THE DEVELOPMENT AND APPLICATION OF EPS CONSTRUCTION METHOD IN TAIWAN

Lee-kuo Lin[1] Fu-sen Chen[2] Tai-an Ho[3] Jia-xiong Wei[4]

ABSTRACT

Up to today, every city area in Taiwan is still continuously expending. Such situation is causing serious problem of the resource of construction material. Based on the Construction Union's report, the average progress of public construction projects is about 20% delay due to the insufficient supply of construction materials, such as aggregate, sand and etc. Therefore, how to use the expanded polystyrene (EPS) as a replacement material will be an effective research and problem solution. The EPS construction method refers to employ large EPS blocks with unit weight between 12kgf/m^3 and 30 kgf/m^3. The advantages of this construction method are EPS can be used not only as a ground fill replacement material but also to reduce the load applied to foundation ground.

This paper will introduce the following topics related with Taiwan based on a two years' research: the background and initial condition of construction industry, the investigation of EPS production, the experimental result of laboratory test, the practice application projects and development situation. The purpose of this paper's presentation is trying to motivate more and more people involve to the research and development (R&D) domain of EPS construction method in Taiwan.

Keywords: Construction material, Expanded Polystyrene, EPS, Replacement material, EPS construction method, Chinese National Standard, CNS.

[1] Associate Professor of Civil Engineering Department, National Taipei University of Technology, Taipei, Taiwan, R.O.C
[2] Manager of Geotechnical Engineering Department, China Engineering Consultants, Inc., Taipei, Taiwan, R.O.C.
[3] Division Chief of Geotechnical Engineering Department, China Engineering Consultants, Inc., Taipei, Taiwan, R.O.C.
[4] Graduate Student of Civil Engineering Department, National Taipei University of Technology, Taipei, Taiwan, R.O.C.

PREFACE

In Taiwan, public constructions are built in each year to reach the purpose of national development, which is scientific island. Meanwhile, every city in Taiwan is still continuously growing, such situation is reasonably need to build lots of civil engineering constructions. Based on these constructions, the insufficient supply of construction materials is getting serious (Lin, 1998). For example, during last year the lack of coarse aggregate in the region of northern Taiwan is about 67 million tons, and the lack of sand is about 57.7 million tons (Lin etc., 2001). In order to solve this problem, finding appropriate alternative material is a necessary issue. In these alternations, expanded polystyrene (EPS) has highly potential to be a good replacement material.

EPS MANUFACTURING AND APPLICATION

A block of EPS is made from the particle of polystyrene (PS) with expanded and melted process in an automatic mold by adding steam gas. Expanded polystyrene is created during a two-stage process. In the first stage, expandable polystyrene resin is pre-expanded by a hydrocarbon-blowing agent that is contained within tiny resin beads. When the beads are exposed to steam, the polymer softens and the blowing agent expands, creating a cellular structure within the "pre-puff" beads. After a short stabilization period, the pre-puff is placed in a large rectangular block mold and steam is injected into the mold. Under this heat and pressure, the beads further expand and fuse to form a molded block (Bartlett, 2000; Negussey, 1997; Frydenlund, 1996)（refers to figure 1）. The result is a white, synthetic material that has a texture of closed, gas filled cells. Individual cells, or beads, are still visible after the molding process, but the beads have coalesced, to form a closed fabric, with essentially no void between the cells (Bartlett 2000). The manufacture process can be made in an EPS manufacturer. In Taiwan, there are 18 EPS manufacturers. This research visited 4 of those EPS manufacturers, then derived the whole manufacture process as shown in figure2. Figure 3 to figure 6 are practice pictures that were taken by visiting several EPS manufacturers.

EPS construction method is aimed to effectively utilize the material characteristics of expanded polystyrene such as its lightness, compressibility, self-supporting and water resistance (Sanders and Seedhouse, 1994; Duskov, 1997). EPS blocks are used as effective material for embankment and bankfilling in order to reduce their earth pressure and surcharge load of these works (Bartlett, 2000). EPS was invented in the 1950s. The first below ground application was to insulate foundations of residential homes in Scandinavian countries in the 1960s (Horvath, 1996). The placement of EPS underneath pavements to prevent seasonal freeze-thaw developed concurrently in Scandinavia, Canada, and the United States (Bartlett, 2000). In the 1970s, the use of EPS as lightweight embankment in highway and earthwork developed concurrently in the United States and Norway (Horvath, 1995). Most notably in 1972, the Norwegian Road Research Laboratory (NRRL) placed EPS in the approach fill of the Flom Bridge (Aaboe, 2000). Since that time, the NRRL has carried out a research and monitoring program on this installation and others, which has greatly added to the knowledge of the long-term performance and material properties of geofoam. EPS construction method is getting popular and widely adopted in America and Europe (Norwegian Road Research Laboratory, 1992). In the United States, EPS has been used in highway construction projects in Colorado, Hawaii, Indiana, Michigan, New York, and Utah. EPS is used in ground fill applications where a lightweight fill material is required to reduce stresses on underlying soils. It has been used in applications worldwide for over 30 years (Miki, 1996).

EPS SPECIFICATIONS AND EXPERIMENTAL PROPERTIES

The quality of EPS product is fully depended on several factors. There are properties of raw materials, steam gas pressure, feeding speed, manufacture machine, thickness of EPS block, shape of mold and cooling speed (Lin etc., 2001). Up to today, in Taiwan, the only specification related with EPS material is Chinese National Standard (CNS). It includes:

(1). CNS 2535 – expanded polystyrene thermal insulation material.
(2). CNS 3915 – general expanded polystyrene material.
(3). CNS 3637 – single expanded polystyrene particle.
(4). CNS 2536 – testing method of expanded polystyrene thermal insulation.
(5). CNS 3894 – inspecting method of single expanded polystyrene particle.

Table 1 and table 2 show the CNS standard properties of two kinds of EPS thermal insulation plates.

In Taiwan, there are three major kinds of EPS products using in the practice application, expanded polystyrene (EPS), expanded polypropylene (EPP) and expanded polyethylene (EPE) (figure 7). These products are used for package or thermal insulation. Only in rare case to use EPS as a special formwork material or specific model as shown in figure 8 and figure 9. This research used several EPS samples to test their engineering properties in laboratory. The testing result is brief shown in table 3.

PRACTICE APPLICATION AND DEVELOPMENT

Up to today, there is no any official and formal record about EPS practice project in Taiwan. The only trying case was built on May 5, 1995 in the western coast express way. Such project built a 30m testing road shoulder with 3m width, 1.5m height roadbed of EPS blocks, (Lin 1998). The newest EPS application project was held in Taipei Dagi Bridge (figure 21). This project used 2440m^3 of 25 kgf/m^3 (25k) EPS as lightweight fill materials to reduce about 555 tons loading weight compared to fill with general soil. Practice construction pictures of this project are shown in figure 22 to 24. It is another EPS project in Taipei City, Jomei express way, which is working in designing phase. The draft of EPS construction specification of this project is designing with Taipei City Government and China Engineering Consultants Incorporation (CECI).

In current, EPS construction method is gradually getting notice, especially after several EPS development activities were done as shown in table 4. However, EPS used for construction application needs more researches and local statistic data for reference of construction planning and specification. Because of that, it is important to have more engineers to join this subject.

CONCLUSIONS

The EPS construction method is employed in area where conventional solution is costly or time consuming. In general, selection of an appropriate EPS material is based on consideration of its relevant engineering properties as well as cost, durability, and environmental factors.

The process of each construction engineering will follow five steps as its life cycle：(1) conceptual phase (2) plan and design phase (3) bid and contract phase (4) construction phase (5) performance and maintenance phase (refers to figure25). To properly apply EPS as a backfill soil replacement material must to understand enough of EPS engineering properties. The purpose of this paper's presentation is trying to motivate more and more people involve to the research and development (R&D) domain of EPS construction method in Taiwan.

REFERENCES

Aaboe, R., (2000). Evidence of EPS long-term performance and durability as a light weigh fill, Transportation Research Board79th Annual Meeting, Washington, D.C.

Bartlett Steven (2000), Design of Geofoam Embankment for the I-15 Reconstruction, Proceeding of the technique conference of EPS construction, pp10-1-10-10.

Duskov, M. (1997). EPS as a lightweight sub-base material in pavement structures. Ph.D. Thesis, Delft University of Technology, The Netherlands.

Frydenlund, T. E. and Aaboe, R. (1996). Expanded Polystyrene -The Light Solution. Proceedings of the International Symposium on EPS Construction Method, Tokyo.

Horvath, J. S. (1995). Geofoam Geosynthetic, Horvath Engineering PC, Scarsdale, New York.

Horvath, J. S. (1996). Geofoam Geosynthetic: Past, Present, and Future, Electronic Journal of Geotechnical Engineer.

Miki, G. (1996). EPS Construction Method in Japan. Proceedings of the International Symposium on EPS Construction Method, Tokyo.

Negussey, D. (1997). Properties and applications of geofoam. Society of the Plastics Industry, Washington, D.C.

Norwegian Road Research Laboratory (1992). Expanded polystyrene used in road embankments: Design, Construction and Quality Assurance. Form 482E. Oslo.

Sanders, R. L. and Seedhouse, R. L., (1994). The use of polystyrene for embankment constructions. Contract Report 356. Transportation Research Laboratory, Crowthorne, UK.

Lin Lee-kuo, J. Y. Tsay, Fu-sen Chen, Tai-an Ho (2001), Construction and Application of EPS Light-Weight Filling Construction Method, Proceedings of 9th Conference on Current Researches in Geotechnical Engineering, Shihman Reservoir, Tai-Yuan, Taiwan, R.O.C. ppE030-1-E030-9.

Lin Lee-kuo, (1998), The Supplying Condition of Aggregate and Application of EPS Construction Method in Taiwan, Proceedings of Conference on New Technique in Geotechnical Engineering, Taiwan, R.O.C. pp1-17.

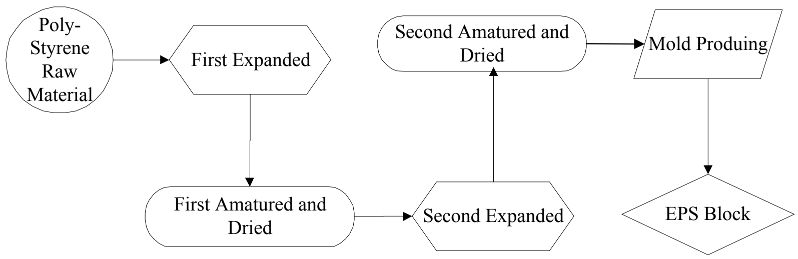


Figure 1 EPS expended process

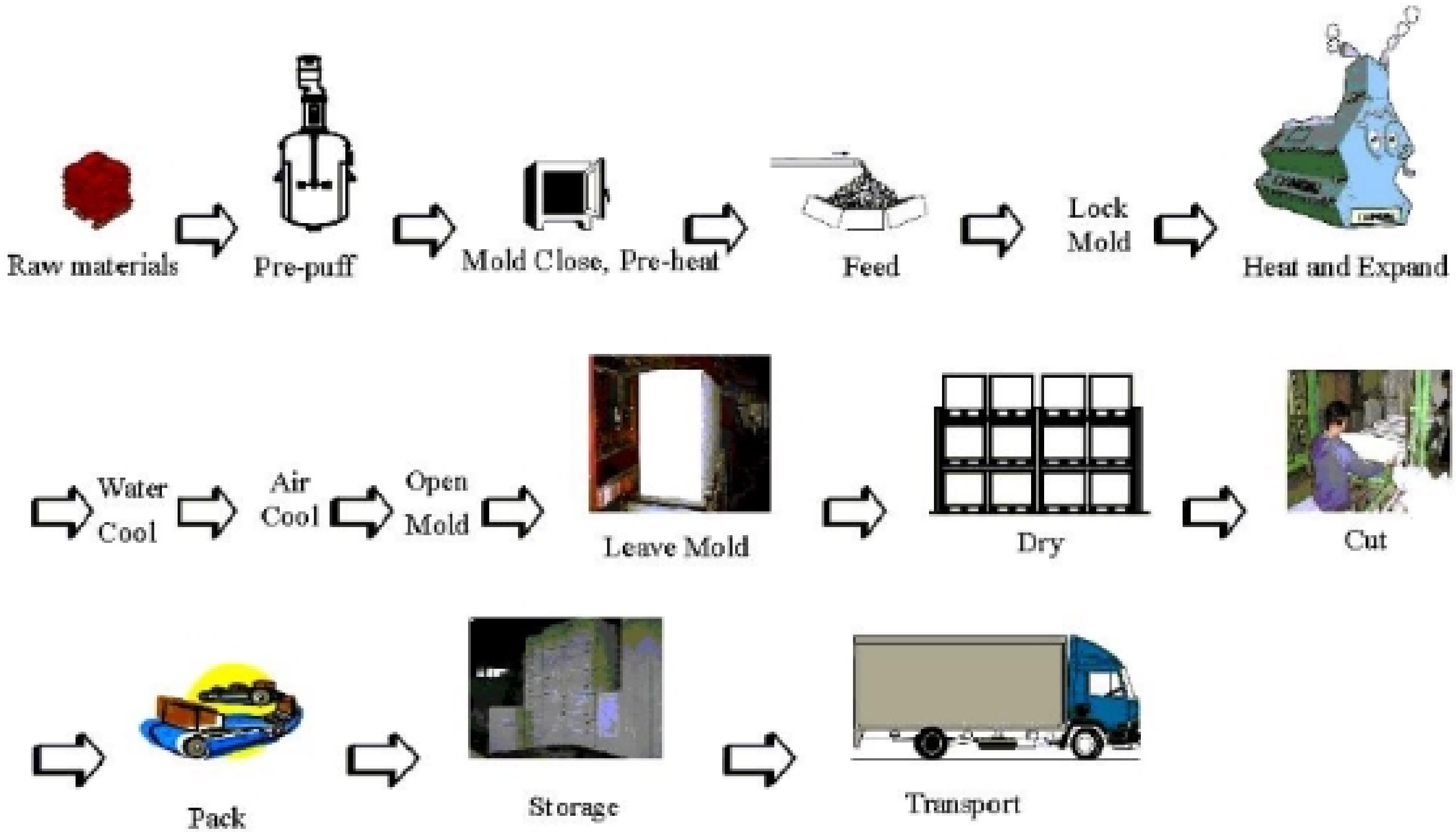


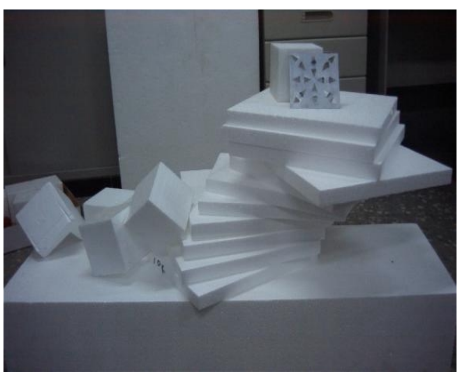
Figure 2 The flow chart of EPS manufacture

Figure 3 Beads of PS and EPS

Figure 4 EPS expanded machine

Figure 5 EPS mold

Figure 6 Storage of EPS products



(a) EPS

(b) EPP

(c) EPE

Figure 7 EPS major products in Taiwan

Figure 8 EPS special formwork

Figure 9 EPS special model

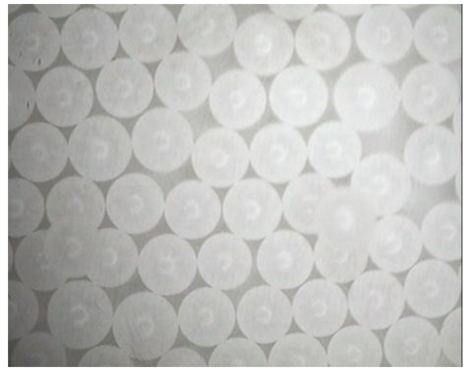


Figure 10 Optical microscope picture of PS bead

(a) EPS pre-puff beads

(b) EPS block

Figure 11 Optical microscope pictures of EPS

Figure 12 EPS sample in moisture absorption test

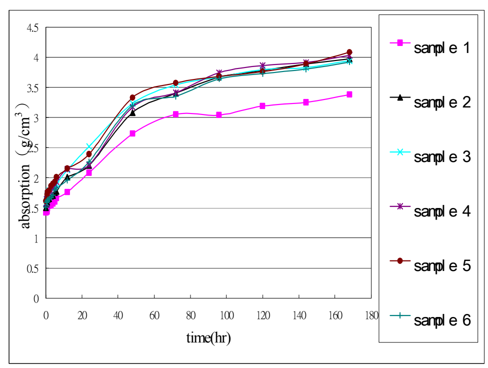


Figure 13 12K EPS moisture absorption curve

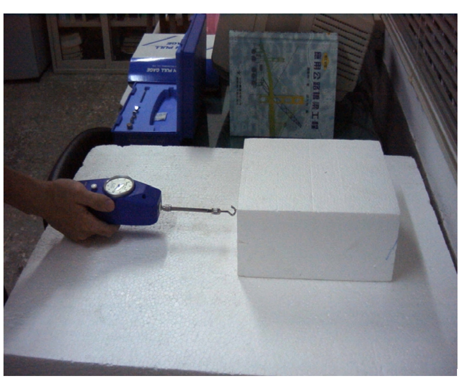


Figure 14 EPS friction coefficient test

Figure 15 Cutting EPS sample for unit weight test

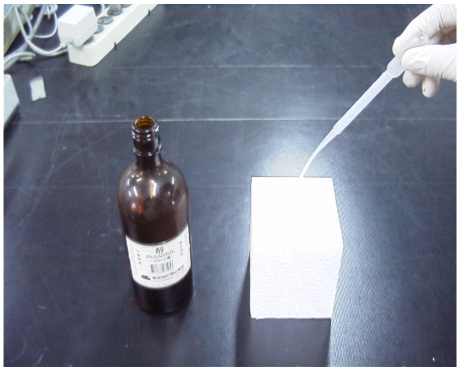


Figure 16 EPS surface erosion test

Figure 17 EPS single axis test

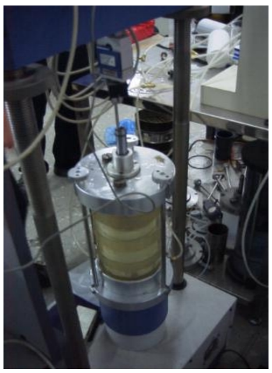


Figure 18 EPS Triaxial test

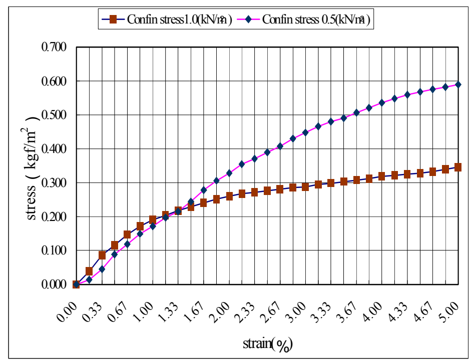


Figure 19 EPS stress and strain curve with triaxial test

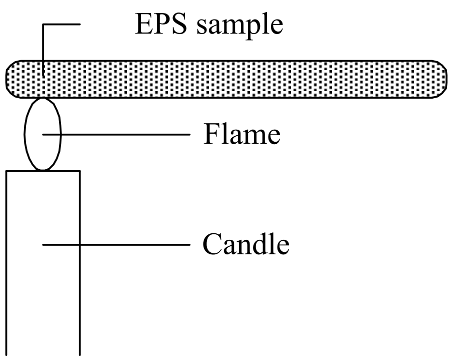


Figure 20 EPS fire resistance test

Figure 21 Model of Dagi bridge in Taipei City

Figure 22 EPS packing situation

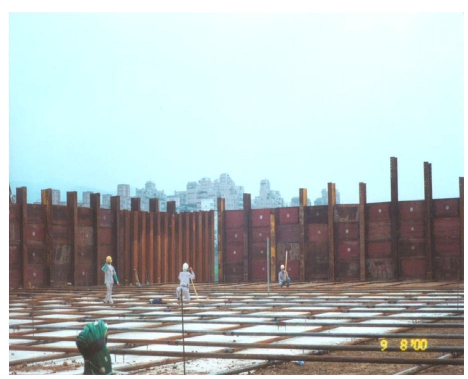


Figure 23 EPS level measurement

Figure 24 EPS backfill

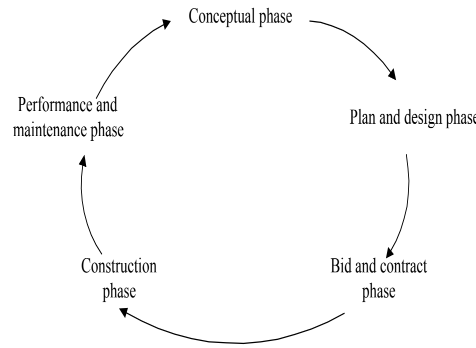


Figure 25 Construction life cycle

Table 1 Character of EPS thermal insulation plate and tube (type A)

Type	Density kg/m^3	Thermal conductivity (average temperature 20±5℃) W/m•k{kcal/m•h•c}	Bending strength $N/cm^2\{kgf/cm^2\}$	Compressive strength $N/cm^2\{kgf/cm^2\}$	Absorption g/cm^2	Combustion	Permeable Conductivity(thickness25mm) ng/m^2•s•Pa {g/m^2•h•mmHg}
Thermal insulation plate special type	above 27	below 0.03{0.029}	above 35{3.5}	above 14{1.4}	below 1	The blaze snuffs out itself less than 3 seconds, doesn't remain ashes and doesn't burn over critical temperature.	187{0.09}
Thermal insulation plate type 1	above 30	below 0.036{0.031}	above 45{4.5}	above 16{1.6}			146{0.07}
Thermal insulation plate type 2	above 25	below 0.037{0.032}	above 30{3.0}	above 12{1.2}			208{0.10}
Thermal insulation plate type 3	above 20	below 0.040{0.034}	above 22{2.2}	above 8{0.8}			250{0.12}
Thermal insulation plate type 4	above 15	below 0.043{0.037}	above 15{1.5}	above 5{0.5}	below 1.5		292{0.14}
Thermal insulation tube type 1	above 35	below 0.036{0.031}	above 30{3.0}	—	When thickness below 30mm the absorption is below 2.		
Thermal insulation tube type 2	above 30	below 0.036{0.031}	above 25{2.5}				
Thermal insulation tube type 3	above 25	below 0.037{0.032}	above 20{2.0}				

Table 2 Character of EPS thermal insulation plate and tube (type B)

Type	Thermal Conductivity(Average Temperature 20±5 ℃)W/m•k{kcal/m•h•c}	Bending Strength $N/cm^2\{kgf/cm^2\}$	Compressive Strength $N/cm^2\{kgf/cm^2\}$	Combustion	(Reference) Permeable Conductivity(thickness25mm) ng/m^2•s•Pa {g/m^2•h•mmHg}
Thermal insulation plate Special Type 1	below 0.040{0.034}	above 20{2.0}	above 16{1.6}	The blaze snuffs out itself less than 3 seconds, doesn't remain ashes and doesn't burn over critical temperature.	Below 146{0.07}
Thermal insulation plate Special Type 2-a	below 0.034{0.029}		above 10{1.0}		
Thermal insulation plate Special Type 2-b			above 18{1.8}		
Thermal insulation plate Special Type 3	below 0.028{0.024}	above 25{2.5}	above 20{2.0}		
Thermal insulation tube Type 1	below 0.040{0.034}	above 15{1.5}			—
Thermal insulation tube Type 2	below 0.034{0.029}				
Thermal insulation tube Type 3	below 0.028{0.024}	above 20{2.0}			

Table3. The result of EPS test

Test	Simple type	Brief test result description	Reference Picture
Optical microscope observation test	Polystyrene raw material	Particle of Polystyrene is uniform and with round appearance shape.	figure 10
	$18kgf/m^3$ (18K) EPS sample	Structural organization of EPS is puffy, expanded grain interface is binding well, small void can be obviously seen.	figure 11
Moisture absorption test	$12kgf/m^3$ (12k) EPS sample	Moisture absorption is defined as absorption water weight by per cubic volume. After 7days, the moisture absorption ratio is about 4%.	figure 12 figure 13
Friction coefficient test	12K EPS sample	The measurement data of measured friction coefficient between EPS and EPS is from 0.51 to 0.64, average value is 0.5872.	figure 14
Unit weight test	18K and 12K EPS sample	Unit Weight between measured and manufactured have a little difference, average difference is less than 5% .	figure 15
Surface erosion test	12K EPS sample	Erosion liquids, such as methylbenzene, methane, gasoline, tetra-ketone, hydrochloric acid will erode EPS surface.	figure 16
Single axis test	12K EPS sample	When compression strain greater than 1% , stress and strain curve present a non-linear relation.	figure 17
Triaxial test	12K EPS sample	When EPS sample fail, shear-zone does not happen, destruction can not meet with mohor-columb principle, so EPS is not belong to c,ø materials.	figure 18 figure 19
Fire resistance test	General EPS and fire resistance EPS samples	Fire resistance EPS can stop spontaneous combustion effectively within 3 seconds, but general EPS sample will burn continuously.	figure 20
Poison ratio test	12K EPS sample	Measured of Poison ratio is from 0 to0.0003, average is 0.00015.	figure 21

Table4. EPS development activities in Taiwan (Lin, 2001)

Date	Activity	Summary
1995,5,10 to 1995,5,20	Research of super lightweight embankment in Western Coast express way.	The first research project of EPS embankment in Taiwan.
1998,12,22 and 1998,12,23	Conference of New Technique in Geotechnical Engineering	Four EPS articles were held, about 100 audiences attended.
1999,4,29	Project of Li Mountain slope sliding restoration and prevention.	Use EPS to solve the unstable slope and sliding problem in Li mountain. This project have stopped due to Chi- Chi earthquake on 1999,9,21.
1999,6,4	Symposium of automatic, effective construction method and technique for application of road slope	Beside other topics, Associate professor of National Taipei University of Technology, Lin Lee-Kuo had a speech of " Practice of EPS Application to Road Slope"
1999,8,2	Symposium of EPS light weight fill construction method apply to road construction	This conference was focusing on the introduction of "EPS light weight fill construction method.
2000,3,3	Conference of Lightweight fill construction method technique.	Five papers were held, two speakers were invited from U.S.A and two speakers were invited from Japan, about 300 audience attended.
1999,6,1 to 2000,5,31	Research of EPS light weight fill construction method	The purpose of this research is to collect and derive the information of EPS production, property and application, program director is Lin Lee-Kuo.
2000,8 to 2000,10	EPS temporary backfill of Taipei Dagi bridge construction.	This program used $2440m^3$ of 25K EPS as a replacement fill material to reduce 555 tons loading.force.