RICE HUSK ASH

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Introduction

Rice husk ash (RHA) is a by-product from the burning of rice husk. Rice husk is extremely prevalent in East and South-East Asia because of the rice production in this area. The rich land and tropical climate make for perfect conditions to cultivate rice and is taken advantage by these Asian countries. The husk of the rice is removed in the farming process before it is sold and consumed. It has been found beneficial to burn this rice husk in kilns to make various things. The rice husk ash is then used as a substitute or admixture in cement. Therefore the entire rice product is used in an efficient and environmentally friendly approach. In this article we will be exploring the common processes of burning rice husk and the advantages of using the burnt ash in cement to facilitate structural development primarily in the East and South-East Asian regions. We will be investigating prior research from various sources, as well as prepare specimens of our own to perform a range of strength tests.

Rice Production

Rice is a heavy staple in the world market as far as food is concerned. It is the second largest amount of any grain produced in the world. The first largest is corn, but is produced for alternative reasons as opposed to rice which is produced primarily for consumption. Therefore, rice can be considered the leading crop produced for human consumption in the world. The leading region of the world which produces rice is Asia, especially South-East and East Asia. Rice can easily be grown in tropical regions on any type of terrain. It is well-suited to countries and regions with low labor costs and high rainfall, as it is very labor-intensive to cultivate and requires plenty of water for cultivation (Wikipedia, Rice). The plains in South-East Asia provide the perfect accommodations.

COUNTRY	RICE PADDY	RICE HUSK
Bangladesh	27	5.4
Brazil	9	1.8
Burma	13	2.6
China	180	36.0
India	110	22.0
Indonesia	45	9.0
Japan	13	2.6
Korea	9	1.8
Philippines	9	1.8
Taiwan	14	2.8
Thailand	20	4.0
US	7	1.4
Vietnam	18	3.6
Others	26	5.2
Total	500	100

Table 1: World Production Rate for Rice Paddy and Rice Husk (Million Metric Tons), courtesy of Hwang & Chandra

The following table from Hwang and Chandra's article "The Use of Rice Husk Ash in Concrete" shows the amount of rice cultivated and the significant amount of rice husk accumulated across the world. About 20% of a dried rice paddy is made up of the rice husks. The current world production of rice paddy is around 500 million tons and hence 100 million tons of rice husks are produced, Hwang (185). China and India are the top producers of rice paddy, but most all other countries referenced in this table are in South-East and East Asia.

The next table shows the consumption of rice by the world's population. It was compiled by the United States Department of Agriculture in 2003-2004. It shows the demand of rice production. The world's necessity for rice consumption fuels the need to keep producing rice at such a large scale.

Table 2: World Rice Consumption, courtesy Wikipedia

Consumption of rice by country—2003/2004 (million metric ton)	
China	135
India	125
Egypt	39
Indonesia	37
Bangladesh	26
Brazil	24
Vietnam	18
Thailand	10
Myanmar	10
Philippines	9.7
Japan	8.7
Mexico	7.3
South Korea	5.0
United States	3.9
Malaysia	2.7
Source: United States Department of Agriculture	

Disposal

Disposal of rice husk ash is an important issue in these countries which cultivate large quantities of rice. Rice husk has a very low nutritional value and as they take very long to decompose are not appropriate for composting or manure. Therefore the 100 million tons of rice husk produced globally begins to impact the environment if not disposed of properly.

One effective method used today to rid the planet of rice husk is to use it to fuel kilns. These kilns help to produce bricks and other clay products that are used in daily life. Burning the rice husk is an efficient way to dispose of the rice cultivation by-product while producing other useful goods. After the kilns have been fired using rice husk, the ash still remains. As the production rate of rice husk ash is about 20% of the dried rice husk, the amount of RHA generated yearly is about 20 million tons worldwide (Hwang, 185).

Burning

The rice husk ash is a highly siliceous material that can be used as an admixture in concrete if the rice husk is burnt in a specific manner. The characteristics of the ash are dependent on the components, temperature and time of burning (Hwang, 185). During the burning process, the carbon content is burnt off and all that remains is the silica content. The silica must be kept at a non-crystalline state in order to produce an ash with high pozzalonic activity. The high pozzalonic behavior is a necessity if you intend to use it as a substitute or admixture in concrete. It has been tested and found that the ideal temperature for producing such results is between 600 °C and 700 °C. The following graph shows the curve for obtaining reactive cellular rice husk ash with certain burning temperatures and time fired. If the rice husk is burnt at too high a temperature or for too long the silica content will become a crystalline structure. If the rice husk is burnt at too low a temperature or for too short a period of time the rice husk ash will contain too large an amount of un-burnt carbon.

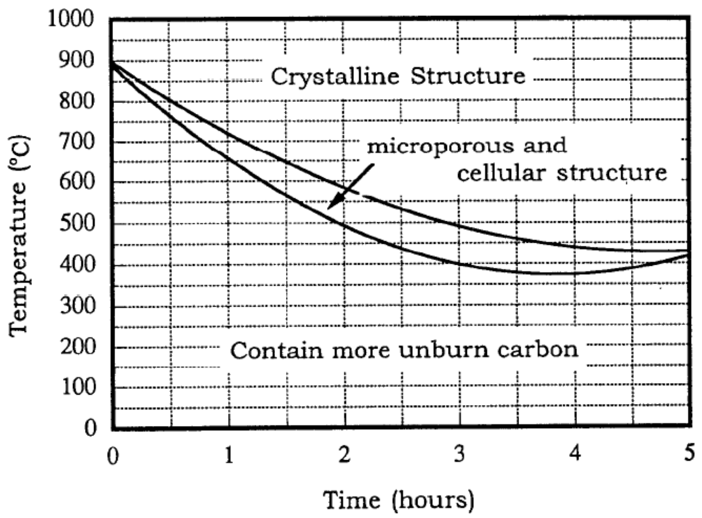

Figure 1: Optimum Incineration Condition Curve, courtesy of Hwang & Chandra

Engineering Performance

The performance of rice husk ash cement is important to investigate to be sure that it can be used in place of a normal batch of cement. All projects must be considered on a separate basis beforehand, but there are some common characteristics of rice husk ash cement that may be beneficial to certain locations, situations, or projects.

Structural Integrity

The use of pozzolanas as alternatives for the commonly used Portland cement have been used in the past few decades either for cost reduction, performance & durability enhancement, or environmental reasons (Nair, 861). Malhorta and Mehta state that pozzolanas are defined as siliceous or siliceous and aluminous materials which in themselves possess little or no cementing property, but will in a finely dispersed form in the presence of water chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. When water is added to a mixture with pozzolanic material it acts as cement, in some instances providing a stronger bond than cement alone.

The cost reduction is especially important for the areas of Africa, South America, and South-East Asia where the poverty level and wealth of the areas are low. This can allow for cheap building material without the loss of performance, which is crucial for any developing nation to continue to grow.

Corrosion Performance

The addition of rice husk ash to a concrete mixture has been proven to increase corrosion resistance. It has a higher early strength than concrete without rice husk ash. The rice husk ash forms a calcium silicate hydrate gel around the cement particles which is highly dense and less porous (Song, 1779). This will prevent the cracking of the concrete and protect it from corrosion by not allowing any leeching agents to break down the material. The study done by Song and Saraswathy found that the incorporation of RHA up to 30% replacement level reduces the chloride penetration, decreases permeability, and improves strength and corrosion resistance properties.

Effect of Humidity

The effects of humidity can result in a drastic change in the final behavior of the concrete. The comparative tests performed and documented by Jauberthie between specimens stored in dry and wet conditions have shown that at high humidity conservation the mortar gains strength by virtue of the well developed pozzolanic reaction (Jauberthie, 243). This added strength is only under compression forces, specimens are more brittle under a smaller flexural load than specimens stored at 50% relative humidity. The following table explains the figures that were found from the experiment. As for climates of South-East and East Asia, the high humidity levels indicate that there will be a higher compressive strength, but more brittleness in the concrete produced. That is unless it is stored in a facility with regulated humidity levels. For the use of concrete with rice husk ash mixtures, it would be recommended to use it for columns or structural walls which tend to support compressive forces.

Table 3: Courtesy of Jauberthie

Physical properties of mortar at an age of 1 year

Storage	Density (kg/m³)	Flexural strength (MPa)	Compressive strength (MPa)	Young's Modulus (GPa)	Flexural Modulus (GPa)
50% HR	1110	7.2	20.6	1.0	0.8
95% HR	1145	6.5	23.8	2.6	1.4

Experiment

Casting

To complete an analysis of our own, we produced four batches of concrete with varying amounts of rice husk ash substituted for Ordinary Portland Cement. There was a control group with no rice husk ash, one with 15% substitution, 30% substitution, and 40% substitution. We mixed the samples and did the testing at the Center for Vocational Building Technology (CVBT) in Nong Khai, Thailand. This is important because it fits the conditions of more rural and developing countries, where cement is expensive and rice cultivation is widespread. The technique and procedure used was replicated of that used by the villagers at the same building factory. This gives us more accurate results compared to the products used in these areas.

We used the CVBT's standard mix proportions they use for paving slabs without dye. For each batch 6kg of standard OPC, 16.1 kg of sand, 17.42 kg of 3/8" aggregate, 53 mL of super plasticizer, and 2.7 L of water was mixed together. The super plasticizer added was equal to 1% of the weight of cement in the mix. To find the amount of water necessary, first the moisture content of the sand was calculated. For the third and fourth batch, the concrete was not workable so more water was added to the mix. 500 mL of extra water was added in each batch in order to achieve a constant slump throughout the experiment. The following figure from Ganesan's article shows the percentage of cement replacement level versus standard consistency. It indicates that the water required for standard consistency linearly increases with an increase in RHA content. As ashes are hygroscopic in nature and the specific surface area of RHA is much higher than cement, it needs more water (Ganesan, 1680). For this reason, extra water was added to the 30% RHA and 40% RHA batches.

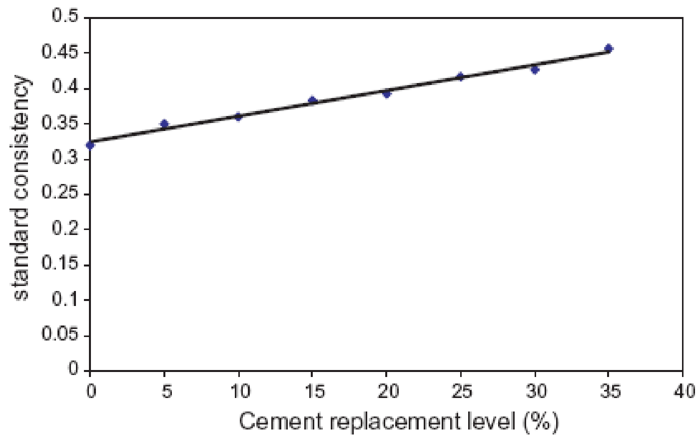

Figure 2: Water Needed vs. Cement Replacement, courtesy of Ganesan

Infused with the water was a super plasticizer, known as F2 at this specific site. This ingredient is used to reduce the amount of water needed to produce a sufficiently low viscosity, by producing charged ions that repel each other in the mix. The repulsion of the charged ions helps the particles in the concrete mix slide past one another respectively on a microscopic level. The molds were set on a vibrating table once the concrete was placed in them. The vibrating causes the concrete to better fill the molds and allows the air to escape producing a form without voids. The lack of air voids increases the strength of the product.

For each of the four batches two cubes and three slabs were produced. The cubes were tested for failure by compression tests. They were constructed in standard size for Thailand's test procedures (15cm x15cm x 15cm). The cubes were tested at seven days and fourteen days. Only two cubes were made for each batch because there was a limited supply of molds. The paving slab testing is more pertinent towards the CVBT because slabs are their most successful product. Because of this, it was agreed that bending tests on the paving slabs would be the most pertinent assessment. Three slabs were constructed for each batch in order to get a more accurate analysis than the compression cubes. The slabs were tested after seven, fourteen, and twenty eight days of curing.

The curing process used was one little nugget of appropriate technology known solar-thermal high-humidity curing. The specimens were placed outside under a clear plastic sheet. The high heat in the region was of concern because the drying process is sped up tremendously. In order to achieve normal curing process water was added under the plastic daily, which caused moisture to accumulate inside the "curing chamber". Overall the process was faster, but low input, and produced acceptable results.

Testing

Compression Test

The compression tests for the concrete cubes were done at the Nong Khai Technical College**.** Thai standard test procedures were used. All specimens were weighed at the time of each respective test. The testing machine applies a constant uniform pressure to the cubes until failure occurs. Failure was observed when the cube no longer could resist the force applied to it without breaking apart.

Bending Test

The bending tests for the concrete paving slabs were performed at the CVBT at seven, fourteen, and twenty eight days after the casting. A triple point bending test was done. This involves two metal rods with a diameter of 31mm placed symmetrically under the slab separated by 15.3 cm. One rod the same size was placed on top in the middle of the slab to apply a force. A hydraulic jack was placed on top to provide the force in order to break the slabs. A constant force was applied slowly until failure when the slabs were completely severed.

Results

Table 4: Compression Results

Batch Number	% Rice Husk Ash	Date Produced	Date Tested	Age at Test	Weight (g)	Force (kN)
1	0	29-Apr-09	6-May-09	7	7632	520
1	0	29-Apr-09	13-May-09	14	7576	713
2	15	29-Apr-09	6-May-09	7	7584	580
2	15	29-Apr-09	13-May-09	14	7520	703
3	30	30-Apr-09	7-May-09	7	7148	508
3	30	30-Apr-09	14-May-09	14	7332	664
4	40	30-Apr-09	7-May-09	7	7098	420
4	40	30-Apr-09	14-May-09	14	7150	408

Table 5: Bending Tests Results

Batch Number	% Rice Husk Ash	Date Produced	Date Tested	Age at Test	Force		Weight (g)
					(Bars)	(kg)	
1	0	29-Apr-09	6-May-09	7	180	649	6609
1	0	29-Apr-09	13-May-09	14	220	791	6603
1	0	29-Apr-09	27-May-09	28	340	1224	6636
2	15	29-Apr-09	6-May-09	7	190	685	6534
2	15	29-Apr-09	13-May-09	14	250	898	6583
2	15	29-Apr-09	27-May-09	28	320	1152	6496
3	30	30-Apr-09	7-May-09	7	180	649	6425

3	30	30-Apr-09	14-May-09	14	210	756	6260
3	30	30-Apr-09	28-May-09	28	280	1008	6351
4	40	30-Apr-09	7-May-09	7	150	543	6300
4	40	30-Apr-09	14-May-09	14	180	649	6346
4	40	30-Apr-09	28-May-09	28	210	756	6274

Analysis

For the bending tests there is a direct correlation between the weights of the mix at the time of testing to the percentage of rice husk ash substituted for Ordinary Portland Cement. The more rice husk ash that is used in the mix, the lighter the finished concrete becomes. There is one outlier for the 30% RHA substitution that seems lighter than it should be. This could be because the slab may not have been vibrated enough to fill the voids. These air voids can decrease the weight of the concrete. Also there is always human error that will account for outliers because it is not possible to make multiple batches the same each time. The mix proportions were kept at a constant except for the percentage of rice husk ash, but the time to prepare and cast varied slightly. More batches and more specimens to test would have been ideal and would have provided a more accurate indication of the correlation. The following graph shows that the correlation still is strong even with the small sample size.

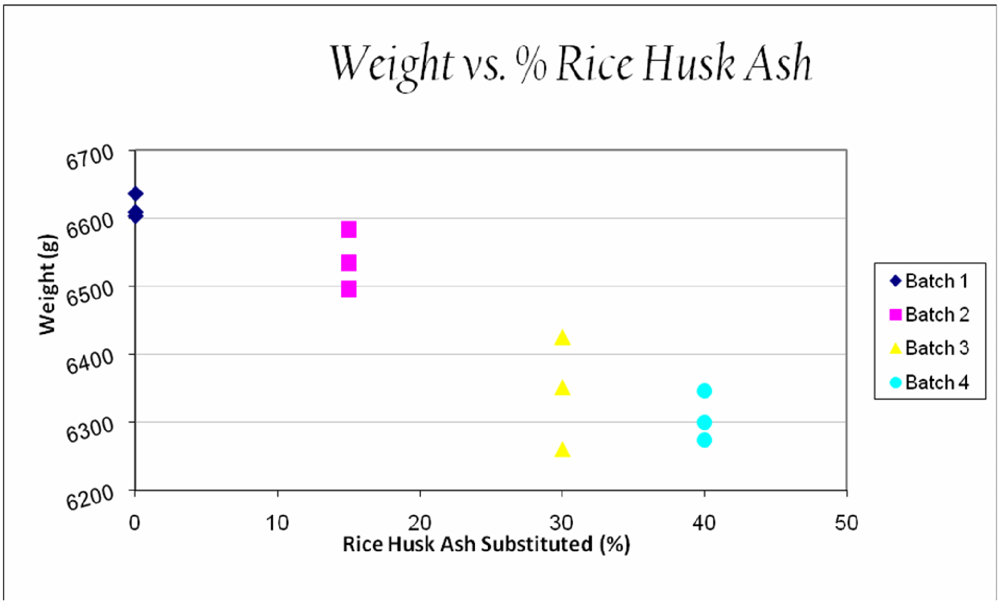

Figure 3: Bending test weight to %RHA correlation

The graph below shows the strength curve of each batch for the paving slabs that were tested using a triple point bending method. The dark blue line is the control batch with no rice husk ash. There is a trend that the final strength after twenty-eight days is decreased with the increase of rice husk ash substitution. The strength is not decreased significantly until the rice husk ash substitution is greater than 30%. At 30% rice husk ash substitution the strength of our batch produced was only decreased by only around 16% of the control batch. Depending on the project and the area's code enforcement, this should be a sufficient strength.

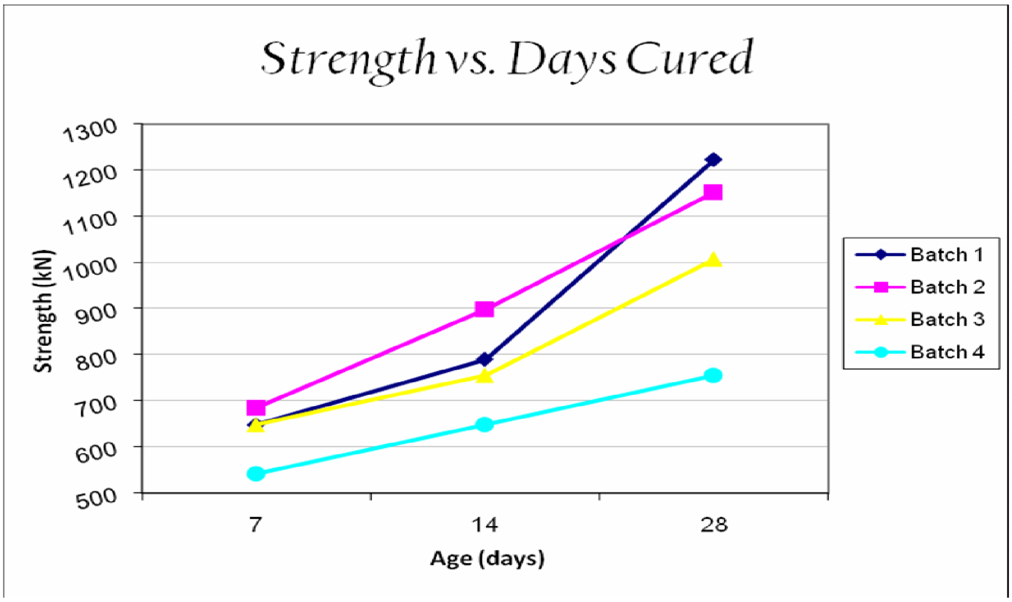

Figure 4: Bending test strength curves

For the compression test specimens the weight to rice husk ash percentage correlation follows the same trend as the paving slab specimens. This further proves that the substitution of rice husk ash will decrease the weight of the final project. Figure 3 shows the relationship for our compression cube specimens.

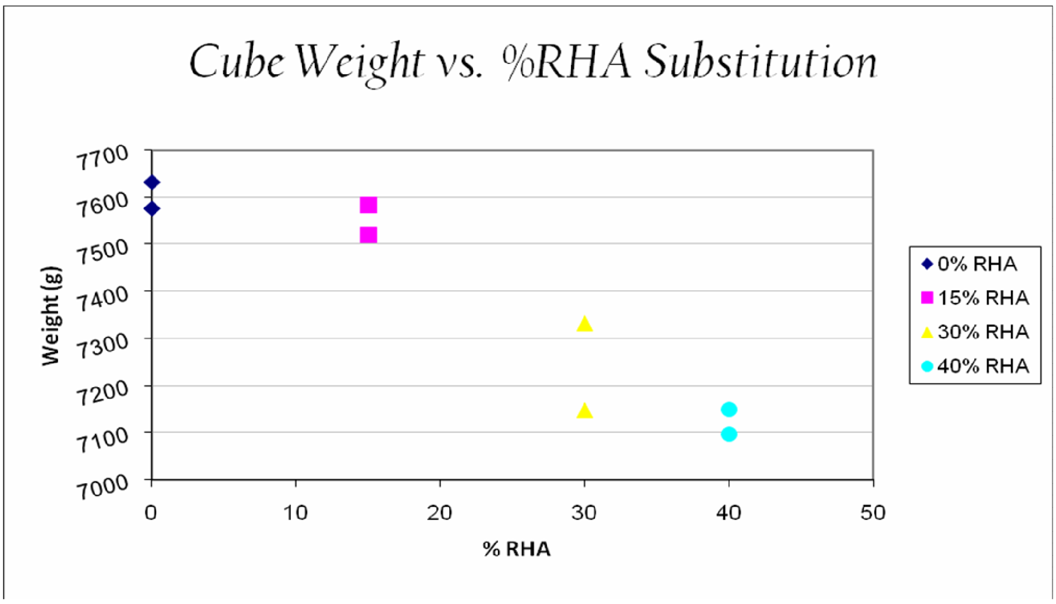

Figure 5: Compression cube weight correlation

The following graph, figure 4, shows the strength curves for the compression samples. There were only enough samples to test at seven and fourteen days, but the tests follow the same trend as the paving slabs. The strength is decreasing as the percentage of rice husk ash is increased. The strengths for batches 2 and 3 are close to the control batch; with the 30% rice husk ash substituted less than 10% decrease from the first batch. The 40% rice husk ash has a significant decrease in strength.

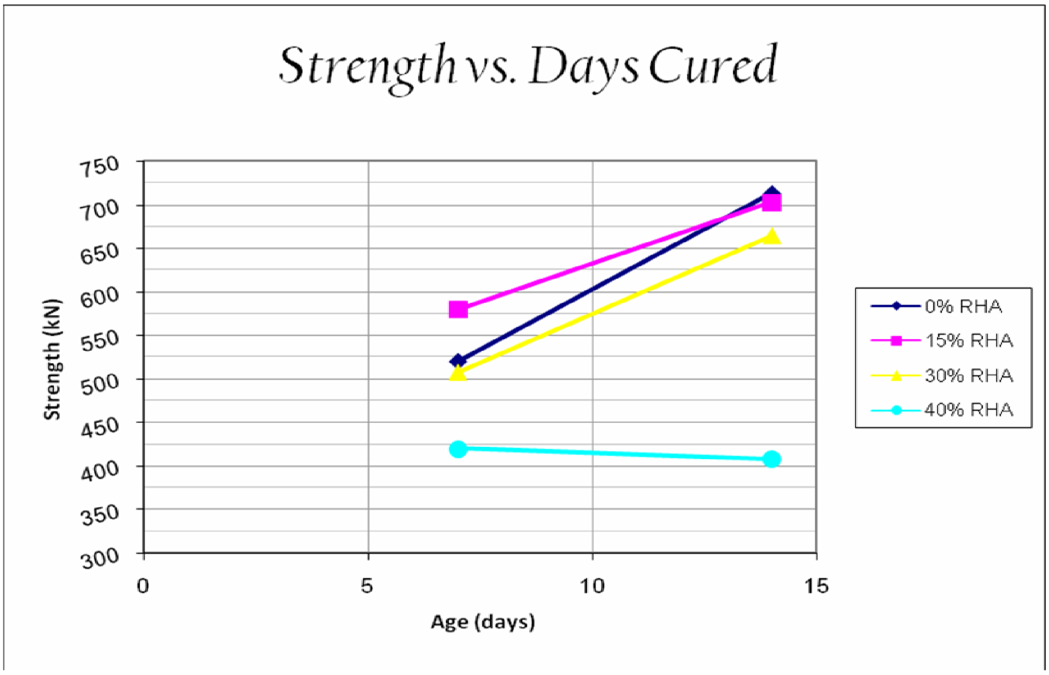

Figure 6: Compression tests strength curves

Recommendation

After completing our research and testing samples of our own, it is our recommendation to use rice husk ash substitution for Ordinary Portland Cement up to 30%. This will decrease the weight of the finished project, decrease the cost, and dispose of the rice husk ash waste product. This is the best option where rice production is prevalent, including most of Asia especially South East Asia. This area is mostly underdeveloped with higher rates of poverty. The cheaper cost of concrete can lead to more secure and longer lasting infrastructure. The use of rice husk to fuel brick kilns and complement cement in building materials transforms it from prevalent waste product into an abundant resource.

Highlights of Recent Related Rice Husk Research

Since western-style buildings have become prevalent in SE Asia, elevated indoor temperature due in part to solar heat gain has become a widespread problem, often remedied with energy-intensive air conditioning. In 2007, C. Lertsatitthanakorn and S. Atthajariyakul of Mahasarakham University, and S. Soponronnarit of King Mongkut's University of Technology Thonburi (Thailand) studied the thermal performance of RHA based sand-cement blocks as insulating thermal mass. They built a small room (5.75 square meter floor) out of standard commercial clay brick, and another out of blocks composed of RHA, sand, and cement at a ratio of 544:320:40. They took continuous temperature measurements inside both for the Thai summer month of March, and found that the RHA blocks allowed 46 W less heat transfer than the clay bricks. Also included in the study was an economic analysis of potential energy savings.

In 2008, Sumin Kim of Soongsil University, (Seoul, Republic of Korea) Investigated the effect of combining rice husk itself (not ash) with gypsum in the manufacture of drywall boards. Kim found that at rice husk levels up to 30%, the modulus of rupture and modulus of elasticity increased, but decreased at levels over 40%. Internal bonding strength increased for RH levels up to 20%, but decreased at higher levels. At higher rice husk content, the product absorbed less moisture, and became slightly more combustible, but up to 30% RH still met Japanese Standards Association first class incombustibility requirements. The author concluded that 20% rice husk by weight is the ideal mixture for improving gypsum boards while lowering costs and helping reduce the rice husk disposal issues.

A method has been developed by which the pozzolanic activity of a batch of ash can be measured in 28 hours (as opposed to 7 or 28 days) by mixing a sample with Portland cement, measuring the electrical conductivity of the solution, and comparing it to values from the reaction of a solution with a known pozzolanic activity level. (Sinthaworn, Waste Management, 2009)

Rice husk can be co-combusted with coal to help clean up coal-fired power plant emissions. 10% to 30% biomass appears to yield the lowest overall pollutant per unit of energy ratio, though the co-firing may produce more ultra-fine particles, and increase problems of "slagging, fouling and formation of clinker" in conventional systems. (Chao, Bioresource technology, 2008)

RHA can be added to soil to aid in compactibility. According to Basha and Muntohar (Electronic Journal of Geotechnical Engineering, 2003), the plasticity of soil is reduced when rice husk ash and/or cement is added, as is the maximum dry density, and the optimum moisture content is increased. They state that considering plasticity, compaction, and economy, the ideal soil additive mix is within 6-8% cement and 10-15% RHA.

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