels, dams and in sandy ground beneath new buildings in earthquake-prone areas.
Backpack materials for tunnels, especially shield tunnels, must have be water proof, able to spread ground load and resistance to earthquakes.

This paper describes the characteristics of Aquaphalt as applied as a backpack material.

Table-1 shows the composition of Aquaphalt.

It is composed of asphalt emulsion, cement and high absorptive polymer.

Figures 1 and 2 show the results of the cone penetration test(reduced compressive strength) and the axial compression test(compressive strength) after 7 days curing in water. The reduced compressive strength and the compressive strength of the mixture using jet cement is about $0.5kgf/cm^2$ at one hour. and about $2.0kgf/cm^2$ at 7 days, while reduced compressive strength and compressive strength of the mixture using high early portland cement is about $0.02kgf/cm^2$ at one hour, and about $1.5kgf/cm^2$ at 7 days. As shown in Fig-1, the strength over the short time range(initial strength) of the Aquaphalt is about the same even with a high content of high absorptive polymer, but the compressive strength of the Aquaphalt increases a little with increase of cement content. The compressive strength of plastic material commonly used in backpack material is $0.1kgf/cm^2$ at one hour, and $20kgf/cm^2$ at 7 days.

The strength of Aquaphalt is thus much lower than that of materials commonly used for backpack material, but on other hand, ductility is much higher. Ductility is in fact a more desirable property for this use because in the event of an earthquake, movement of rock surrounding the structure can be great enough that normal backpack fractures(0.5% Strain at failure),fracturing tunnel segments and allowing leaks. The ductility of Aquaphalt(1%-5% strain at failure) enabls it to cusion shock from earthquakes, maintaining the integrity and watertightness of the tunnel structure.

Table-2 shows the results of the permeability test. Aquaphaltis highly water proof, comperative with cement and its water permeability, like that of asphalt, drops slightly with increase in pressure. The water permeability of the Aquaphalt is 10^{-9} sec^{-1} under $3kgf/cm^2$ pressure.

Figures 3 and 4 show the results of the torsion test on cylidrical hollow specimen. The shear modulus of the Aquaphalt is about 200 kgf/cm^2 in 1×10^{-4} strain. White circles shows the shear modulus of samples of mixture(No2) after 10 days curing in water while subjected to a 1 kgf/cm^2 stress. The same samples were then reimmersed in water, without applied strain, for 4 more days, and retested. Ordinarily, such samples would show a severly reduced shear modulus, due to microscopic fracture incurred during the earlier test. However, as the black circles in Figure 3 shows, shear modulus, and thus strength, are not adversely affected by the strain at all. Also, the coefficient of damping is significantly higher than that of presently applied backpack materials.

Fig-4 shows the hysteresis curve of Aqaphalt. Normal backpack materiales fracture at these levels of strain, but Aquaphalt withstood five cycles, as can be seen on the figure. The strain increased slightly on each cycle, which shows again that fracture was not taking place inside the material.

Fig-5 shows a cross section of Aquaphalt as seen under an electron microscope.

Table-1 Composition of New Material(unit g)

Specimen No	1	2#	3	4	5	6
Material						
Asphalt Emulsion	2000	2000	2000	2000	2000	2000
High Early Portland Cement	600	600	600	800		
Jet Cement					400	600
High Absorptive Polymer	40	60	80	60	60	40

#: standard specimenn

Table-2 Results of Permeability Test(cm/sec)

Curing Time in Water	7 days		28 days	
Confining Pressure (kgf/cm^2)	1	3	1	3
New Material (specimen No2)	8.0×10^{-9}	2.0×10^{-9} - 2.0×10^{-10}	1.9×10^{-9} - 8.9×10^{-10}	
Plastic Material Commonly Used in Backpack Material	1.7×10^{-7}	2.2×10^{-7}		

Fig-6 shows the system of material injection in a shield tunnel. As the boring machine moves forward through the rock, it gradually leaves the constructed tunnel behind; after it has left enough space for a new segment (typically one meter), a segment, composed of several arc-shaped sections, is installed in front of the last one. The boring machine is slightly larger in diameter than the outer diameter of the segment; the segment is actually installed inside a lip running around the circumference of the rear of the boring machine. There is thus a narrow space between the segment and the rock face. Two of the sections of the segment, typically installed at the '10 o'clock' and the '2 o'clock' positions, have ports for injecting the backpack material, while a third at the '12 o'clock' position, has a port for water drainage. The material is injected as soon as all the sections are in place. However, present materials are highly viscous and do not spread well during injection, leaving voids which allow water from surrouding rock to leak through the cracks between segments. Aquaphalt is transported into the tunnel in the form of two liquids, one, 'Liquid A', being asphalt emulsion and cement, and the other, 'Liquid B', high absorptive polymer. Liquids A and B are mixed in a tube mixer. This is called a 1.5 shot system because Liquid B is mixed on the midway in a tube. The mix flows from the tube mixer through a short hose to the port. As the gel which forms in the mixer and the hose has a very low viscosity, comparable to milkshake mix, the gel spreads throughout the space between the segment and rock face, filling it completely. The gel repels water, pusing it back into cracks in the rock face or through the draimage port. The gel adheres firmly to the rock face or through the drainage port. The gel adheres firmly to the rock and to the segment. As it solidifies over the next several days, it swells slightly, maintaining the seal between the tunnel and the rock face.

Aquaphalt is to be used in 1990 in the Tokyo Bay Tunnel(diameter 14m, length about 10kmx3), which will be built using shield method.

In present, we also developed the Aquaphalt which does not use the high absorbtive polymer.

1 Nakahara.Y.and et al, Annual Report of Kajima Institute of Construction Technology Kajima Corporation, Vol 29, June, pp 1-8, 1981 (In Japanese)

2 Engineering News Record, pp26-28, July 20, 1989

Dear Sir or Madame

I am submitting the enclosed paper for consideration for an article in NATURE. I believe it meets two of your standards for publication: it furnishes a new material which has been searched for by many in the past, and it furnishes a new practical method.

This paper describes the characteristics of a new material, 'aquaphalt', which I have developed over the past 10 years as an asphalt emulsion which hardens in water. The new material i cheap, sticky and soft similar to asphalt. Aquaphalt is liquid in ambient temperature and after mixing, it changes to gel type mixture in 30 or 60 seconds. The mixture does not disperse in water and gradually becomes hard whether in water or air. The mixtu has the desirable properties of watertightness, resistance to earthquakes, and good adhesion to other materials.

I believe it will be welcomed by other researchers and by companies in civil engineering.

Sincerely Yours,

Akihiro MORIYOSHI

Fig-1 shows the relation between reduced compressive strength and time.

Test method: Cone Penetration Test

This is a test of the strength of cement mortar. A Penetration cone (weight 0.1kgf, head angle 15^{O}) is allowed by its own weight into the test material. The volume of the indentation yields the material strength, called the 'Reduced compressive strength'.

Fig-2 shows the relation between compressive strength and compressive strain.

Test method: Axial Compression Test

A specimen is compressed at $15^{O}C$ at rate of strain 1.0%/min. The size of the specimenn is 5cm(diameter)x10cm(height).

Figure 3 shows the relations of shear modulus and coefficient of damping with strain.

Test method: Hollow Cylindrical Torsion Test

The sample of Aquaphalt (outer diameter 10 cm, innner diameter 6cm, height 17.5cm), cured for 7 to 14 days in water, is fixed at both ends and subjected to torsion. Stress is controlled by electro servo machine under the following conditions: confining pressure, 0.4 kgf/cm^2; sinusoidal wave frequency 0.05 Hz; temperature, $20^{O}C$; maximum stress, 1.0 kgf/cm^2. The white circles show the tests on samples which were cured for 10 days in water with an applied 1 kgf/cm^2 stress. Black circles show the results of the same tests on the same samples. The samples were cured for 4 more days in water with no applied stress. Shear modulus of the samples actually rose, despite the punishment of the earlier tests.

Figure 4 shows the hysterisis curve of Aquaphalt.

Test Method: Hollow Cylindrical Torsion Test

Samples were subjected to an alternating stress of 0.3 kgf/cm^2, resulting in a strain of initially one percent. Despite five cycles through this high strain, which would fracture commonly used tunnel backpack materials, Aquaphalt retained its integrity, showing a high flexibility.

Accordingly, it is conducted that a large strain does not effect the results of the torsion test and the Aquaphalt does not fail at the 5th application 1% strain.

Table-2 shows the results of the permeability test (specimenn No2)

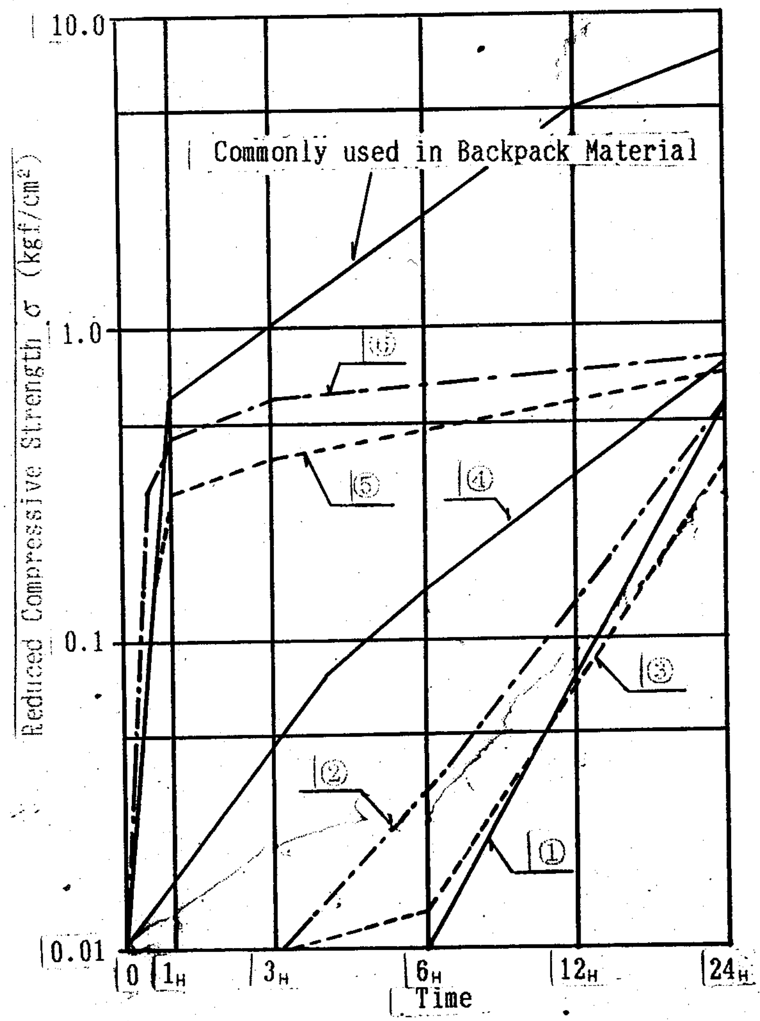
Test method: Permeability Test

The sample (diameter 10cm, height 5cm) is fixed in a confining cell and subjected to 1-3 kgf/cm^2 water pressure.

The water permeability of the Aquaphalt is remarkably smaller than that of the plastic material which is commonly used in backpack material, and the water permeability of the Aquaphlt becomes lower when the confining pressure increases.

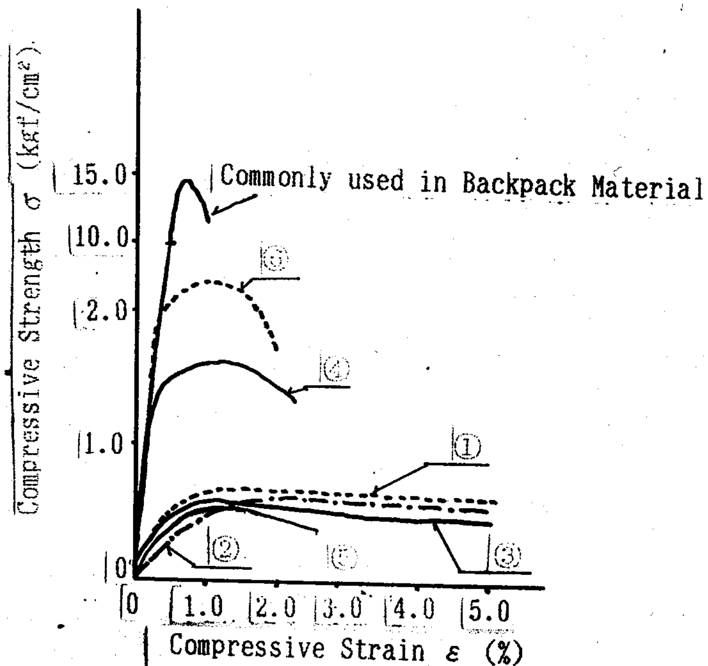
Fig-5 shows the cross section of Aquaphlt under an electron microscope. The sample was cooled by cryostat to -110°C to prevent volitiles from evaporating in the vacuum required for the operation of an electron microscope. A small piece was broken off the sample and its surface was examined at 3500 magnification.

Fig-6 shows the system of injection of backpack material in a shield tunnel.



10.0
1.0
0.1
0.01
Reduced Compressive Strength σ (kgf/cm²)
Commonly used in Backpack Material
⑥
⑤
④
③
②
①
0
1H
3H
6H
12H
24H
Time

Fig-1



Cross Head Speed 1mm/1min.
(7 days curing in water)

Fig-2

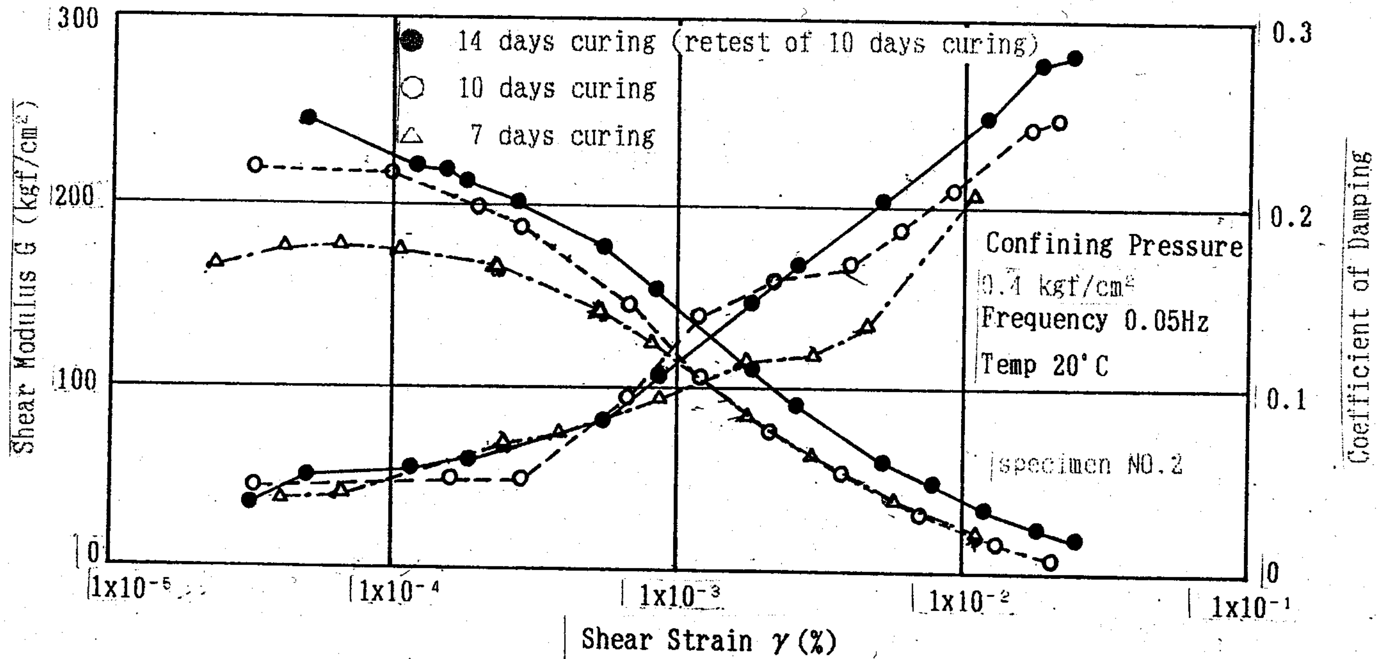
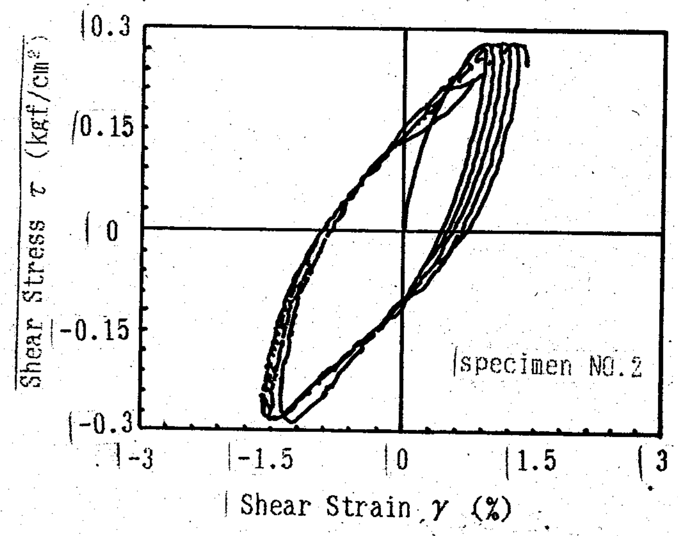


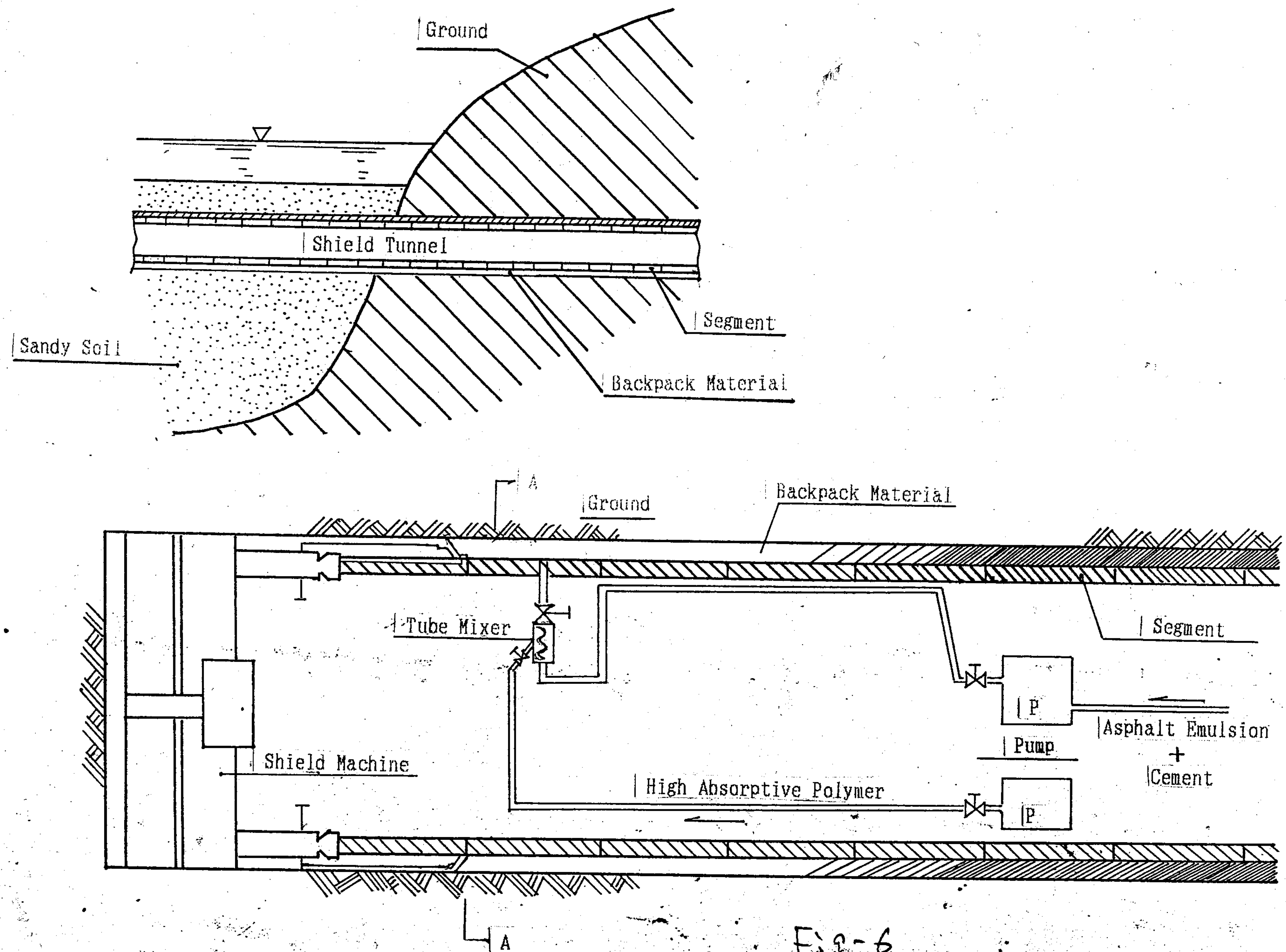
Fig-3 Hollow Cylindrical Torsion Test



0.3
0.15
0
-0.15
-0.3
-3
-1.5
0
1.5
3
Shear Stress τ (kgf/cm²)
Shear Strain γ (%)
specimen NO.2

Fig-4

Fig-5 The cross section of Aquaphalt under an electron microscope



Ground
Shield Tunnel
Segment
Sandy Soil
Backpack Material
A
Ground
Backpack Material
Tube Mixer
Segment
P
Asphalt Emulsion
+
Cement
Pump
Shield Machine
High Absorptive Polymer
P
A

Fig-6