出國報告（出國類別：實習）

# 研習生質物混燒與有機光電材料技術並參加 2013 世界煤灰會議


服務機關：台灣電力公司綜合研究所

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派赴國家：美國

出國期間：102 年 4 月 18～5 月 1 日

報告日期：102 年 7 月

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# 行政院及所屬各機關出國報告提要

出國報告名稱：研習生質物混燒與有機光電材料技術並參加 2013 世界煤灰會議

頁數＿＿　含附件：■是□否

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出國類別：□1 考察□2 進修□3 研究■4 實習 5□其他

出國期間：102 年 4 月 18 日～5 月 1 日　出國地區：美國

報告日期：102 年 7 月 1 日

分類號/目

關鍵詞：煤灰、生質能、煙氣

內容摘要：(二百至三百字)

本公司因二氧化碳減量需求，逐步使用生質燃料是必然的之趨勢，其中使用傳統燃煤鍋爐混燒木質生質能源，近年來世界各國戮力發展。由於木質生質燃料與煤炭熱值與化學成分不盡相同，燃燒後對煙氣處理系統的影響、副產物成分變化對煤灰性質的影響及利用方式

的差異等值得加以探討，因此前往美國電力研究所觀摩生質能混燒及煙氣處理技術，了解生質燃料儲存環境、燃燒、運轉條件、煙氣控制情形及產生之煤灰利用可能面臨之問題，以作為本公司生質燃料加入燃煤機組運轉之參考，依據 EPRI 曾經進行相關研究，5%生質燃料混燒對 PC 鍋爐無不良影響。生植物中含的 F 將會毒化 SCR 的觸媒，影響其運轉壽命。EPRI 進行多項除汞技術研究，使用的方法有：脫硫設備的化學法，脫硫設備的添加，溴的添加法，煙道中的活性碳噴入法，每種方法均有其缺點及限制，因此相關的研究仍在積極進行。

2013 世界煤灰會議(World of Coal Ash 2013 )在美國肯德基洲的 Lexington 舉辦，本所發表”Properties of CLSM Separation Dike using Coal Ash”論文一篇。會議中因為美國 TVA 電廠於 2008 發生濕式灰塘崩壞事件，造成極大的環境汙染，因此本次有 32 篇文章進行灰塘有關的討論，另有 6 篇文章探討濕式灰塘液化問題的文章，本室目前進行灰塘地改的液化分析，實驗室的結果，應可作為比對驗證。生質燃料混燒煤灰利用之改版研究，歐洲的經驗，值得本公司借鏡。

# 摘要

本公司因二氧化碳減量需求，逐步使用生質燃料是必然的之趨勢，其中使用傳統燃煤鍋爐混燒木質生質能源，近年來世界各國戮力發展。由於木質生質燃料與煤炭熱值與化學成分不盡相同，燃燒後對煙氣處理系統的影響、副產物成分變化對煤灰性質的影響及利用方式的差異等值得加以探討，因此前往美國電力研究所觀摩生質能混燒及煙氣處理技術，了解生質燃料儲存環境、燃燒、運轉條件、煙氣控制情形及產生之煤灰利用可能面臨之問題，以作爲本公司生質燃料加入燃煤機組運轉之參考，依據 EPRI 曾經進行相關研究，5%生質燃料混燒對 PC 鍋爐無不良影響。生植物中含的 F 將會毒化 SCR 的觸媒，影響其運轉壽命。EPRI 進行多項除汞技術研究，使用的方法有：脫硫設備的化學法，脫硫設備的添加，溴的添加法，煙道中的活性碳噴入法，每種方法均有其缺點及限制，因此相關的研究仍在積極進行。

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# 目次

# 一、出國目的

因應全球能源需求遽增，能源價格上揚，而目前生質能爲全球四大能源，僅次於石油、煤及天然氣，是目前最廣泛使用的一種再生能源，本公司因二氧化碳減量需求，逐步使用生質燃料是必然的之趨勢，其中使用傳統燃煤鍋爐混燒木質生質能源，近年來世界各國戮力發展。由於木質生質燃料與煤炭熱值與化學成分不盡相同，燃燒後對煙氣處理系統的影響、副產物成分變化對煤灰性質的影響及利用方式的差異等值得加以探討，因此前往美國電力研究所觀摩生質能混燒及煙氣處理技術，了解生質燃料儲存環境、燃燒、運轉條件、煙氣控制情形及產生之煤灰利用可能面臨之問題，以作爲本公司生質燃料加入燃煤機組運轉之參考。另外有機高分子光電材料是目前科學家人認爲具有潛力可提升太陽能吸收效率的材料，因此美國 DOE 於 2009 年投入研發能量，本次出國順道前往研習相關技術。

目前全球發電結構中燃煤發電占 40%，國內則爲 33%，預估未來 30 至 50 年內均將維持此一比例，燃煤必然產生大量的煤灰、FGD 石膏及汙泥等副產物，在節能減碳議題發燒的情形下，電廠副產物的資源化再利用，國際間持續的投入人力與物力，從事相關研究。2013 世界煤灰會議(World of Coal Ash 2013 )在美國肯德基洲的 Lexington 舉辦，本所發表”Properties of CLSM Separation Dike using Coal Ash”論文一篇，因此參加該會議，發表論文，與各國專家交換研究心得，可藉以了解世界各國在燃煤副產物資源化利用研究技術上最新的發展，累積增加相關研究的能量。

# 二、出國行程

102 年 4 月 18 日～4 月 18 日　往程(台北一舊金山)

102 年 4 月 19 日～4 月 20 日　觀摩生質能混燒及煙氣處理技術
（參訪美國電力研究所 EPRI）

102 年 4 月 21 日～4 月 25 日　參加第 15 屆 2013 世界煤灰會議
(World of Coal Ash 2013)

102 年 4 月 26 日～4 月 29 日　有機高分子光電技術
(參訪紐約州立大學紐約分校)

102 年 4 月 30 日～5 月 1 日　返程(紐約---台北)

# 三、行程介紹

## 3-1 觀摩生質能混燒及煙氣處理技術(美國電力研究所 EPRI）

本次參訪位於加州 Palo Alto 燃燒與環境控制部門，主要進行的有關燃燒控制、污染防治及先進燃煤技術、二氧化碳捕捉與封存二氧化碳捕捉與封存三大項工作，本次主要拜訪對污染防治部門。

### 3-1-1 煙氣處理技術

有關煙氣處理技術，依據 EPRI 研究分析燃煤機組燃燒效率、鍋爐中的氣燃比與汙染物控制之間的關係如圖一所示，氣燃比對鍋爐效率而言，有一最佳化比率，然而一氧化碳、氮氧化物、硫氧化物、燒失量及其他汙染物，會隨著氣燃比的增加而增加，因此爲取得污染防治控制及鍋爐燃燒效率之間的平衡，會有一最佳化控制區域。這樣的分析結果，對於電廠的運轉相當的重要。

圖一、火力電廠燃燒效率與污染物排放關係

當今污染防治控制關注的焦點法規爲汞與空氣毒性標準 MATS(Mercury and Air Toxic Standard)及空氣清淨法案 CAIR(Clean Air Interstate Rule)，有關汞污染防治，希望能利用現有的污染防治設備進行修改而達到目的，使用的方法有：脫硫設備的化學法，脫硫設備的添加(如圖二所示)，溴的添加法，煙道中的活性碳噴入法(如圖三所示)。

使用活性碳的噴入法除汞，會影響飛灰中的未燃碳含量，而影響飛灰的銷售，若輔以鍋爐中溴的噴入除汞，可大大減少活性碳噴入量，試驗結果如圖四所示，則可減少活性碳添加對飛灰利用的衝擊。

圖二、脫硫設備除汞的修改

圖三、煙道活性碳的噴入

使用活性碳的噴入法除汞，會影響飛灰中的未燃碳含量，而影響飛灰的銷售，若輔以鍋爐中溴的噴入除汞，可大大減少活性碳噴入量，試驗結果如圖四所示，則可減少活性碳添加對飛灰利用的衝擊。

但溴的添加，無論使用自鍋爐或煙道中，均有相當的疑慮，如圖五所示，對鍋爐及煙道可能產生腐蝕，FGD 廢水可能增加溴的污染，若溴被固體副產物吸收，也可能產生溶出的效應，這些疑慮也是我們在除汞的同時，必須關心的。

圖四、活性碳噴入法結合鍋爐溴的添加對汞去除效率的影響

圖五、使用溴添加除汞對電廠造成的衝擊

### 3-1-2 生質能混燒

生質物具有:(1)高揮發性有機物質，(2)低能量密度低熱值，(3)低質量密度，(4)低硫分，(5)鹼金族及鹼土金族元素含量高(鉀、鈉、鈣、及鎂)，(6)高濃度的磷、氯及水氣含量，(7)低灰分融熔溫度，(8)無法以目前燃煤機組之磨煤機研磨，故燃料顆粒粗且具不規則形狀。圖六為固體燃料燃燒過程的示意圖，第一時間加熱後，產生蒸發現象，進一步吸熱，顆粒表面的揮發物質進行熱裂解(pyrolysis)，揮發性物質很快的與氧反應而消耗掉，殘留下的石油膠 Char 為固定碳物質，繼續氧化燃燒，最後殘留的即為我們所稱的飛灰。當生質能與煤炭混燒時，因為生質物的水分含量較高將延緩揮發及燃燒的時間，也會造成火焰分離，並對 NOX 的產生及火焰的穩定性產生影響。由流體動態計算程式 CFD(Computational fluid dynamics)計算出 32 MW wall-fired pulverized coal (PC) 鍋爐，混燒 20% 木屑前、後鍋爐溫度分布如圖七、八，生植物的混燒的確會造成鍋爐溫度下降。

圖六、固體燃料燃燒過程

圖七、未混燒之鍋爐溫度分布

圖八、20% 木屑混燒之溫度分布情形

又由於生質燃料的鹼金族及鹼土金族之金屬元素含量較高，再加

上磷及氯元素的增加，尤其是氯元素將促使細顆粒飛灰的產生，這將影響鉀及其他組成的傳送，也會傷害下游的煙氣處理設備。而鉀及鈣含量的增加，將降低灰份熔融的溫度，增加爐渣的產生，爐管將沉積灰渣而影響鍋爐效率。

SCR 處理煙氣中氮氧化物的反應是如下：

$2\ NH_3 + 2\ NO + 1/2\ O_2 \rightarrow 3\ H_2O + 2\ N_2$

$4\ NH_3 + 2\ NO_2 + O_2 \rightarrow 6\ H_2O + 3\ N_2$

當生植物中含有一些煤中沒有的元素，將使得 SCR 的觸媒活性位置失效，再加上小顆粒的灰、氣溶膠及濃縮物聚集堆疊於觸媒的微細孔洞，使得觸媒失效，這兩種促使 SCR 失效的示意圖如圖九所示。在美國曾經進行 PC 鍋爐的生質能混燒試驗，但未有常規性的混燒電廠，因此有關混燒飛灰的應用於混凝土，雖然 ASTM 也如同台灣 CNS 不被允許，但目前尚未遭遇需修改規範的壓力。美國未使用生質能發電，且每年出口數百萬噸的生質燃料到歐洲，歐洲電廠使用生質燃料，有使用流體化床 100%燃燒生質燃料，也有與媒混燒，或與天然氣混燒這幾種型態。

圖九、兩種使得 SCR 觸媒失效的示意圖

## 3-2 參加第 15 屆 2013 世界煤灰會議

第 15 屆 2013 世界煤灰會議(World of Coal Ash 2013 WOCA)，是由美國煤灰協會 ACAA (The American Coal Ash Association)及肯德基大學(The University of Kentucky)能源應用研究中心 CAER (Center for Applied Energy Research)主辦，本次 WOCA 會議，約有 600 人參與，共有 164 篇文章發表，會議的抬頭雖爲世界媒灰會議，實際文章探討的包含石膏、煤灰等燃煤產生的固體副產物相關問題的

探討，發表的文章如附件一所示，文章的主題可主要分爲(1)灰塘相關(32篇)，(2)水泥混凝土(17篇)，(3)法規(11篇)，(4)環境相關(10篇)，(5)化學類(20篇)，(6)利用類(11篇)，(7)液化(6篇)，(8)農業利用(3篇)，本所發表”Properties of CLSM Separation Dike using Coal Ash”論文一篇，如附件二，本篇文章主要討論縣西隔堤的配比及工程性質試驗結果及部分現地施工情形，獲得在場不少回應，大致覺得全煤灰控制性低強度材料(CLSM)的應用，是一個很好的煤灰出路，再加上2008年曾發生灰塘煤灰的溢流事件，若可以CLSM的概念，將煤灰加少量固化材，填於灰塘，既可增加水中煤灰的凝聚力，增加儲存空間，亦可使得灰塘土質有些許的強度，便不致有溢流、崩塌的現象，本篇文章獲選2013世界煤灰會議最佳海報論文獎，本項榮譽給予本研究團隊極大的鼓舞和激勵。

本次發表的文章中，有32篇文章探討灰塘的問題，比例相當的高。灰塘議題之所以受到如此之重視，主要受到2008年12月位於田納西州TVA Kingston 火力電廠之溼式灰塘溢流，造成0.34$Km^2$之灰塘土地流失(如圖十所示)，4,200,000 $m^3$的煤灰漿沖毀下游民宅，淹沒了400英畝土地(如圖十一所示)，也流進了Emory and Clinch 河流(這是田納西河的支流)(如圖十二所示)，這是美國前所未有的灰塘溢流事件規模，根據調查，這次事件排放了 140,000磅的砷至Emory河流中，兩倍於美國所有電廠排入河流中的砷，又由最新TVA電廠提送美國環保署的"The new Toxics Release Inventory (TRI) data”，TVA電廠這次事件總共排放了2.66百萬磅的10種毒性物質:砷、鋇、铬、銅、鉛、錳、汞、鎳、釩和鋅，這又比2007年調查全美電廠排放2.04百萬噸的毒性重金屬量又高出許多。因此這次事件引起了美國環保署極大的重視，不僅花極大的經費清理流出的煤灰，對於煤灰對環境的衝擊，再次引起關注，有關灰塘的管理，也投注相當的人力予以審慎評估，因此本次會議有關灰塘的議題研討，熱絡非常。

圖十、TVA 灰塘崩塌隔天之空照圖

圖十一、灰塘崩塌沖毀民宅

圖十二、TVA 電廠灰塘溢流後五天 Clinch and Emory 河流中仍有煤灰流動著

因為 TVA 灰塘事件，使得美國對於煤灰利用的推動，產生兩極化的看法，環保人士對於煤灰對環境的危害，存有疑慮，對於煤灰利用採較保守的態度，另一派則站在資源利用、節能減碳的觀點，較積極的推動煤灰資源化的利用，這真是環境與發展的兩難議題，煤灰必定隨著燃煤產生，灰的存在也必須去處理，與其推放處置，造成管理上的困擾，若可積極利用，便可減少處理龐大灰量的困境，煤灰既使有

略高於一般土壤的重金屬含量，若以水泥固化製作混凝土的方式應用，其溶出可大大的減少，應可減少對環境的衝擊，也可因此減少水泥用量，達到節能減碳的環保目的。

另外有 6 篇文章探討濕式灰塘液化問題的文章，Ohio state university 並在實驗室進行三軸試驗，探討煤灰液化行為，因為煤灰與一般土壤有極大的不同，是一個完全沒有顆粒間凝聚力的材料，因此其液化行為與一般土壤也會有所不同，本室目前進行灰塘地改的液化分析，應可利用實驗室的結果，微觀性質探討，加以比對驗證，因此值得進一步對相關研究進行了解探討。

會中有幾篇歐洲煤灰規範問題探討的文章，歐洲生產的飛灰，每年約有 6 百萬噸，佔利用量一半，使用於混凝土(如圖十三所示)，為了因應生質能的混燒飛灰的利用，2005 年修訂了煤灰利用於混凝土的規範 EN 450-1:2005，訂定飛灰卜作嵐性質材料適合 EN206-I type Ⅱ之添加，其 $SiO_2$ 含量至少 25%，混燒比例不可超出 20%(by dry mass)，灰分量不可大於 10%，混燒不包含垃圾及工業廢棄物之焚化灰，化學成分要求較嚴格:$Cl^- <0.1\%$，$SO_3<3\%$，Free CaO <2.5%，$SiO_2>25\%$，$SiO_2+Fe_2O_3+Al_2O_3>70\%$，$Na_2O<5\%$，$MgO<4\%$，可溶性之 $P_2O_5<100ppm$。

圖十三、1993 至 2009 歐洲飛灰利用量與利用途徑

2012 年進一步的調高混燒的比率，煤不得小於 60%，亦即生質能混燒量可達 40%(乾重比)，若混燒綠色木頭則可達 50%，但屬於生質能產生的灰不可大於 30%。但燃燒的固體生質燃料必須符合 EN 14588:2010 的規定，其中包含了畜牧業的殘留物，不包含 4.52, 4.132 和 4.17 的廢木頭，EN 14588:2010 針對不同生質燃料限制其鉀、鈣及磷氧化物含量，相對的，混燒產出的飛灰性質要求如表一及表二所示，很多的限定，比起 2005 年的規範都予以放寬，化學含量的限值，

也如此，採取源頭也就是生質能的飛灰成分管制，有關 free 氧化鈣則限定大於 1.5%，必須進行健度試驗。

表一、2005 與 2012 EN450 的分類與要求比較(一)

表二、2005 與 2012 EN450 的分類與要求比較(二 )

歐盟爲了修改規範進行的相關研究如圖十四、十五及十六所示，可看出歐盟爲了生質能混燒的飛灰利用，積極地進行有關試驗所花費的工夫，試驗的項目除了化學成分對混凝土影響，生物中特有成分的探討，試驗方法的分析，均投注相當的資源，加以澄清，確定其性質，方進行規範的修訂。會中曾與報告人歐洲燃煤產物學會(European Coal Combustion Products Association ecoba)主席 Fernando Caldas Vieira 先生討論有關歐洲飛灰混凝土規範修改經驗，歐洲是先進生質能的混燒，飛灰暫時不予販售，將產生的飛灰送至各國家有關的實驗室進行必要的混凝土性質探討，彙整試驗結果，並加以分析，才進行規範的修訂，這樣的流程，值得本公司參考。本所進行生質混燒飛灰的 CNS 規範修訂工作，亦將依據歐洲經驗，研訂規範策略的策略。

圖十四、爲了修改規範進行之 Free CaO 與健度關係圖

圖十五、灰分中全磷與溶解磷之關係圖

圖十六、濕式法與乾式法分析出的 45µM 殘餘量的比較結果

EN-206 則規範了爐石與非灰等波索蘭材料添加於混凝土的規範，包含添加比例、水灰比及不同暴露條件下的添加情況。EN 13282 則規定了剛性道路的水泥基的膠結料使用，若有波索蘭材料的添加，測試齡期可延長至 56 天，富含氧化鈣的 CFB 爐灰，在實驗室確認性質無虞的情況下，可加以利用，此項規定在 UAP 8/2012 是不被允許的。EN 14227 有關道路“Hydraulically Bound Mixtures“飛灰的添加，及添加飛灰的物理化學性質規範(Part 4 如表三所示)，part 13 的飛灰作爲土壤之規範目前在審議當中。另外還有 EN 12620 aggregates for concrete、EN 13043 aggregates or bituminous mixtures and surface treatments、EN 13139 aggregates for mortars、EN 13242 aggregates for unbound and hydraulically bound materials 及 EN 13055 for lightweight aggregates 等與煤灰資源化利用有關的規範在審議並近乎完成的階段。由此可看出歐洲對於煤灰資源化利用的推動，相對美國是更積極與努力的。

表三、作爲道路使用之飛灰物理化學性質規範

## 3-3 有機高分子光電技術

高分子機光電材料爲一種具導電性的高分子聚合物，又稱導電塑膠與導電塑料，最簡單的例子是聚乙炔。當高分子結構擁有延長共軛雙鍵，π軌域鍵電子不受原子束縛，能在聚合鏈上自由移動，經過摻雜後，可移走電子生成空穴，或添加電子，使電子或空穴在分子鏈上自由移動，從而形成導電分子。常見的導電聚合物有、聚苯胺、聚吡咯、聚噻吩和聚對苯乙烯，以及它們的衍生物。

和傳統無機材料比起來，導電聚合物在製程上較簡單，像是可以用旋轉塗佈或噴墨式，在原料和製程上都較便宜，初始投資(建廠)成本不用像無機材料需要十幾億美金以上，性質上則有可僥性，可製做成薄膜狀，目前性質已可追上無定型矽晶材料。導電聚合物常被用於電力裝置，例如電池中的電極，電解電容器及電子感應器，在導電聚合物之光子放射研究可能使導電聚合物在未來可用於發光二極體 (LED) 和平面顯示器。導電聚合物亦可成爲安裝在奈米級電子裝置內的「分子電線」。

美國能源部先進能源研究中心(EFRC Energy Frontier Research Center)投注相當多的經費進行高分子基光捕獲材料(Polymer-Based Materials for Harvesting Solar Energy PHaSE)研發計畫，主要分爲：(1)高分子設計及合成技術，(2)控制元件及型態研發、(3)裝置設計整合之光電特性研發。本計畫由麻州州立大學整合規劃，其目的希望能增加太陽光的波長帶吸收，以提高轉換效率。

# 四、心得

1、　本次出國在 2013 世界煤灰會議 WOCA (World of Coal Ash) 會議中發表之 "Properties of CLSM Separation Dike using Coal Ash"一文獲得最佳 Poster 論文獎，本文內容主要討論線西隔堤的配比及工程性質試驗結果及部分現地施工情形，現場也獲得相當多的肯定，代表全煤灰控制性低強度材料(CLSM)的應用，對混凝土利用不完的煤灰，是一個很好的出路。

2、　美國 TVA 電廠於 2008 發生灰塘崩壞事件，造成極大的環境汙染，因此使得美國近幾年來對煤灰的利用推動保守謹慎，但也有另一股勢力，站在節約資源的觀點上，極力推動煤灰的資源化利用。個人認爲：煤灰必定隨著燃煤產生，在必須使用燃煤發電的情形下，灰的存在也必須去處理，與其推放處置，造成管理上的困擾，若可積極利用，便可減少處理龐大灰量的花費及管理困境，煤灰既使有略高於一般土壤的重金屬含量，若以水泥固化製作混凝土的方式應用，其溶出可大大的降低，應可減少對環境的衝擊，也可因此減少水泥用量，達到節能減碳與減少資源開發環保雙贏的結果。

3、　濕式灰塘的軟弱地盤造成了 TVA 的崩塌溢流事件，提醒了我們，煤灰以泥漿放流方式，填入灰塘，是否可靠？大片鬆軟又無凝聚力的土壤，若可在進入灰塘前，即以 CLSM 的概念，加入少量的固化材，填於灰塘，既可增加水中煤灰的凝聚力，增加儲存空間，亦可使得灰塘土質有些許的強度，便不致有溢流、崩塌的現象，若需土地再利用時，也不須經過費時又費工的地改過程。

4、　本次有 6 篇文章探討濕式灰塘液化問題的文章，Ohio state university 並在實驗室進行試驗探討煤灰液化行爲，本室目前進行灰塘地改的液化分析，實驗室的結果，應可作爲比對驗證，頗

值得進一步了解探討。

5、　生質燃料混燒煤灰利用之改版研究，歐洲經驗；鍋爐混燒後的灰，收集送交各國進行相關的混凝土性質試驗，各項試驗結果，送規範委員會審議，進行規範的修改，詳細的流程及試驗項目將進一步地了解，作爲本所進行”生質燃料混燒飛灰之成分與性能分析及 CNS3036 改版研究”之參考。

6、　在會議場中與中國大陸相關人員交流了解，近幾年來大陸堆動煤灰資源化利用非常積極，利用率也增加相當的快，除利用於一般的水泥製品外，也積極的研發高價化的利用，以弭補偏遠地區燃煤發電產生的煤灰利用率偏低的問題，創造高價化的利用，可補貼遠距的運費。本所因人力不足，對於高價化煤灰產品開發，未投入人力研發，實屬可惜。

7、　EPRI 曾經進行相關研究，5%生質燃料混燒對 PC 鍋爐是 OK 的。生植物中含的 F 會毒化 SCR 的觸媒，影響其運轉壽命。美國出口生質燃料到歐洲數百萬噸，EPRI 曾進行生質能混燒研究，但並未積極推動生質燃料與煤的混燒。

8、　美國 EPA 新制定的新空氣法案，制定汞的排放標準，2015 年需低於目前標準 2 個級數，也就是燃燒熱值高於 8300BTU/LB，汞排放標準 1.4~1.7μg/$NM^3$，(目前台灣 EPA 制定的汞排放草案 5μg/NM3)，因應此嚴格的法規，EPRI 進行多項除汞技術研究，使用的方法有:脫硫設備的化學法，脫硫設備的添加，溴的添加法，煙道中的活性碳噴入法，每種方法均有其缺點及限制，因此相關的研究仍在積極進行。

# 五、建議事項

就本次灰塘地改抗震技術研習及參加第 7 屆淨煤技術及燃料電池國際研討會的心得，提出以下幾點建議以供參考：

(1)、世界煤灰會議是針對燃煤電廠固體副產物處理問題研討的會議，開始的年代最早，每兩年舉辦一次，今年第 15 屆，隨著時空的轉移，煤的使用仍是目前能源供應的大宗，因此獲得大家關注的程度，有增無減。整體而言，有關煤灰資源化利用比例，台電公司將近 90%的成績可說相當傲人，台電經驗，值得向全世界宣揚。

(2)、本公司因爲推動全煤灰控制性低強度材料的應用，底灰的利用也逐年增加，建議本公司所有火力電廠的底灰出灰系統，均可改爲淡水出灰，增加供應量，則煤灰 100%利用的成績，將指日可待。

(3)、本公司火力電廠之更新工程，大都在現有電廠旁邊，許多土建工程，應大力推動使用煤灰，不僅減少工程材料費用，減低材料運送及水泥使用的碳排放，可說是火力電廠落實清潔生產的具體作爲，全煤灰 CLSM 應用於線西隔堤工程，即是最佳實例。

(4)、2008 年美國 TVA 電廠濕式灰塘發生崩塌溢流事件，對同樣以泥漿方式將煤灰送進灰塘的台電灰塘，應檢討以 CLSM 的概念，將煤灰加少量固化材，填於灰塘，既可增加水中煤灰的凝聚力，增加土質的穩定性，減少其流動的可能性，也增加灰塘的儲存空間，亦可使得灰塘土質有些許的強度，土地利用時，亦不需進行費時、費力的地改。

(5)、本所進行生質能混燒飛灰應用於混凝土的相關國家標準改版研究，就歐洲成功進行相同規範修改的經驗，爲了取得規範審議委員會委員們的信心，火力電廠必須先進行混燒，並取得足夠的混燒飛灰樣本，分送不同單位，進行混凝土性質的試驗，綜合分析後，方可竟其功。

(6)、本公司若因碳權因素，必須推動生質能的混燒，應更精細的評估混燒對鍋爐、效率及煙氣處理造成的影響，做最佳化分析，避免爲解決碳權問題，卻衍生其他問題，歐洲經驗應是我們可以了解與效法的。

# 附件一

WOCA

*2013 CANCELLATIONS*

*AND*

*PRESENTATION CHANGES*

SINCE THE AGENDA BOOK

WAS PRINTED

See Session Room Posters

For On-Site Changes

and/or

Cancellations

| BALLROOM 1 | BALLROOM 2 | BALLROOM 3 | BALLROOM 4 | BALLROOM 5 |
|---|---|---|---|---|
| Ponds II | Cement & Concrete II | Regulations I | Utilization I | Chemistry II |
| **1:00 p.m.** | | | | |
| #143 Laboratory Testing of Woven and Non-Woven Geocomposites for Use in CCB Landfill Drainage Systems<br>*William Wolfe, Tarunjit Butalia* | #103 Examination of Precursors in Fly Ash for Development of an Engineered Geopolymer Concrete<br>*Fernando Soto, Kunal Kupwade-Patil, Milap Dhakal, Shathabish NaraseGowda, Daniela Mainardi, Erez N. Allouche* | #119 Updated Canadian CCP Use Statistics Reveal Evolution of Coal Ash Industry in Canada<br>*Anne Weir* | #78 Development of Dry FGD By-Product Utilization as Building Materials in China<br>*Qingfa Su, Yabing Jiang, Manyuan Lu, Yongrui Chen, Muh-Cheng M. Wu* | #26 Transformations of mercury, arsenic, and selenium in river sediments contaminated with coal ash: Sediment microcosm studies<br>*G. Schwartz, H. Hsu-Kim* |
| **1:30 p.m.** | | | | |
| #5 An Innovative Composite Liner System for Coal Combustion Residual Containment Projects<br>*Ed Zimmel, Dhani Narejo, Jimmy Youngblood* | #61 An Innovative Approach for Mercury Capture<br>*Christopher Poling, Thomas Lesniak, Melissa Harrison* | #135 European Product Standards - Update on status and changes with relevance to CCPs<br>*Fernando Caldas-Vieira, Hans-Joachim Feuerborn, Angelo Saraber* | #91 An Innovative Design for Coal Ash Impoundment Capping and Closures with Significant Cost, Performance and Environmental Co-Benefits - The Exposed Geomembrane Solar Cap<br>*Mark Roberts, Christopher Hardin* | #149 Reduction of Nickel Leachability from IGCC Slag<br>*Oriol Font, Xavier Querol, Pilar Coca, Alejandro Muñoz, Francisco Garcia-Peña* |
| **2:00 p.m.** | | | | |
| #39 Geosynthetics for the Management, Containment and Closure of Coal Combustion Residual Disposal Facilities<br>*Ernest H. Heins* | #77 High Strength Building Materials from Geopolymerization of Fly Ash<br>*S. K. Nath, D. K. Sinha, S. Khan, S. Maitra S. Kumar* | #109 CCR Management Audits: Preparing for the Future Proactively<br>*Jason M. Pokorny, Steven F. Putrich* | #111 The Morgantown STAR Project: A Fly Ash Beneficial Reuse Case Study<br>*Brandie M. Sebastian, Robin Lee, Robert Sawyer, Shawn Seaman* | #134 Research on Calcium Silicate from Desilication Filtrate of Fly Ash<br>*Li Yonghui, Li Huiquan, Li Shaopeng, Ma Yanli, He Shiyue* |
| **2:30 p.m.** | | | | |
| #153 Building a New Ash Repository over a Former Coal Mine<br>*Stephen L. Whiteside, Steve Marshall, Simon Witney, David Murray, Michelle Cooke* | #20 Fly Ash Separation Technology and its Potential Applications<br>*Yang Dong, Jinder Jow, Shih-Yaw Lai, Jianhui Su* | #144 CCPs in a New Regulatory Era<br>*Thomas H. Adams* | #55 Coal Ash as a Potential Scrubber for Quarry Sludge and Trace Elements<br>*Roy Nir Lieberman, Yaakov Anker and Haim Cohen* | |

**3:00 p.m.**

COFFEE BREAK IN EXHIBIT HALL

**3:30 p.m. - 5:00 p.m.**

## THOROUGHBRED PRE-FUNCTION AREA

~~**#28** Effect of Amount of Fly Ash on Shear Strength of Reinforced Concrete Beams~~
~~*Mahdi Mohammadi, Jeffery S. Volz and John J. Myers*~~

#34 Effects of the CFBC fly ash substitution ratio, water/binder ratio and curing temperature on hydration of CFBC fly ash cement pastes

*Guanjie Zhai, Xiaoxu Fu, Qin Li, Jianping Zhai, Della Roy, Feihu Li*

**#42** Properties of CLSM Separation Dike using Coal Ash
*L.W. Guo, C.L. Hwang, Y.Y. Yen, M.B. Yang, C.T. Lai and S.H. Cheng*

**#43** Production of Alite-Calcium Sulfoaluminate-Ferrite Cements from Coal and Other Industrial By-products
*Tristana Duvallet, Thomas L. Robl*

**#57** Evaluation of Heavy Metal Contamination and Geochemical Characteristics of CCPs in Korea
*Jaesung Park, Woosook Choi, Taewan Kim, Younghwan Son*

**#68** Use of Fly Ash as Soil Amendment for Biofuel Feedstock Production with Concomitant Disposal of Waste Accumulations
*Harold Pettigrew, Olumdayo Adeleke, Dafeng Hui and E. Kudjo Dzantor*

**#80** Effect of Soil Amendments using Coal Ash on Soil Quality and Crop Growth in South Korea
*Se-Jin Oh, Sung-Chul Kim, Hyun-Soo Yun, Seung-Min Oh, Sang-Phil Lee, Rog-Young Kim, Jae E. Yang*

**#81** Evaluation of Stabilization Effect of Coal Fly Ash for Acid Mine Drainage from Mine Waste in South Korea
*Se-Jin Oh, Sung-Chul Kim, Sung-Woo Moon, Eun Kyung Lee, Rog-Young Kim, Jae E. Yang*

**#85** Changes in Crushing and Granularity Characteristics of Bottom ash as Compaction Energy
*Woosook Choi, Younghwan Son, Jaesung Park, Sookack Noh and Taeho Bang*

**#85** Composition, morphology and trace element leaching from US coal fly ash
*A.Deonarine, A. Kolker, F. Huggins, A. Foster*

**#97** Commercial Use of CCBs: Changes, Challenges and Opportunities
*Matthew Erbe, Robin G. Lee, Jennifer Gunnelson, Leonard G. Rafalko, Paul Petrick, John Sherwell*

**#99** Design of Fly-Ash Concrete Masonry for Optimal Carbon Sequestration
*Andrew J. Salber, Christopher W. Swan*

**#110** Practical Carbon Sequestration and Mine Reclamation Using High Volume Ash Concrete
*Shen-En Chen, Peng Wang, Ben Smith, Christopher Hardin, and John Daniels*

**#114** Civil Site and Stormwater Design Considerations for the Closure of Coal Ash Impoundments
*Nick Perrotta and Christopher Hardin*

**#124** Study on Efficacy of Flyash Suitability as a Substitute for Development of Fire Retardency in Polyester Resins
*Jagdish, Ishtiaque Ahmad and Zulfiqar Ahmad*

**#127** Use of Vermicomposting Biotechnology for Recycling of Coal Ash in Agriculture
*G.N.Chattopadhyay, Gourab Roy and Wasim Iftika*

**#128** The Creep Behavior of Bottom Ash by controlling size at Undrained condition
*Taewan Kim, Younghwan Son, Taeho Bang, Sookack Noh and Jaesung Park*

**#129** Applicability of Coal Combustion Products as Vertical Drain Method in Soft Ground Improvement
*Hyun-Young Shin, Kyoung-O Kim, Tae-Hoon Kim, Byeong-Il Kim and Sang-Jae Han*

**#130** Shearing Characteristics of Artificial Soil Mixture with Reclaimed Coal Ash
*Kyoung-O Kim, Hyun-Young Shin, Yoo-Seok Kim, Duk-Ho Choe and Wan-Jei Cho*

3:30 p.m. - 5:00 p.m. cont.

## THOROUGHBRED PRE-FUNCTION AREA

**#131** Experimental Study on the Thermal Characteristics of Controlled Low Strength Materials with Coal Ash
*Hyuk-sang Jung, Jin-young Kong, Yo-seph Byun, Seung-jun Lee and Byung-sik Chun*

**#133** Research of Comprehensive Utilization of High-alumina Fly Ash by Alkali Solution
*MA Yan-li, Li Huiquan, Li Shao-peng, LI Yong-hui*

**#150** Converting IGCC Fly Ash in an Inert Landfilling Material
*Oriol Font, Xavier Querol, Pilar Coca, Alejandro Muñoz, Francisco García-Peña*

**#170** Neutralizing Effect of Coal Ash on Abandoned Coal Mine Producing Acid Mine Drainage
*Jae E. Yang, Se J. Oh , Hyun S. Yun, Sang P. Lee, Rog Y. Kim, Sung C. Kim, Jin K. Lim, Kee S. Lee, Do Y. Won, Soon Y. Kwon*

**#172** Effect of grain size on mineral carbonation of coal combustion fly ash for $CO_2$ sequestration
*N.L. Ukwattage, P.G. Ranjith*

**#173** Feasibility study of coal ash as a stowing material
*Kislay Kumar*

**#174** Performance Assessment of Concrete with Partial Replacement of Portland Cement by Coal Ash
*Antonio Eduardo B. Cabral, Mylene M. Vieira, Maria Viviane A. dos Santos*

**#175** Dense Slurry Ash Management
*Geza Walter, Alex Zekovich*

**#176** Grey Area in the Rainbow Nation
*Walied Jessat, Tobile Bokwe and Warren Funston*

**#178** Reactive Transport Modeling of FGD Gypsum Bed to Simulate Time Dependent Dissolution, Porosity Evolution, and Leachate Composition -
*Mina Mohebbi, Jean-Patrick L. Brunet , Li Li, Farshad Rajabipour, Barry E. Scheetz*

## AGENDA & SESSIONS

Wednesday, April 24, 2013

7:00 a.m. to 8:00 a.m. CONTINENTAL BREAKFAST IN EXHIBIT HALL — Breakfast Sponsored by:

| BALLROOM 1 | BALLROOM 2 | BALLROOM 3 | BALLROOM 4 | BALLROOM 5 |
|---|---|---|---|---|
| Kingston I – Ecological Investigations | Cement & Concrete III | Regulations II | Carbon I | Chemistry III |
| | | **8:00 a.m.** | | |
| #161 Long-term Sediment Toxicity Bioassays *Rick M. Sherrard* | #104 Effect of Accelerated Sulfate Attack in Geopolymer Concrete *Kunal Kupwade-Patil, Erez N. Allouche, Courtney Alyssa Watts, Shathabish NaraseGowda* | #93 The Social Media Battleground: How Public Perception, Science Communication, Media Coverage, and Politics Are Shaped by Social Media *Dawn Santoianni* | #8 On-Line Carbon in Ash System at PPL Montour for Increasing Ash Sales *Todd Melick, Larry LaBuz, Matthew Paisley* | #67 Weathering and Leaching Characteristics of a Floated Scrubber Sludge Cap at an Abandoned Mine Site in Pike County, Indiana *Luke C. Martin, Tracy D. Branam, Shawn C. Naylor, Greg A. Olyphant* |
| | | **8:30 a.m.** | | |
| #162 Effects of the Kingston Ash Release on Fish Reproduction and Larval Fish *Mark S. Greeley, Jr., S. Marshall Adams, Tyler F. Baker, Logan R. Elmore, Allison M. Fortner, Teresa J. Mathews, Mary K. McCracken, Rick M. Sherrard* | #95 Evaluating Test Methods for Rapidly Assessing Fly Ash Reactivity for Use in Concrete *Michael J. McCarthy, S. M. Sadiqul Islam, Laszlo J. Csetenyi, M. Roderick Jones* | #108 New Developments in CCR Pond Closure Technologies: The End of an Era and a New Paradigm *Steven F. Putrich* | #30 BASF Mercury Sorbent HX™ *William Hizny, Fabien Rioult, Xiaolin Yang* | #56 Morphology Changes in Bituminous Coal Fly Ash via Aqueous Solution Treatment (Acidic and Neutral) *Roy Nir Lieberman, Oriol Font, Xavier Querol, Haim Cohen* |
| | | **9:00 a.m.** | | |
| #163 Effects of the Kingston Ash Release on Fish and Benthic Invertebrate Assemblages *Tyler F. Baker, Kurt M. Lakin, John G. Smith* | #3 Quality Control Tools to Identify Source Variability of Class C Fly ash and its Impact on Freshly Mixed Cement-Fly Ash Paste *Jason D. Rupnow* | #136 Impact of Political Decisions on Production and Use of Coal Combustion Products in Europe *Fernando Caldas-Vieira, Hans-Joachim Feuerborn* | #40 Post-combustion of carbon residues from biomass / RDF co-firing during dry ash removal *Fulvio Bassetti, Daniele Coppola, Daniele Ricci, Osvaldo Sennica* | #35 Using Regenerative Ammonium salts to extract and purify Magnesium Oxide from Victorian brown coal fly ash *Tahereh Hosseini, Lian Zhang* |
| | | **9:30 a.m.** | | |
| #164 Reproduction in Aquatic and Terrestrial Wildlife Following Remediation of the TVA Coal Ash Spill in Kingston, TN *Michelle Beck, David Steen, James Van Dyke, William A. Hopkins* | | | #21 Chemical Composition Determination and Thermal Analysis for Some Typical Biomass Ashes in China *Weidong Wang, Xin Liu, Yanli Zheng, Peng Wang, Yong Dong, Chunyuan Ma* | #132 Extraction of Gallium from High-alumina Fly Ash by Modified Ion-exchange Method *Shaopeng Li, Wenfen Wu, Fei Li, Weijun Bao, Huiquan Li* |
| | | **10:00 a.m.** | | |

COFFEE BREAK IN EXHIBIT HALL — Coffee Break Sponsored by: SEFA

| BALLROOM 1 | BALLROOM 2 | BALLROOM 3 | BALLROOM 4 | BALLROOM 5 |
|---|---|---|---|---|
| Ponds III | Liquefaction I | Ponds & Landfills I | Environmental I | Chemistry IV - Toxicity |
| **10:30 a.m.** | | | | |
| #32 Instrumentation and Monitoring Program - TVA Coal Combustion By-Product Storage Facilities *Hugo Aparicio, Will Mattingly, Jennifer McCosby, Rachel Combs, Gabriel Lang* | #146 Establishing Liquefaction Characteristics of Ponded Coal Combustion Residuum *Nathan Yencho, Brian Dudley, Pedro Amaya, William Wolfe, Taranjit Butalia* | #9 Strategic Planning for Siting Coal Combustion Residual Disposal Facilities *Sean Rome, M. Kent Atkins* | #47 Mine wastewater treatment by highly calcareous and siliceous fly ash: a comparative study *Dimitrios Alexopoulos, Grigorios Itskos, Charalampos Vasilatos, Nikolaos Koukouzas, Michael Stamatakis* | #50 Ecological Effects of Coal Combustion Products (CCPs): A Literature Review of Observed Effects and Considerations for Managing Risks *David B. Mayfield, Sagar Thakali, W. Tyler Mehler, Ari S. Lewis* |
| **11:00 a.m.** | | | | |
| #90 Preparing for Closure of the John Sevier Fossil Plant: Re-routing of the Bottom Ash Pond Outfall Driven by NPDES Requirements *April L. Vance, Shannon E. Bennett, Joshua D. Kopp* | #21 Cyclic Triaxial Testing of Water-Pluviated Fly Ash Specimens *Jeffrey S. Dingrando, Michael E. Kalinski, Ali Salehian, Benjamin B. Zand* | #26 Considerations in the Development of a Coal Combustion Products Landfill *Kenton J. Yang, John M. Reichling, Peter M. Chemmery* | #82 Groundwater Evaluation for Ash Ponds at a Coal Fired Power Plant in Texas *Camona V. Smith, Kevin Pasternak, James R. Crysup* | #95 Coal Ash Material Safety - A Health Risk-Based Evaluation of USGS Coal Ash Data from Five US Power Plants *Lisa JN Bradley* |
| **11:30 a.m.** | | | | |
| #11 Project Considerations for New Coal Ash Landfills *Rome, M. Sean, Al-Hawarin, Mohamad* | #113 Use of Instrumented Test Fill to Assess Static Liquefaction of Impounded Fly Ash *Omer Bozok, Paul J. Sabatini, Pedro J Amaya* | #151 Challenges Associated with Operating Ash Ponds while Preparing for Closure – A Case History of TVA's Widows Creek Fossil Plant Ash Pond Complex *Jimmy Mullins, Jay Mokatoff, Jeremy Heyerly* | #158 Porewater Studies Subsequent to the Kingston Ash Event *William J. Rogers, Neil E. Carriker, Rock J. Vitale, Jennifer N. Goble, Eric E. Rodgers, Joseph P. Kraycik* | #112 Designation of Pulverised Fuel Ash and Furnace Bottom Ash as Wastes in the United Kingdom *Robert A Carroll* |
| **Noon - 1:00 p.m.** | | | | |
| LUNCH ON YOUR OWN | | | | |

| Time | BALLROOM 1 | BALLROOM 2 | BALLROOM 3 | BALLROOM 4 | BALLROOM 5 |
|---|---|---|---|---|---|
| | Kingston II - Application of Kingston Ecological Results | Cement & Concrete IV | Regulations III | Environmental II | Chemistry V |
| 1:00 p.m. | #165 Human and Ecological Risk Characterization for the River System at the TVA Kingston Ash Recovery Project<br>*Daniel Jones, Mark Stack, Suzy Young, Neil Carriker* | #41 Effects of Mixing and Transportation on Characteristics of Cementitious Systems Containing Fly Ash<br>*Lapyote Prasittisopin, David Trejo* | #92 Job Impacts in the Coal Industry: What Can We Expect from the Natural Gas Boom and Environmental Regulations?<br>*Dawn Santoianni* | #105 In Situ Stabilization/ Solidification (ISS) in the Power Industry and Applications for Coal Combustion Products (CCP)<br>*Christopher A. Robb, Roy E. Wittenberg, Glenn R. Luke* | #154 Spatial and Temporal Variations of Groundwater Chemistry Before and During Coal Mine Reclamation Using Flue Gas Desulfurization (FGD) Materials<br>*Chin-Min Cheng, Robert Baker, Tarunjit Butalia, Harold Walker, John Massey-Norton, William Wolfe* |
| 1:30 p.m. | #166 Evaluation of Remediation Alternatives and Selected Remedial Actions<br>*Craig Zeller* | #60 Study of Leachates from Fly Ash-Stabilized Pit Wastes<br>*Monte L. Ellis, Jane V. Thomas* | #6 Regulatory and Legal Applications: Fly Ash Use in Cement and Cementitious Products<br>*Steven T. Moon* | #98 Dust Suppression In Coal Ash Applications<br>*Aaron Valencic* | #106 Managing Geochemistry of Multiple Coal Ash Metals of Potential Concern – The New Regulatory Context and Its Practical Implications for New and Existing Facilities<br>*Jeff Gillow, Chris Lotes, Dave Liles, Peter Kariher, Mike Hay* |
| 2:00 p.m. | #167 Development of a Long-Term Monitoring Plan for the Kingston Ash Spill<br>*Neil E. Carriker* | #168 Leaching Comparison of Natural and Coal-Derived Lightweight Aggregates used for Concrete Masonry Units<br>*John Groppo, Kevin Henke* | #33 Stigma and Regulatory Uncertainty: Proposed Coal Ash Disposal Regulation Effects on U.S. Beneficial Use Markets and Practices<br>*John N. Ward* | #155 Results of a Feasibility and Preliminary Engineering Study for a System to Process and Stabilize Scrubber Waste from the APS Four Corners Unit 4 and 5 FGD Systems<br>*Gordon Maller* | #2 Low temperature plasma ashing of coal for quantitative mineral analysis<br>*James Bond, Louis Giroux* |
| 2:30 p.m. | PANEL DISCUSSION<br>Moderated session *presenters will be available to take questions.* | #[illegible]5 Assessing Leachability and Compressive Strength of Fly Ash Blended Cement<br>*Radhika [illegible], Lokeshappa B, Anil Kumar Dikshit*<br>Cancelled | #72 Greatest Challenges for CCP Management and What To Do About Each<br>*Mark Rokoff, James Heyerly, James Moseley* | #63 CCP Landfill Leachate Generation and Leachate Management<br>*I. Kyle Baucom, Cedric H. Ruhl* | #115 Detailed characterization of reactivity of fly ash by SEM/EBSD and image analysis<br>*Kazuo Yamada, Haruka Takahashi*<br>Cancelled |
| 3:00 p.m. | COFFEE BREAK IN EXHIBIT HALL | | | | |

| BALLROOM 1 | BALLROOM 2 | BALLROOM 3 | BALLROOM 4 | BALLROOM 5 |
|---|---|---|---|---|
| Ponds IV | Liquefaction II | Ponds & Landfills II | Environmental III | Chemistry VI |
| **3:30 p.m.** | | | | |
| #29 Performance Based QC/QA Specifications for TVA's CCP Stacking Facilities: Part I. Evaluation of Performance Requirements *Barry R. Christopher, David J. White, Roberto L. Sanchez* | #138 Dynamic Geotechnical Laboratory Testing of Coal Combustion Products *Kevin M. Foster, Adrian Rodriguez-Marek, Russell A. Green, Roberto L. Sanchez* | #52 Characterization and Estimation of Settlement of In-Place Sluiced CCP Materials Under Monotonic Loading *Jason S. Reeves Michael G. Rowland* | #58 Recommended Guidelines for the Use and Application of the Leaching Environmental Assessment Framework (LEAF) for Coal Combustion Residuals *John L. Daniels, Christopher D. Hardin, Jenet T. Hattaway* | #27 The Agglomeration and Collection of Precharged PM1 in Typical ESP *Peng Wang, Zhongyang Luo, Yong Dong, Lin Cui* |
| **4:00 p.m.** | | | | |
| #46 Performance Based QC/QA Specifications for TVA's CCP Stacking Facilities: Part II. Proposed Specifications *David J. White, Barry R. Christopher, Roberto L. Sanchez* | #145 Cyclic Liquefaction Assessment of a Hydraulically Placed Fly Ash *Miguel A. Pando, Youngjin Park, Vincent Ogunro, John Daniels* | #59 Improving Risk Assessments for Coal Combustion Residual Impoundment Dikles and Dams *John R. Menninger, D. Nathan Beach, Daniel E. Hoffma* | #54 Steam Electric Power Generating Facilities: Meeting Future Wastewater Treatment Requirements *Bernardino P. Nanni, Justin L. Bolender, Spencer D. Whittier* | #169 Survival Guide for the New Steam Electric Generating Effluent Guidelines *Ivan A. Cooper* |
| **4:30 p.m.** | | | | |
| #40 Challenges of Closing Large Fly Ash Ponds *John Seymour, Steve Macrowski, Pedro J. Amaya, John Esser* | #23 Evaluation of Liquefaction Potential at Fly Ash Storage Reservoirs *Pedro J Amaya, Behrad Zand, Donald Fuller, Jeffrey Dingrando, Vik Gautam, Thomas Kovacic, Paul Sabatini, Rodolfo Sancio, Nicholas Perrotta, Christopher Hardin* | #75 Considerations for Treating Landfill and Impoundment Leachate with Impacts from Planned Effluent Guidelines *Larry Linguist, Michael Cook, Mark Rokoff* | #156 Storing Fly Ash in A Concrete Dome: A Case Study *Benjamin K. Davis, Bill Fedorka, Tim English,* | #37 Current Status and Prospect of Fly Ash Utilization in China *Zhenhua Tang, Shuhua Ma, Jian Ding, Yuejiao Wang, Shili Zheng and Guanjie Zhai* |

## AGENDA & SESSIONS

**Thursday, April 25, 2013**

7:00 a.m. to 8:00 a.m. CONTINENTAL BREAKFAST IN ~~EXHIBIT HALL~~ THOROUGHBRED PRE-FUNCTION

| BALLROOM 1 | BALLROOM 2 | BALLROOM 3 | BALLROOM 4 | BALLROOM 5 |
|---|---|---|---|---|
| Ponds V | Cement & Concrete V | Utilization II | Pond Closure | Beneficiation I |
| **8:00 a.m.** | | | | |
| #10 Utilizing Cut-Off Walls for Groundwater Remediation Issues associated with Coal Ash Landfills *Rome, M. Sean, Al-Hawaree, Mohamad* | #76 Design, Fabrication and Testing of a Full-Scale Geopolymer Concrete Median Barrier *Milap Dhakal, Mir Al-Masud, Shaurav Alam, Carlos Montes, Kunal Kupwade-Patil, Erez Allouche, Aziz Saber* | #141 Mechanically Stabilized Earthen (MSE) Berm Basics – Applicability, Design Standards and Construction Quality Control/Assurance *Carlton L. Dudding, Scott K. Sheridan* Moved to 8:30am | #122 Ash Pond Decommissioning Strategies: Case Study for a Midwest Coal-Fired Utility *Todd McDaniels, Steven F. Putrich* | #36 Separation Technologies' Automated Fly Ash Beneficiation Process selected for New Korean Power Plant *J. D. Bittner, S. A. Gasiorowski, T. W. Bush, F. J. Hrach* |
| **8:30 a.m.** | | | | |
| #125 Use of Bottom Ash in the Reinforced Zone of a Mechanically Stabilized Earth Wall for the Vertical Expansion of a Sluiced CCR Pond at the Trimble County Generating Station *Nicholas G. Schmitt, Brian Cole* | ~~#66 Evaluation of Frost Resistance of Ternary Cementitious Concretes with Cement-Fly Ash-Silica Fume *Chang-Seon Shon, Young-Sang Kim, Don Saylak*~~ Cancelled | #142 Laboratory and Pilot-Scale Field Testing of CCB Flowable Grout for Mining of Coal *James Kirch, Tarunjit Butalia, William Wolfe* moved to 9:00am | #69 Evaluation of the Settlement Behavior of Flyash for Ash Basin Closure Projects *Christopher Hardin, Behrad Zand, Pedro Amaya, Roger Falmezger, Scott Heisey* | #7 Beneficiation of Dry Scrubber Material (DSM) through Pelletization *Keith C. Day, Michael DiNovo* |
| **9:00 a.m.** | | | | |
| #107 Filter and Drainage Systems at CCR Disposal Facilities - State of Practice *Sarah Fick, Cuneyt Gokmen, Mehmet Iscimen, Neil Davies* | #64 Influence of Coal Fly Ash on Mechanical Properties of Mortar Consisting of Total Dissolved Solids *Bijoy Krishna Halder, Vivek Tandon, Anthony Tarquin, Ramana V. Chintalapalle* | #82 Electronic Information Systems of the Open Access for Effective Solution of both Environmental and Coal Ash Utilization Issues *V.Y. Putilov, I.V. Putilov, E.A. Malikova* moved to 9:30am | #24 Closure of the Failed Ash Dredge Cell at Kingston – The Engineering Challenge *Vernon J. Dotson, Jr., Darrell E. Herron, Alan F. Rauch, Micahel J. Steele* | #16 Efficient Pneumatic Conveying Dense Phase vs Dilute Phase: How Being Accurate is More Cost Effective than being Conservative *Kody W. Smajstrla* |
| **9:30 a.m.** | | | | |
| #86 Use of Calcium Based Products to Stabilize Ponded Coal Combustion Products - Techniques and Results *Eric A. Berger, Howard B. Fitzgerald* | #139 Fly Ash - Calcium Sulfoaluminate Blended Cement and its Application in Ultra-Low Density Foamed Concrete *M. Roderick Jones, Kezban Ozlutas, Anthoula Ouzounidou, Robert Rathbone* moved to 8:30am | #18 Manufacturing of Fire-Resistant Panels Using FGD Gypsum and Fly Ash from Power Plants in Xinjiang, Northwest China *Jing Li, Xinguo Zhuang, Xavier Querol, Carlos Leiva, Oriol Font, Yunlong He* Moved to 8:00am | #102 100-m Hurdles: Overcoming Challenges on a Fast-Track Ash Pond Conversion and Closure Project for TVA to Meet Regulatory Deadlines *Stephen L. Whiteside, James D. Mullins, Megan Hayward, David Mason* | #148 Advances in Chemical Beneficiation of Fly Ashes Containing Natural Carbon or Powdered Activated Carbon *Carl Howard, Shrief Kabis, Stephen Farrington* |
| **10:00 a.m.** | | | | |
| | | COFFEE BREAK | THOROUGHBRED PRE-FUNCTION | |

AGENDA & SESSIONS

Thursday, April 25, 2013

| BALLROOM 1 | BALLROOM 2 | BALLROOM 3 | BALLROOM 4 | BALLROOM 5 |
|---|---|---|---|---|
| Ponds VI | Cement & Concrete VI | Utilization III | Pond Liners | Beneficiation II |
| **10:30 a.m.** | | | | |
| #19 Dry Fly Ash Placement - Overcoming Unique Challenges and Streamlining Field Operations<br>*Ali Ebrahimi, Sarah Fick, Ceneyt Gokmen, Mehmet Iscimen* | #123 Statistical Software to improve the accuracy of geopolymer concrete mix design<br>*Carlos Montes, Sergio Gomez, Niraj Khadka, Erez N. Allouche* | #70 Benchmarking Study for CCP Beneficial Reuse: A View of the Market<br>*Mark Rokoff, Sheryl Smith, Tara V. Masterson, Michael E. Sutton* | #1 The Rising Demand for Lined Landfills: Impacts to Both the Power and Solid Waste Industries from Increased Coal Combustion Product Landfilling<br>*Shane R. Womack* | #157 Staged Turbulent Air Reactor (STAR) Beneficiation Process – Commercial Update<br>*William Fedorka, Jimmy Knowles, John Castleman* |
| **11:00 a.m.** | | | | |
| #74 CCP Landfill and Dry Stack Operational Challenges and the Engineering Solutions that Work<br>*Shane Harris and Michael Stepic, Ron Hager, Nick Golden* | ✓ #116 A Summary of Proposed Changes to AASHTO M 295 Resulting from NCHRP Project 18-13 - Specifications and Protocols for Acceptance Tests of Fly Ash Used in Highway Concrete<br>*Lawrence Sutter, R. Douglas Hooton, Scott Schlorholtz* | #160 Regulatory implications low pH coal combustion products Australian perspective<br>*Jane T Aiken, Craig Heidrich* | #159 Applying Geosynthetics (with Capabilities of Monitoring Stability and Leakage) to Earthen Structures<br>*Wilson B. Harvie, Rex A. Peppler* | #84 Can density based coal processing techniques be applied to fly ash benefication?<br>*Robert Bissett* |
| **11:30 a.m.** | | | | |
| #121 Evaluation of Drainage Layer Alternatives for Proposed Landfill Liner at the EW Brown Generating Station<br>*M. Brian Cole, Nicholas G. Schmitt,* | #12 Application of Fly Ash in ASHphalt Concrete: from Challenges to Opportunities<br>*Konstantin Sobolev, Ismael Flores, Justin David Bohler, Ahmed Faheem, Art Covi* | ~~#[illegible]5 Coal Ash as a Potential Scrubber for Quarry Sludge and Trace Elements~~<br>~~*Roy Ni[illegible]eberman, Yaa[illegible] A[illegible]er and H[illegible] Cohen*~~<br>moved to:<br>Utilization I<br>at 2:30pm | | #117 Separation of fines unburned carbon in slags from traveling grate boilers using flotation<br>*Iván Navarro-Espinosa, Juan Barraza* |
| **Noon** | | | | |
| CONFERENCE ENDS | | | | |

# Properties of CLSM Separation Dike using Coal Ash

**L. W. Quo[1], C. L. Hwang[2], Y. Y. Yen[2], M. B. Yang[2], C. I. Lai[3] and S. H. Cheng[3]**

[1]Taiwan power Research Institute, Chemistry and Environmental Research Labs, No. 84, Da-An Rd., Shu-Lin Dist., New Taipei, Taiwan 23847; [2]National Taiwan University of Science and Technology, Department of Construction Engineering, No. 43, sec. 4, Keelung Rd., Da-An Dist., Taipei, Taiwan 10607; [3]National Taiwan University of Science and Technology, Office of Research and Development, No. 43, sec. 4, Keelung Rd., Da-An Dist., Taipei, Taiwan 10607.

KEYWORDS: separation dike, coal ash, CLSM, mix proportion

ABSTRACT

Taiwan Power Company (TPC) plans to substitute sea sand, the traditional construction material of ash pond dike, by Coal Ash - Controlled Low Strength Material (CA-CLAM) which consists of large amount of coal ash from thermal power plants and a little amount of cement. The purpose of such a plan is to develop a new utilization approach of coal ash to improve the quality and to reduce the cost of the dike construction. As a result, a few basic engineering properties of CA-CLAM as used in dike construction at the coastal site with shallow seawater are studied in the paper.

According to the design requirement of 40-60 kgf/cm$^2$ for 28-day compressive strength, two mix proportions of CA-CLAM are finally adopted based on a series of mix trial tests. The one contains higher ratio of fly ash to bottom ash and another higher ratio of bottom ash to fly ash. Afterward, several test items are conducted including slump flow, flow cylinder, setting time, compressive strength, splitting tensile strength, sulfate attack, one dimensional consolidation, influence of dry-wet cycle in seawater together with wave action, erosion of wind with coal ash particles, and placement into water.

For the given two mix proportions, the 28-day compressive strengths of CA-CLAM mixtures are 36.8 $kgf/cm^2$ and 37.1 $kgf/cm^2$, respectively, as flow cylinder is 150±5mm. Around 40-day age, their compressive strengths can reach 40 $kgf/cm^2$ or more. In additional, their 28-day splitting strengths are 4.32 $kgf/cm^2$ and 4.14 $kgf/cm^2$, respectively. The two mixtures show good resistance to sulfate attack, however, the mixture with higher ratio of fly ash to bottom ash has less material segregation than ones with higher ratio of bottom ash to fly ash. After a testing period of 90 days, both dry-wet cycle in seawater together with wave action, and erosion of wind with coal ash particles do not cause the detrimental effect on either the appearance or the strength of CA-CLAM mixtures.

## INTRODUCTION

Coal ash is the by-product of thermal power generation and, in general, around 80% of coal ash is fly ash and 20% bottom ash in Taiwan. The Environmental Protection Administration in Taiwan has officially announced coal ash as a kind of general industrial wastes. Since 1992 the annual production amount of coal ash from the thermal power plants of TPC has been more than 1.5-million tons and the utilization options of TPC coal ash have included concrete, CLSM, highway base, highway pavement, site backfilling, etc. (Hun *et al*., 2009). Due to lower and lower utilization rate together with more and more dumped ash in recent years, TPC intends to construct an ash pond at the Chung-Hua Coastal Industrial Park for the ash treatment of Taichung thermal power plant and to build a separation dike of 1,570 m in length for the construction need of ash pond. The site of the dike locates at a near-ocean area generally with 2-m deep seawater.

Recently, Taiwan Power Research Institute (TPRI) of TPC has actively implemented the study in light of CLSM (Quo *et al.*, 2009; Quo *et al.*, 2008) and obtained viable application in the backfilling of pipe trench (Quo *et al*., 2011). To cope with the above-mentioned dike construction, TPRI undertakes a comprehensive follow-up program to study the suitable mix proportion, material placement, engineering properties of CA-CLAM mixtures both in the lab with simulated site condition and at outdoor similar sites. These results are provided for the dike construction plan at a site with shallow seawater. This paper aims to make a brief introduction in terms of lab test results as well as site on-going construction.

## EXPERIMENTAL DESIGN

### Experimental parameters

To develop the CA-CLAM meeting economy as well as construction requirements, as above-mentioned, TPRI has executed a series tests on mix proportions and on the relevant basic engineering properties under the given 28-day compressive strength of 40-60 kgf/cm$^2$. The test results indicate that CA-CLAM mixtures with more bottom ash have lower strength but the lower strength can be offset by using more cement. Taking into account of design requirements for the part of dike beyond seawater possible different from that below seawater, two mix proportions which meet the strength requirement are then selected in the paper to further evaluate more of their engineering characteristics. As shown in Table 1, No 1 CA-CLAM contains higher ratio of fly ash to bottom ash and No 2 CA-CLAM higher ratio of bottom ash to fly ash.

### Experimental materials

The physical as well as chemical properties of experimental materials used in the paper are briefly introduced as follows:

1. Cement: Type 1 Portland cement produced by Taiwan Cement Corporation meets ASTM C150 standard.
2. Fly ash: The chemical properties of class F fly ash from Taichung thermal power plant are shown in Table 2.
3. Bottom ash: A few chemical properties and physical properties of bottom ash from Taichung thermal power plant are listed in Table 2 and Table 3, respectively.
4. Mixing water:
   (1) Fresh water: Tap water meets CNS3090 standard.
   (2) Seawater: The water from Linkou thermal power plant has 0.8% of salt content.

Table 1 Two CLSM mix proportions

| Type | Mix parameters | | Mix amount (kg/m$^3$) | | Unit weight (kg/m$^3$) |
|---|---|---|---|---|---|
| No 1 CA-CLAM | Water/Cement ratio | 3.945 | Cement | 103 | 1,668 |
| | Cement/Coal ash ratio | 0.085 | Fly ash | 730 | |
| | Bottom ash/Coal ash ratio | 0.4 | Bottom ash | 487 | |
| | - | - | Water | 409 | |

| | | | | | |
|---|---|---|---|---|---|
| No 2 CA-CLAM | Water/Cement ratio | 3.323 | Cement | 124 | 1,647 |
| | Cement/Coal ash ratio | 0.105 | Fly ash | 450 | |
| | Bottom ash/Coal ash ratio | 0.62 | Bottom ash | 734 | |
| | - | - | Water | 413 | |

Table 2 Chemical properties of fly ash and bottom ash

| Specimen No. | | Bottom ash | Fly ash |
|---|---|---|---|
| Water content (%) | | 0.22 | 0.45 |
| Dry basis | LOI (%) | 6.2 | 7.6 |
| | $SiO_2$ (%) | 59.3 | 52.2 |
| | $Al_2O_3$ (%) | 19.4 | 19.5 |
| | $Fe_2O_3$ (%)） | 9.5 | 7.4 |
| | CaO (%) | 2.8 | 5.3 |
| | MgO (%) | 0.76 | 1.83 |
| | $Na_2O$ (%) | 0.19 | 0.75 |
| | $K_2O$ (%) | 0.76 | 1.18 |
| | $SO_2$ (%) | 0.55 | 1.03 |
| | PH Value | 9.6 | 11.7 |

Table 3 Physical properties of bottom ash

| Sieve No. | 1/2" | 3/8" | #4 | #8 | #16 | #30 | #50 | #100 | base |
|---|---|---|---|---|---|---|---|---|---|
| Residue weight percentage | 2 | 1 | 8 | 25 | 20 | 9 | 8 | 10 | 18 |
| Specific gravity=2.13; Water absorption (%)=3.4; Fineness（FM）=3.22 | | | | | | | | | |

Experimental items and apparatus

A few fresh mixture properties, hardened mixture properties and durability such as workability, setting time, strength, resistance to sulfate attack are investigated in the paper. The relevant test standards and test apparatuses are presented as follows:

1. Workability: Slump flow and flow cylinder are evaluated in accordance with ASTM-C143-98 and ASTM-D6103-97, respectively.
2. Setting time: Both initial and final setting time are measured based on ASTM-C403.
3. Strength: According to ASTM-D4832-95 and ASTM-C469-96, compressive strength and splitting tensile strength are evaluated, respectively, at the age of 7, 14, 28, 56 and 90 days.

4. Sulfate attack: After 28-day curing, the resistance of CA-CLAM specimens to sulfate attack is studied by ASTM-C1012.
5. Influence of dry-wet cycle in seawater together with wave action: A self-designed equipment shown in Figure 1 is made to simulate the change of seawater level and the action of wave by wind at the ash pond. Each cycle takes 8 minutes. After mold removal, specimens are placed in the tanks. The strength at the age of 1, 14, 28, 56 and 90 days are checked.

Figure 1 Dry-wet cycle test

6. Erosion of wind with coal ash particles: A self-designed equipment shown in Figure 2 is made to simulate the action of sand on specimen surface caused by strong wind with minimal speed of 20m/s. After mold removal, specimens are placed in the device. The change of appearance and weight of specimens are observed and measured at the age of 1, 14, 28, 56 and 90 days.


Figure 2 Erosion test of wind with coal ash particles

7. CLSM placing into water: A self-designed equipment with the size 150*150*20 cm shown in Figure 3 is made to simulate the placement of CA-CLAM into seawater in ash pond. Both the motion of CA-CLAM in the transparent tank and the segregation of CA-CLAM are observed. After a period of 28 days, then cores are taken at different parts of the solid block to investigate their compressive strength.

| No 1 CA-CLAM | No 2 CA-CLAM |
|---|---|
| | |
| | |

Figure 3 Acrylic apparatus for placement test into water

## TEST RESULTS AND DISCUSSION

### Workability

The workability of No 1 CA-CLAM and No 2 CA-CLAM is shown in Table 4. The purpose of slump flow test is to understand the flow ability of mixture. According to the results of slump flow test, No 1 mixture which has higher fly ash content exhibits inferior performance to No. 2. Because the particle size of fly ash is finer than that of bottom ash, fly ash having more surface area can absorb more mixing water, leading to poor flowability. The purpose of slump flow test is to realize the placeability of mixture. According to the results of flow cylinder test, both mixtures have good placeability to meet design requirement of 150mm. Taking into account of cost, surfactant is not adopted in the paper.

Table 4 The properties of fresh and hardened CA-CLAM mistures

| Item | workability (mm) | | compressive strength (kgf/m$^2$) | | | | | splitting tensile strength (kgf/m$^2$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | slump flow | flow cylinder | 7 d | 14 d | 28 d | 56 d | 90 d | 7 d | 14 d | 28 d | 56 d | 90 d |
| No.1 | 300 | 155 | 18.9 | 30.5 | 36.8 | 44.0 | 49.8 | 2.9 | 3.8 | 4.3 | 5.1 | 5.3 |
| No.2 | 400 | 165 | 20.1 | 28.6 | 37.1 | 37.4 | 47.0 | 3.1 | 3.8 | 4.1 | 4.6 | 4.8 |

### Setting time

The setting times of No 1 CA-CLAM and No 2 CA-CLAM are illustrated in Figure 4. The cement content of No 2 mixture is 124kg/m$^3$, higher than103kg/m$^3$ of No 1. Also, the ratio of water to cement of No 2 mixture is lower than that of No 1. As a result, No 2 mixture exhibits faster setting behavior. The initial and final setting times of No 2 mixture are 5hr (400psi) and 16hr (4000psi), respectively faster than 8hr and 18hr of No 1.

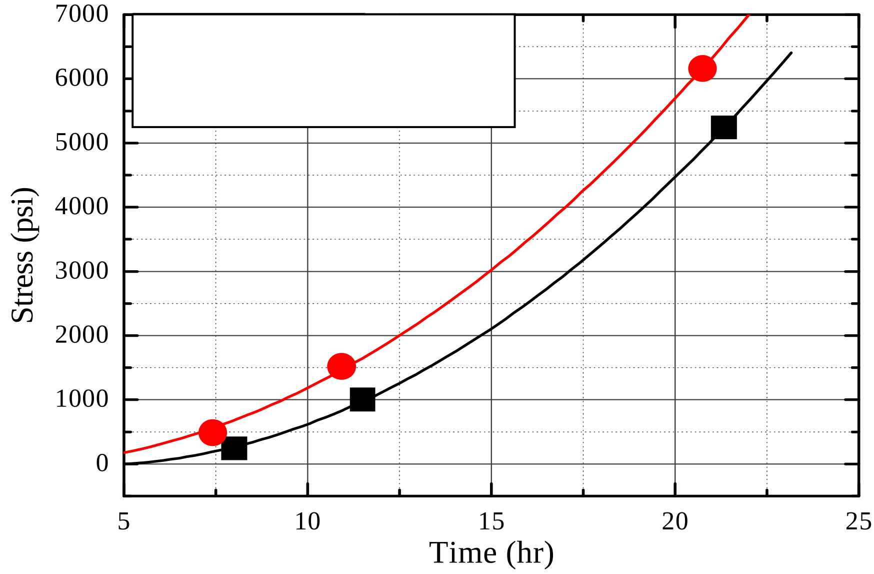



Figure 4 Setting time of No 1 CA-CLAM and No 2 CA-CLAM

Strength

The compressive strength and splitting tensile strength of the CA-CLAM mixtures are listed in Table 4 and plotted in Figure 5 and Figure 6. As compared to No 2 mixture, based on Figure 5, No 1 has lower early compressive strength but higher at later age. It can be explained that No 1 contains less amount of cement, resulting in lower early strength, and contains less bottom ash which is porous as well as brittle material, leading to higher strength at later age. As to splitting tensile strength, based on Figure 6, similar results to compressive strength can be observed.

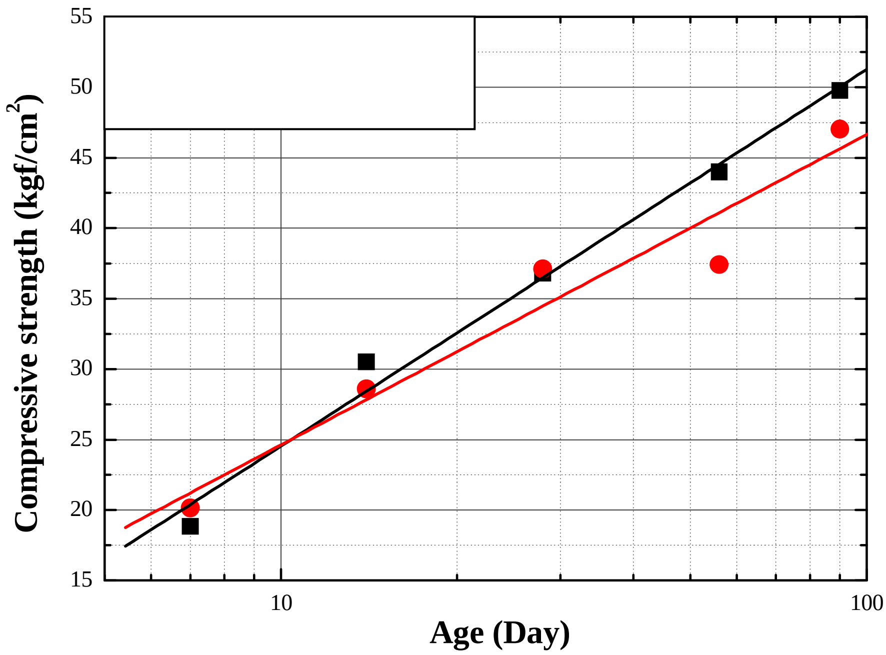


Figure 5 The development of compressive strength

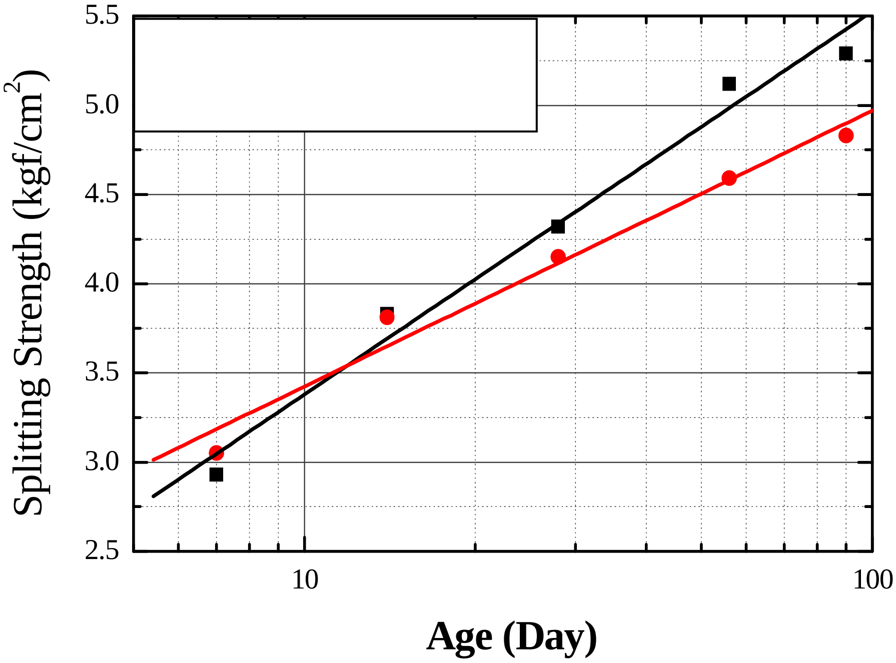



Figure 6 The development of splitting tensile strength

Sulfate attack

The weight variation of the CA-CLAM mixtures during sulfate attack test is presented in Figure 7. As seen, both mixtures have similar weight variation and specimen weight is increased with cycle no. Although the weight is increased 20% at the end of cycle 15, specimens still have as good as original appearance. It can be explained that the specific weight of CA-CLAM mixture is much lower than that of normal concrete, implying more pores in CA-CLAM mixture. During test, sulfate salt crystallization can occupy these pores, leading to no collapse by swelling.

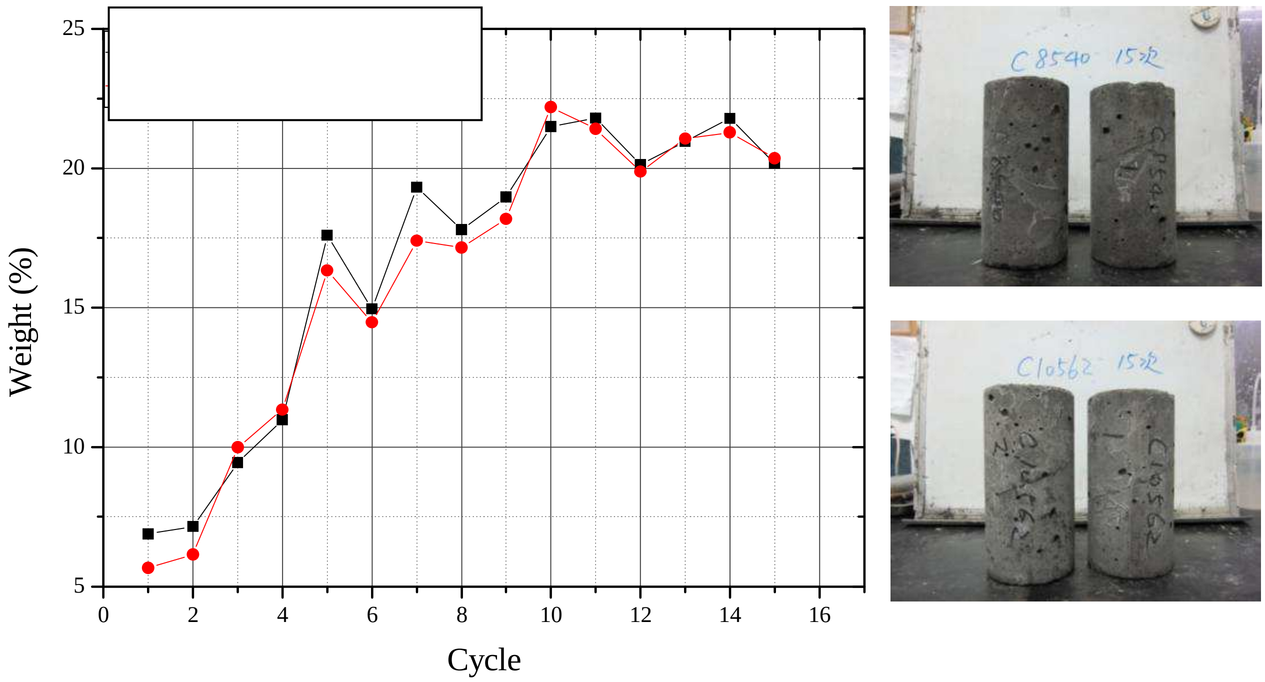


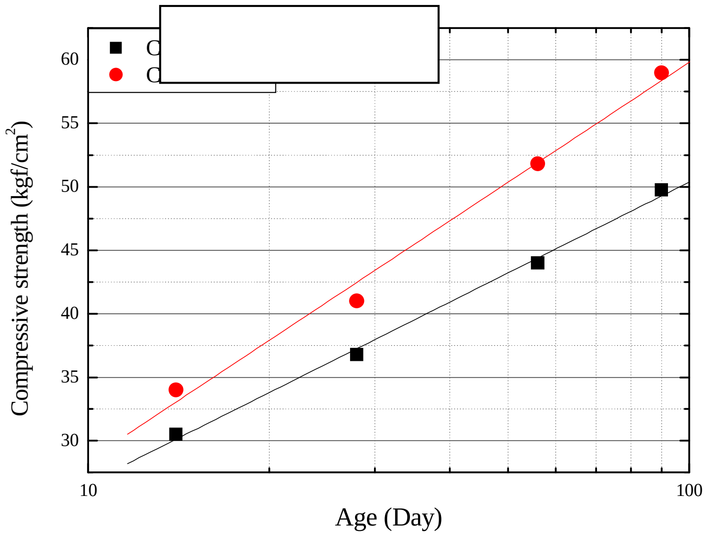

Figure 7 Weight variation during sulfate attack test

Influence of dry-wet cycle in seawater together with wave action

The compressive strength development of the CA-CLAM mixtures during the influence test of dry-wet cycle in seawater together with wave action is given in Figure 8. The test results show that such compressive strength is higher, averagely 16%, than that of specimen under normal curing condition. The reason is chloride in seawater which is used as soaking water during the test can enhance the strength development.

Erosion of wind with coal ash particles

The weight variation of the CA-CLAM mixtures during erosion test of wind with coal ash particles is shown in Figure 9. As observed, weight loss is same for both mixtures and weight loss can reach 22% at 14 days. In the paper to simulate the site condition and to prevent the damage to strength from drying, specimens are not dried in the beginning of test. It is clear that early significant weight loss results from the loss of moisture inside specimens and from the loss of surface due to significant bleeding. After 14 days, the extra weight loss is kept around 0.5%, indicating no severe erosion of wind with coal ash particles to CA-CLAM mixtures.



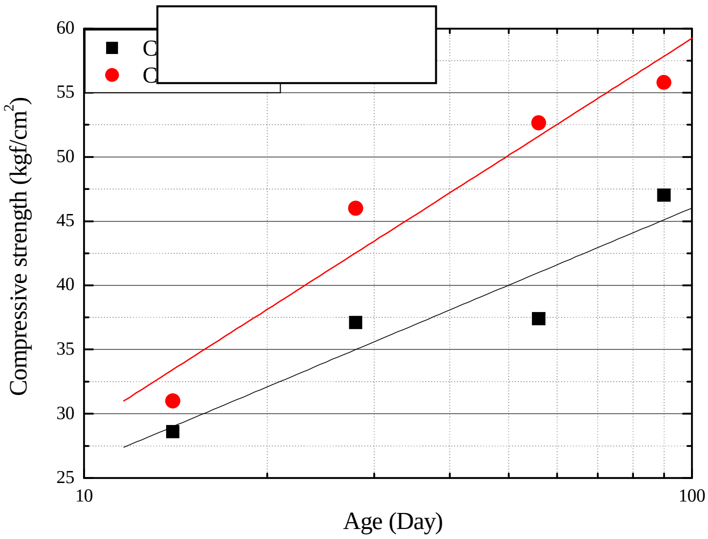




Figure 8 Compressive strength development during the influence test of dry-wet cycle in seawater together with wave action

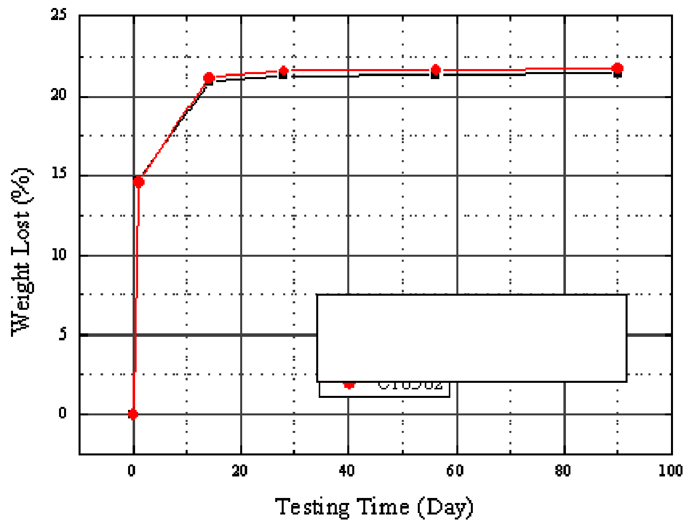


Figure 9 Weight variation during erosion test of wind with coal ash particles

Placement into water

After 28 days of placement, as shown in Figure 10, acrylic tank is removed and a few cores are taken to be investigated their compressive strength. Since CA-CLAM is placed at one fixed corner, it results in significant material segregation due to different particle weight of fly ash and bottom ash. Especially for No 2 CA-CLAM with more bottom ash, even some cores cannot be taken at the part of the block with little of fly ash.

Figure 10 CA-CLAM block

## CONCLUSIONS AND ON-GOING CONSTRUCTION

### Conclusions

Based on the above experimental materials and methods, the conclusions are obtained as follows:

1. The 28-day compressive strength of CA-CLAM made by a little amount of cement as well as large amount of coal and mixed by fresh water can be higher than 35 $kgf/cm^2$. After 40 days, the compressive strength can be higher than 40$kgf/cm^2$ and splitting tensile strength higher than 4 $kgf/cm^2$.
2. CA-CLAM mixtures show great resistance to sulfate attack without any collapse after 15 cycles.
3. Out of consideration of the initial moisture loss inside specimen and surface weight loss resulting from bleeding, the weight loss remains 0.5% in the period of 14 days to 90 days, indicating no severe erosion of wind with coal ash particles to CA-CLAM mixtures.
4. In case of placement into water, CA-CLAM with more fly ash exhibits better performance to reduce material segregation in water.
5. CA-CLAM made by a little amount of cement as well as large amount of coal ash and mixed by fresh water can be used in dike construction to save the consumption of natural materials such as gravel and sand which are traditional materials in dike construction.

### On-going construction

Based on the test results of a comprehensive CA-CLAM program conducted by TPRI, CA-CLAM made by a little amount of cement as well as large amount of coal ash and mixed by fresh water has been used in a separation dike construction at the Chung-Hua Coastal Industrial Park since 2012. The dike is 1570 m in length, 6m in height, and 10m as well as 20m in breadth for top section and bottom section, respectively. Lots of blocks are also fabricated by CA-CLAM used as mold during placement, as Figure11 shows.

Figure 11 Photos of construction site

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