Simulation and Analysis of EPS Impact Test

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Abstract

Taiwan is located at the Circum-Pacific seismic region, steep terrain and geological sensitive; the climate type is subtropical warm and humid. Therefore, Taiwan frequently suffers from rainy season and typhoons. Sensitive rock stratum causes a huge disaster of mudflows once every time when heavy rainstorms occur. Also, falling rocks are more commonly occurring at the slope of rock stratum in steep mountains, such as by a single or group of rocks, separated from the cliff face, collapse to free fall, bouncing and rolling, etc. to reach the slope foot with high-speed. Such disaster always causes serious damage of lives and properties.

Expanded Polystyrene; known as EPS, is widely used in Europe and America for alternate material of sand backfill, produced as foam, also called geofoam. This material has characteristics of light-weight, shock absorption resistance and great self-sustain. This study investigates behavior of EPS material by using the ball-drop test to simulate application requirements in fallen rocks prevention engineering. Comparison parameters of this research include the K Value (kg/m^3) of EPS, ball dropping distance, ball size and ball weight. From the simulation test, the EPS specimens that are sustaining the energy force of impact and conditions of destruction and amount of deformation under different variables, are used for regression analysis. Based on the study result, the relationship between impact force and amount of deformation of EPS specimens can be used for anti-collision design. This study expects that the contribution can promote the EPS to be used as an appropriate application material in the construction industry and disaster-prevention engineering.
Keywords: Geofoam, EPS, Rock-fall, Ball-drop Test, Impact test.

I. INTRODUCTION

Taiwan has the appearance of steep mountains with many river rapids, and is located on the border of the Eurasian Plate and Philippine Sea Plate. This situation makes Taiwan one of the frequent earthquake areas in the world [1]. Earthquakes always increase the amount of broken rock in the upstream of rivers within the mountainous area. Therefore, when the warm and damp subtropics climate brings about massive rainfalls every year this will cause debris flow to occur from time to time.

Rock-fall often occurs in the steep rock slopes at the mountains. In Taiwan, there are several serious damages caused by rock-fall disasters (Table 1). So how to reduce the cause of casualties, protect the mountain district roads, as well as humans, cars, houses, and so on, then becomes one of important topics regarding the rock-fall phenomenon and the protection analysis.

Table 1. The record of rock-fall disasters in Taiwan [2]

Items	Event Name	Time	Casualty status
1	Keelung Mountain rock-fall hazard	1964.02	5 deaths 8 injured, and destroyed three houses
2	Eternal Spring Shrine, Cross-Island Highway rock-fall hazard	1987.07	Remaining only two pavilion buildings are not damaged yet
3	Taiji Gorge rock-fall hazard	1986.05	28 deaths
4	Kwun Yam Shan Lingyun Buddhist Temple rock-fall hazard	1992.09	Apse temple damaged
5	Taipei Waishuanghsi Saints Falls rock-fall hazard	1993.05	2 deaths, 26 people were injured
6	Northern Coastal Highway rock-fall hazard	1998.04	6 deaths
7	Zhongshan Road, Keelung City rock-fall hazard	1998.09	3 houses completely destroyed, 1 death, 1 injured
8	Riley earthquake caused the rock-fall events with secondary	1998.07	-
9	Shihding rock-fall hazard	1999.06	1 death
10	Badou Zi rock-fall hazard	2001.09	1 building destroyed ,1 death
11	Road Hsi Chih City, Taipei County hillside community Xiushan rock-fall hazard	2003.09	-
12	Yunlin sunny day inside the forest landslide disaster	2005.01	-
13	Wenshan hot springs of Hualien rock-fall hazard	2005.04	Tourists,1 deaths, 10 injured
14	Shihding rock-fall hazard	2006.06	3 houses and 2 vehicles damaged
15	Hualien Lintienshan rock-fall hazard	2007.1	Destroyed three houses
16	Taroko Swallow Trail	2008.07	1 visitor head laceration
17	Taroko Tunnel of Nine Turns rock-fall hazard	2010.01	1 tourist death

The scientific name of EPS is Expanded Polystyrene. Properties of EPS material include light weight, impact absorption, excellent self-resistance, water resistance, insulation and easy construction [3]. In Europe and The United State of America EPS, so called as geofoam, is used as backfill to substitute embankment material in civil engineering [4]. This study uses EPS specimens in ball-drop tests as a rock-fall simulation test to investigate the mechanical properties and material behavior of EPS. The test attempts to show that EPS may be used as a buffer material for rock-fall protection purposes. During the testing process; various sizes and weights of the dropping balls, dropping distances and impact deformations are recorded for regression analysis. The test results indicate that EPS can be used for the application of rock-fall protection.

II. THE COMPOSITION AND PROPERTIES OF EPS

EPS is a polymer blends material or simply called poly blends material [5]. Since polymer materials have a wide range of recipes, are quick and easy to mold, rich in color, acid, and have a mechanical nature satisfying the needs of daily life, the making of the polymer material has been fully present in most aspects of people's lives. The main raw material for polymer plastics is made by crude oil in the refining process, crude oil by distillation, oil and hydrocarbon separation and other major processes in producing fuel and asphalt, lubricants, and other derivative products [5]. EPS is one of its derivatives (Figure 1), generated by the refining process. Generally 96% of the derivative products consist mainly of non-oil fuel for vehicles and machinery. Plastics materials in the refining process account for about 4% of derivative products, of which the proportion of EPS products is only 0.1%. The EPS manufacturing process involves making a styrene foam material expand in a pressurized cylinder, the cylinder pressure and temperature being monitored according to the operating procedure. The EPS manufacturing process is generally divided into raw materials, quality control, pre-expansion and molding phases [1].

EPS is foamed in the manufacturing plant by a fusion processes so that the finished products is a homogeneous cellular body. One of the main objects is to provide a lightweight and high porosity material that can be used in road-bases, bridges, embankments, retaining walls and other structures, to reduce loading pressure on soil, or to avoid consolidation settlements and lateral displacement. The EPS can also be used as an alternative backfill material [6,7]. The main engineering properties of EPS are shown in Table 2.

Table 2. EPS characteristics and applicability of engineering methods [9]

Features	Engineering properties	Description	The suitability of application
Ultra-light	ρ= 12 ~ 30kg /m^3	Sediment material is about 1.8t/m^3 Concrete is 2.35t/m^3	1. Soft ground 2. Slip region
Compressive strength	q_u = 20 ~140 kPa	1. Compression strain of 1% of the compressive strength 2. Compressive strength due to changes in EPS density	Buffer protection material
Dimensions	1 type block =0.5×1.0×2.0m	Vertical stacking of the EPS will form a straight face. With heavy loads the side still experiences very small distortion	1. Backfill material for retaining wall 2. Embankment site used
Water resistance	Synthetic resin foam, water allocation	When in the groundwater for 9 years only 9%.	Permanent materials
Easy construction	Lightweight, processing, easy to construct	1. Reduce construction labor 2. Do not need the use of construction machines	1. Can be place in a narrow construction area 2. Reduce vibration and noise during construction 3. Quick construction, saving labor

III. TEST DESCRIPTION

In this research, the test is divided into two parts, the first part is measuring the basic physical properties of EPS materials, and the second part is testing with the dropping ball impact test. Fundamental property tests include unit weight, compressive strength, water absorption and hardness test. The dropping ball impact test is used to simulate the performance of rock fall hazards, in order to investigate the EPS impact-absorbing property. The test process is shown in Figure 2.

EPS samples are manufactured by a domestic factory in Taiwan. There are six types of specimens, 11K, 14K, 18K, 22K, 32K and 40K. In the table, the "K Value" is the unit weight of EPS sample. For example if the EPS unit weight is 22kg/m^3 it will be called as "22K".

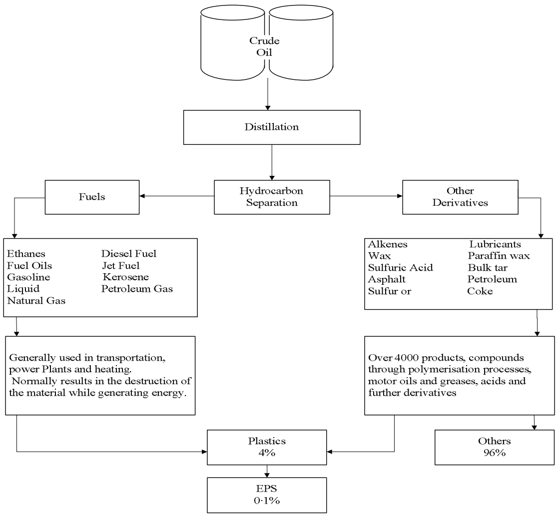

Figure 1. Schematic diagram of crude oil refining process [8]

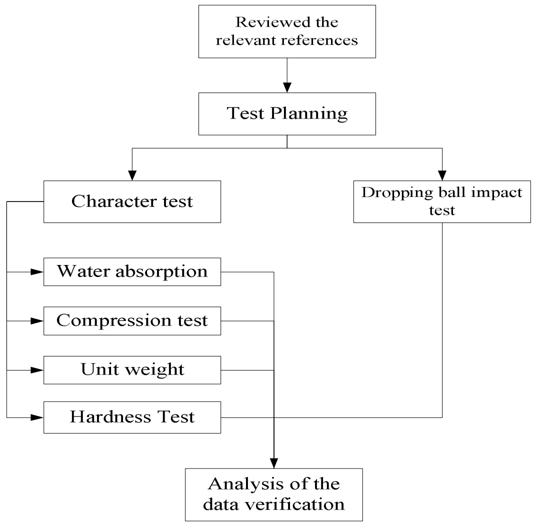

Figure 2. Test flow chart

IV. PHYSICAL TESTS

4.1 Unit Weight Test

The main purpose of this study is to investigate the quality of the domestic production of EPS materials. Three 10cm^3 cube specimens were prepared for each type of EPS sample tested and the unit weight of each specimen was measured. The tested data was calculated with statistical analysis, the standard deviation is between 0.23 and 1.61, and the largest coefficient of variation is 4.80% (Table 3).

Table 3. EPS unit weight of each size and statistical analysis of test data

Types	Design unit weight (kg/m^3)	Measured mass (g)			Average (g)	Unit weight (g/cm^3)	Deviation rate	Standard deviation (S)	Coefficient of variation (V)
		Specimen 1	Specimen 2	Specimen 3					
11K	11.00	10.70	10.80	11.20	10.90	0.0109	0.91%	0.26	2.43%
14K	14.00	13.80	14.20	14.60	14.20	0.0142	-1.43%	0.40	2.82%
18K	18.00	17.70	18.10	18.50	18.10	0.0181	-0.56%	0.40	2.21%
22K	22.00	20.50	20.80	21.80	21.03	0.0210	4.39%	0.68	3.24%
33K	33.00	31.80	33.70	35.00	33.50	0.0335	-1.52%	1.61	4.80%
40K	40.00	40.80	40.80	41.20	40.93	0.0409	-2.33%	0.23	0.56%

4.2 Uniaxial Compression Strength Test

This study uses six different unit weights of EPS samples for uniaxial compression test. Each unit weight is cut to $5cm^3$ for three cube specimens. This test series carried out with the pressure process, synchronous read load and suffered deformation. The test result can be drawing the different uniaxial compressive curve of EPS. According to the Japanese EPS specification (JIS K 7220), the EPS uniaxial compressive strength is using 5% strain stress. This study uses linear interpolation method into the testing record to estimate the compressive strength of 5% strain as shown in Table 4.

Table 4. Linear interpolation method to estimate the compression strength

Sample	11K		14K		18K		22K		33K		40K	
Specimen No.	Strain (%)	Stress (kPa)	Strain (%)	Stress (kPa)	Strain (%)	Stress (kPa)	Strain (%)	Stress (kPa)	Strain (%)	Stress (kPa)	Strain (%)	Stress (kPa)
Specimen 1	4.78	16.4	4.00	52.0	3.98	84.8	4.06	105.2	4.26	192.4	4.60	265
	6.76	19.6	5.98	56.8	5.96	89.6	5.12	106.0	5.04	203.6	5.68	272
	5.00	16.8	5.00	54.4	5.00	87.3	5.00	105.9	5.00	203.0	5.00	267.6
Specimen 2	4.68	16.8	4.80	54.0	3.74	78.0	3.48	92.0	4.64	214.8	4.64	361
	6.64	20.8	6.84	58.8	5.76	92.8	5.42	104.8	5.32	230.4	5.87	377
	5.00	17.5	5.00	54.5	5.00	87.2	5.00	102.0	5.00	223.1	5.00	365.7
Specimen 3	3.44	13.2	4.18	50.8	3.52	81.6	4.60	106.4	4.60	202.0	4.25	314
	5.44	17.6	6.16	58.4	5.48	90.0	6.60	114.4	5.80	212.4	5.60	326
	5.00	16.6	5.00	53.9	5.00	87.9	5.00	108.0	5.00	205.5	5.00	320.7
Average compressive strength (kPa)	-	16.9	-	54.3	-	87.5	-	105.3	-	210.5	-	318

Figure 3 shows the linear and exponential regression results with EPS unit weight (K value) and compressive strength where the compressive strength is estimated from Table 4, and R^2 =0.9812 for linear regression, R^2 = 0.8629 for exponential regression. The linear relationship equation is:

$$y=0.098x-0.934 \tag{1}$$

and the exponential relationship equation is:

$$y = 0.1282e^{0.0852x} \tag{2}$$

x: unit weight of K value EPS (kg/m^3)
y: the uniaxial compressive strength (kg/cm^2)

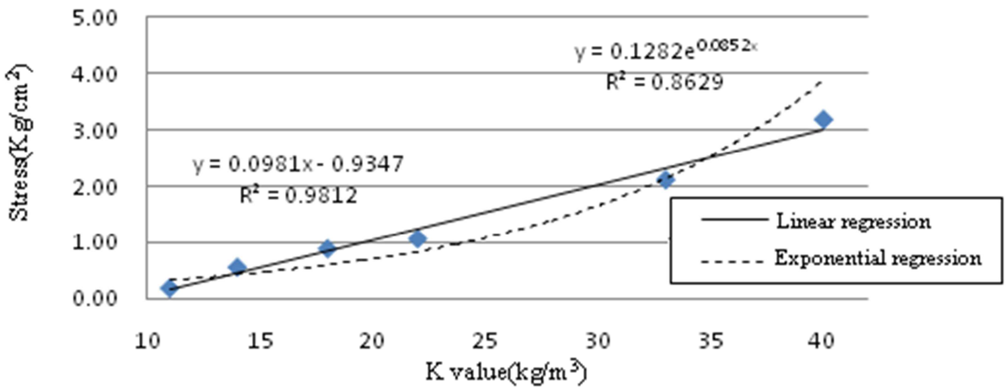

Figure 3. The regression curve of K and compressive strength

4.3 Water Absorption Test

Water absorption was tested using six EPS samples of different unit weights. For each unit weight three pieces of 5 cm^3 cube specimens were prepared. After measuring the weight, all EPS specimens are placed in the tank filled with water. After a cumulative absorption time of 56 days in a submerged position the weight of water absorption was measured.

According to the United States and Japanese standards, the value of water absorption is the absorption water weight per unit volume; therefore this study uses the calculation of water absorption with the following equation:

$$Wi(\%) = (Ww - Wn)/ Vn \times 100 \quad (3)$$

Where Wi: water content of submerged specimens after a certain time period in water expressed as the percentage of water absorption per unit volume.

Vn: specimen volume (125cm^3)

Wn: weight of specimen before immersed in water,

Ww: weight of specimen after a certain time period of submersion.

Results from this study regarding average water absorption by various EPS blocks are shown in Figure 4.

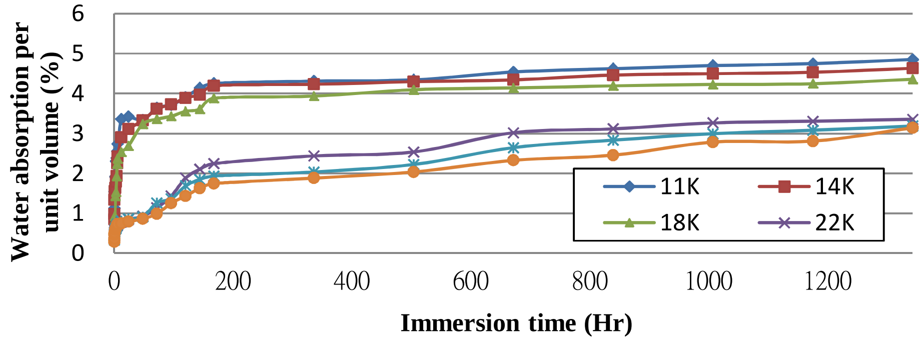

Figure 4. Water absorption of various EPS specimens

4.4 Hardness Test

This study uses the indentation hardness test in order to understand the property of EPS deformation resistance. The load read by the pointer on the measuring dial can be converted to metric standard unit load (Table 5). The test instrument used for testing the hardness of soft rubber, hard foam is the TECLOCK GS-701N. The shape of the pressure needle is 5.08mm in diameter and 2.54mm in height of the dome (Figure 5).

During the testing process, each test location should be chosen at points more than 12mm inside the edge of the specimen margin, and the average of five measuring points should be taken for measuring the hardness. All testing points on the specimen surface must be kept more than 6mm apart. The testing points of this study are shown in Figure 6. All specimens are measured at five points and the average values varying between 33 to 69 degrees are shown in Table 6.

Table 5.Hardness degree and conversion load

Load degree	Load value (mN)	Load value (gf)
0	539	55
10	1323	135
20	2107	215
30	2891	295
40	3675	375
50	4459	455
60	5243	535
70	6027	615
80	6811	695
90	7595	775
100	8379	855

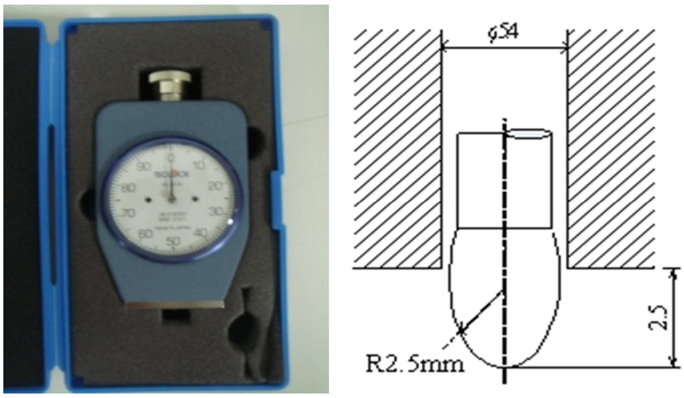

Figure 5. TECLOCK GS-701N Dome hardness and pressure needle

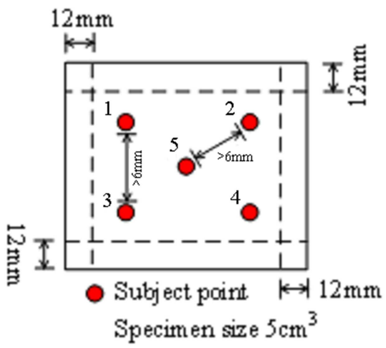

Figure 6. Specimens measured by testing points

Table 6. Hardness load measured result

Types	Standard load degree (degree of hardness pointer)	Load level (mN)	Load level (g)
11K	33.33	3152.33	321.67
14K	40.73	3732.49	380.87
18K	45.47	4103.59	418.73
22K	53.80	4756.92	485.40
33K	66.33	5739.53	585.67
40K	69.60	5995.64	611.80

V. DROPPING BALL IMPACTION TEST

The dropping-ball test apparatus can be divided into four parts, there are frame units, pillars, power switch, magnet and steel ball (Figure 7). The principle of this test is by operating the control switch button to let the steel ball fall freely from a specified height. The maximum drop height of the steel ball is 2 meters. Related test variables are shown in Table 7. The dropping ball simulation test is using 1000 cm^3 cubes of various EPS specimens placed on the base of the dropping ball test apparatus. Different sizes of dropping balls and dropping distances are used to calculate data of impact momentum and energy.

Table 7. Test variables of dropping ball

Dropping ball specifications			Falling height (mm)
Items	Diameter (cm)	Weight (g)	
1	8.0	2076.80	1000.00 1500.00 2000.00
2	7.0	1390.40	
3	5.0	508.60	
4	4.0	261.20	

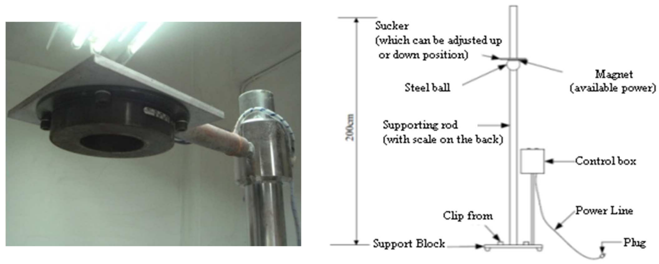

Figure 7. Dropping-ball test apparatus and its magnetic plate

This study uses a dropping ball test to simulate the EPS property of practice application. The testing sample is a 1000 cm^3 cube specimen for each different unit weight of EPS type. When the steel ball hit the EPS specimen's surface, the surface will deform instantly, because the EPS material has high porosity. When the specimen is subjected to a considerable degree of impact it will also rebound (Figure 8), so the final deformation of the specimen does not equal to the initial deformation. By considering the purpose to apply EPS material for shock absorption from falling rock, the initial deformation will be the appropriate data for measurement. After many attempts during this study, the best way to measure the initial deformation is by painting red ink on the ball. The impact area on the specimen's surface will then show after the test. Then the specimen settlement is calculated from the marked area with red ink. From the diameter of the steel ball and the relationship of Pythagorean theory the initial settlement can be derived (Figure 9 and equation (4)). Table 8 shows part of the simulation test result.

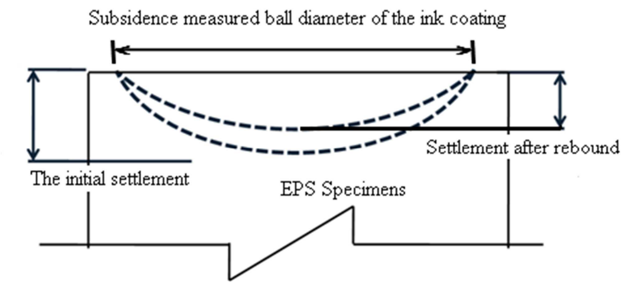

Figure 8. Schematic diagram of specimen with the initial settlement

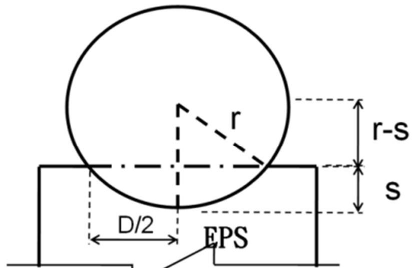

Figure 9. Specimen is calculated initial settlement diagram

$$S = r - \sqrt{r^2 - (\frac{D}{2})^2} \quad (4)$$

Where: r = ball radius, D = steel ball impression diameter, S = initial settlement

Table 8. Measured data of the 8 cm diameter dropping ball test units: cm

Falling height (m)	11K		14K		18K		22K		33K		40K	
	Ave.*	Set.**	Ave.*	Set.**	Ave.*	Set.**	Ave.*	Set.**	Ave.*	Set.**	Ave.*	Set**
1	8	4	8	4	7.63	2.79	9.63	2.79	6.92	1.99	6.38	1.58
1.5	8	4	8	4	7.67	2.86	7.74	2.99	7.3	2.36	6.81	1.9
2	8	4	8	4	8	4	8	4	7.67	2.86	7.23	2.29

∗: Average diameter of impact area

∗∗: Calculated initial deformation from equation (4)

VI. ANALYSIS OF DROPPING BALL TEST

The kinetic energy of free drop motion is described as equation (5), where「I」is the kinetic impulse,「m」 is the dropping ball mass,「g」is the gravity acceleration, and「t1」 and「t2」 are time periods of the ball drop down.

$$I = \Sigma \int_{t_i}^{t_f} F_y dt = \Sigma \int_{t_i}^{t_f} (mg)_y dt = \Sigma[mg(t)_2 - mg(t)_1] \qquad (5)$$

Substituting equation (6) calculation of impulse that「I」 still need to know the speed of object motion at the beginning (v_0) and movement time (t):

$$y = y_0 + (v_0)t + \frac{1}{2} a_y t^2 \qquad (6)$$

Where y is the height of the ball dropping, $y_0 = 0$ at the beginning, v_0 is the ball velocity at the beginning, t is the time before hit the EPS specimen, a_y is the acceleration of gravity = 9.81 (m/s^2). According to equation (5), impulse and equation (6) falling time can be obtained as shown in Table 9.

Table 9. Calculation result of impulse

Dropping ball specifications		According to equation (5) obtain the falling impulse (kg · m^2/s^2)		
Diameter (cm)	Weight (kg)	h=1.0m Falling time: 0.452s	h=1.5m Falling time: 0.553s	h=2.0m Falling time: 0.639s
8.0	2.080	9.223	11.283	13.039
7.0	1.390	6.163	7.541	8.713
5.0	0.510	2.261	2.767	3.197
4.0	0.260	1.153	1.410	1.630

Once the initial deformation and impulse were calculated, both the linear and exponential regression can be derived. For example, Figure 10 is the regression analysis of 11 K EPS specimen, based on the test results.

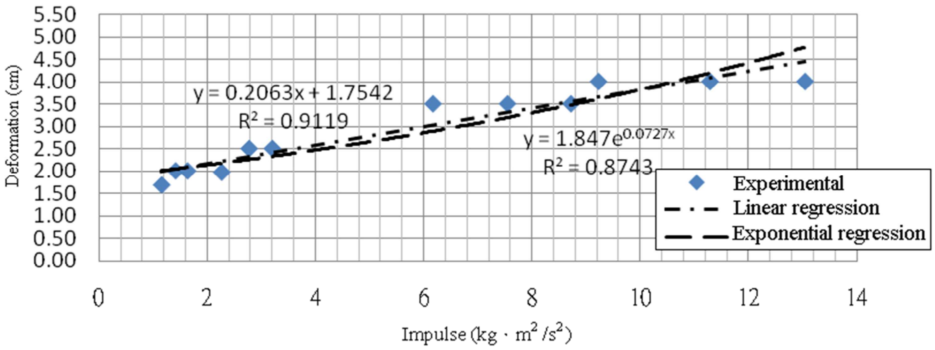

Figure 10. Regression analysis between initial deformation and impulse of 11K EPS specimen

VII. CONCLUSIONS

This study tests the basic physical properties of EPS to investigate the quality of Taiwanese domestic manufacturer's products and by dropping ball impact tests to explore the feasibility of using EPS in rock-fall protection projects. The test results are as follows:

1. The unit weight test: The measured data of six types of EPS compares to the manufacturers design unit weight, the difference rate is -2.33% to +4.39%; standard deviation is 0.23 to 1.61; the highest variation coefficient is 4.80%. This result indicates that Taiwanese domestic EPS materials still need to be improved during the manufacturing process.
2. Uniaxial compression tests: The experimental data obtained by regression analysis and the K value of uniaxial compressive strength relationship is: $y = 0.098x - 0.934$, $R^2 = 0.981$.
3. Water absorption test: The average water absorption for 1340 hours is less than 5% by volume.
4. Hardness test: The measured data of six types EPS specimens are between 33.33 ~ 69.60.
5. Dropping ball impact test: After this study, results of regression analysis are shown in Table 10.

Table 10. Linear and exponential regression equations between K and impulse

Unit weight (K value)	Linear regression		Exponential regression	
	Equation	R^2	Equation	R^2
11K	y=0.206x+1.754	0.911	y=1.847e0.072x	0.874
14K	y=0.217x+1.562	0.877	y=1.669e0.080x	0.794
18K	y=0.196x+1.156	0.902	y=1.294e0.086x	0.877
22K	y=0.194x+1.059	0.927	y=1.245e0.085x	0.943
33K	y=0.135x+0.927	0.930	y=1.028e0.078x	0.898
40K	y=0.112x+0.723	0.948	y=0.813e0.080x	0.935

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