Quantification of Rock Wool Waste Briquette for Recycling

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ARTICLE INFORMATION

ABSTRACT

The compressive tests are the most common method to quantify the material strength. Tumbler method and shatter test is usually used to determine the strength of material subject to handling work. The rock wool briquettes to be recycled had to endurance the drop tests at normal and high temperature conditions. The briquettes (5 cm cube) of different weights were prepared using Portland cement as binder and subjected to drop tests at pre determined heights. A linear relationship was found between breakage index (lost factor) and the drop heights. The results from the test were used to quantify the rock wool briquette for their suitability for recycling to make rock wool fiber on the basis of breakage index. The plant trial results indicated that the drop procedures were very reliable to examine the stabilization effect of brittle material due to repeated drop during recycle operation. Differential Thermal Analysis data also supported the suitability of the briquette for recycling into feedstock for rock wool production due to their higher melting point than raw material.

1. Introduction

The problems associated with the management of solid wastes in today’s society are complex and one of the major problems is their ultimate disposal. However, these residual products still have economic values and can be recycled on an industrial scale basis, into other useful products. The recycling of the residual products involves the reformation or reprocessing of the recovered material (Department of Environment, 2008a; Department of Environment, 2008b; Tyagi, 2007; Rubin and Davidson, 2001; Bishop, 2000).

Rock wool waste is a typical example of valuable residual product or material that can be recycled or transformed into another useful product such as briquette which may be supplemented for primary raw materials and can be fed together with main feedstock. The primary raw materials for the production of rock wool are usually derived mainly from different types of rocks such as basalt and andesite. These rocks are fed to a cupola furnace and burnt together with ‘cokes’ as auxiliary fuel. Sometimes, gas may also be used as the auxiliary fuel especially for the start up of the furnace. The rocks are then melted in the form of rock lava (sometimes, known as ‘diabase’) at extremely high temperature of approximately 1500 °C. Afterward, the diabase is led to a spinner, incorporated with fast rotating wheels that generate small “droplets”. The droplets are then directed through high velocity air-stream to be converted into fibers. During this process, binder and oils are added to the fibers. The
fibers are then collected on a spinning belt as a thin rock wool fleece. The addition of mineral oil is to facilitate the wool to be water repulsive. Subsequently, the thin rock wool fleece is further wounded or crisscrossed on a belt in order to obtain an optimal wool distribution. After that, the wool is collected and weighed at a fixed weight as the rock wool product. The product is also cured in the oven to attain its final shape and stiffness. The curing process involved passing of hot air through the wool together with its binder. Consequently, the package of wool is cooled down with air and trimmed to the required size (length, width and thickness) in accordance to specification set for packing and export. Although from an engineering perspective, the method of rock wool production is realistic, the residual wastes (rock wool wastes) and off specification rock wool that are generated during the overall production process may contribute to major disposal problem unless they are recycled.

Though rock wool has a number of commercial applications such as thermal insulation, fire protection and acoustic insulation (CSR Coolbatts, 2005) but its wastes or rock wool by-products, sometimes referred as 'drop wastes', poses disposal problem. The rock wool waste is characterized as relatively incompressible and non-biodegradable fiber that is not easily incinerated. The density of the rock wool waste ranges between 40 kg/m$^3$ to 150 kg/m$^3$ (CSR Rockwool, 2007) while according to Geankoplis (2003), the density of rock wool range between 128 kg/m$^3$ to 192 kg/m$^3$. The wastes are classified as inert and non-hazardous in accordance to the classification under the Basel Convention on the Control of Trans boundary Movements of Toxic and Hazardous Wastes and Their Disposal (UNEP, 2004) and Malaysian Environmental Quality (Scheduled Wastes) Regulations 2006 (Malaysian Environmental Quality Act, 1974; IMPAK, 2006).

The rock wool wastes (drop wastes) are commercially attractive due to large quantity and high cost of landfill. Thus it needs research for its recycling and converting the wastes into useful products such as briquette and very little work has been done in this area. Technobanoglous et al. (1993) claimed that the fundamental issues worth consideration in wastes recycling include the wastes to be diverted (recycling opportunities), and also buyers of the recovered products. According to Lee (2007) 70% of the virgin rock materials yields rock wool and the remaining as 30% ‘drop waste’ excluding the reject rock wool products. Thus, continual practice of disposing the remaining 30 percent of the drop wastes to landfill would be a big problem.

On a recycling opportunity basis, conversion of the rock wool wastes into good strength briquettes is a function of its compaction (densification) operation process and the physical and chemical properties of binders that are involved in the briquette formation process. This aspect is important since the strength of the briquettes also ease their transportation problem. Moreover, the compaction and binders also play significant role in ensuring the wastes would be converted into value-added products such as compatible or resemblance of the raw materials for the rock wool production process. Additionally, for an economically successful recycling process to be realized, it also would be dependent on constant supply of sufficient waste volume; a suitable collection and transportation system of the wastes to the material recovery facility; a reliable material separation and clean-up process to produce the end recycled materials and product; and finally, secure and stable markets for the raw materials and products (Williams, 2005).

The recycling opportunity for rock wool wastes into new value-added products including briquette, is still new and developing. Indeed, the fundamental issues of proper recycling of rock wool wastes into briquette, and marketing of the recovered products are still unresolved. However, clues for the success of recycling opportunity to obtain good strength briquettes from rock wool wastes rely on several engineering factors especially the effects of binders on the briquette, compaction and mechanism of wastes mixture especially thermal shock (charging) in the blast furnace at extremely high temperature in the range of 300ºC to 1500ºC. Poor quality briquettes (inferior briquettes) are usually the effect of not achieving the optimal physical and chemical properties conditions. Others contributing factors include the mixing ratio and compatibility of binders with the rock wool wastes. Chemical composition of the binders, curing time, and the correct charging temperature during heating in the cupola furnace are also important factors affecting the physical strength of the briquette. Good quality briquettes are those which originated from rock wool wastes that are mechanically resistant and do not easily break up during handling and transportation. The briquettes could be in the form of square, oval, round and hexagon depending on the machine used. At present the data for these factors are very much limited.

Another limiting factor is the lack of information and study on the composition and characteristics of the local content (tropical climatic condition) of non-renewable rocks especially basalt and andesite which needs further investigation for production of effective briquettes. Paroc (2002) reported that although there is similarity in terms of basic principle of rock wool production, different sources of raw material may produce a variety of products of varying quality. Additionally, the rock wool wastes amount or quality would be affected due to its diverse physical and chemical composition. In fact, lack of initiatives for recycling of the rock wool wastes especially involving basalt and andesite rocks is due to limited understanding and data on to how achieve optimal compaction and binders to reformulate rock wool
wastes into high quality briquette. However, lack of information in the literature especially the state of knowledge of recycling drop wastes originated from rock wool is, at its best, fuzzy. Moreover, the large amount of wastes and its disposal issues could also be a prevailing sense of urgency that research efforts should be intensified in this area. An understanding on the recycling scheme is still vague especially when it involved formation of the briquettes using cement binders at the level of laboratory and pilot scale recycling plant.

Hence in this study it is hypothesized that rock wool wastes of basalts or andesite rocks is recyclable into briquettes and provide a viable and an effective supplementary raw materials for rock wool production. Pilot scale recycling plant is used for testing the optimal conditions relating to compaction and binders which are essential for the briquette formation in order to verify the hypothesis. It is envisaged that the results of the study will be useful in resolving the hesitation about the use of testing briquette quality (physical and chemical) through drop, abrasion and compression tests parameters as recycling products and supplementary raw materials for rock wool production (Julius, 1969). These tests have been widely used in an analysis of specific context: compression parameter commonly used in concrete strength analysis, abrasion parameter for assessment of marble quality, and drop parameter commonly used in assessing the coke and coal quality. This study will integrate the three parameters and developed an indicator which is specifically applicable for assessing the quality of the briquettes from recycled of rock wool waste. A review of scientific literature demonstrated that although the interest on the research on the production of rock wool wastes briquettes started as early as 1990 the study was only limited to the laboratory scale and the research areas restricted mainly to briquette compression strength using 20 percent of the wastes and 15 to 20 percents cement binders (Paroc, 2005).

Thus, it is envisaged that the results of this study would provide data on the physical strength of briquette with binder from pilot scale recycling plant model and this contribution provided sufficient reliable design data for prediction of a full scale briquette production plant.

<table>
<thead>
<tr>
<th>Composition</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basalt (Segamat)</td>
<td>45.8</td>
<td>14.4</td>
<td>11.3</td>
<td>7.9</td>
<td>6.6</td>
<td>2.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Andesite (Temerloh)</td>
<td>57.6</td>
<td>18.0</td>
<td>4.6</td>
<td>2.0</td>
<td>2.6</td>
<td>4.2</td>
<td>6.7</td>
</tr>
<tr>
<td>Dolomite (Puchong)</td>
<td>1.4</td>
<td>0.3</td>
<td>0.6</td>
<td>19.4</td>
<td>31.0</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Drop waste (CSR)</td>
<td>45.4</td>
<td>12.6</td>
<td>4.3</td>
<td>10.6</td>
<td>21.3</td>
<td>2.5</td>
<td>2.7</td>
</tr>
<tr>
<td>Cement (OPC-Tasek)</td>
<td>20.6</td>
<td>6.3</td>
<td>3.6</td>
<td>-</td>
<td>63.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Reject rock wool</td>
<td>39.9</td>
<td>13.7</td>
<td>4.2</td>
<td>8.5</td>
<td>22.6</td>
<td>1.7</td>
<td>2.5</td>
</tr>
<tr>
<td>Briquette (12 % OPC)</td>
<td>36.9</td>
<td>12.1</td>
<td>6.5</td>
<td>7.2</td>
<td>24.8</td>
<td>2.0</td>
<td>2.1</td>
</tr>
</tbody>
</table>

2. Materials and Methods

2.1 Rock wool production and waste source

Volcanic rocks especially andesite and basalt are the most suitable raw materials for making rock wool. These rocks are combined with dolomite rock and melted at 1500°C temperature using cupola furnace using coke as fuel. The molten rock or lava is fiberized using four water cooling spinners in cascading arrangements rotating at 3000 rpm. The rock wool fiber were then coated with thermosetting binder, phenol formaldehyde, heat-cured at about 200°C to bond the fiber into a mat or other shape and then cut into suitable sizes as shown in Plate 1.

During the rock wool production process not all of the molten rock is transformed into rock wool. Normally, during the spinning process, 60-70 % of the molten rock will turn into fiber. The remaining is in the form of “shot” which is heavier than fiber and falls at the bottom of cupola furnace as waste. Besides that, a fraction of the molten rock which passed through the spinning wheel, solidified and dropped at the bottom of the furnace as “partial glass” waste. At the off production line, trimming process of the rock wool with some rejected rock wool mat contributes to another 10-15% of the waste. The remaining 2% is dust comings from the bag house. CSR rock wool factory at Bukit Raja (M) Sdn.Bhd consumes about 2.0 tonnes per hour of raw material for making rock wool and all its wastes are sent to the landfill at Jeram, Selangor.

2.2 Briquetting and curing technique

To use the briquettes in the blast furnace, they must have sufficient strength to withstand the conditions similar to that of raw material otherwise they will cause serious problem to blast furnace operation. Hence they are fabricated and tested accordingly. A drop waste from factory was processed and different weight of 5 cm cube briquette prepared by using briquette machine. Ordinary Portland Cement (OPC) has been used as its chemical composition is within the acceptable limit and has advantages over other binders (Hicylimaz, 1994), although slow in providing maximum strength to briquette in a short time. It is also cheap and easily available at the open market and can provided

Table 1: Chemical composition of sample of raw material, drop waste, OPC, reject rock wool and briquette
sufficient strength at low (Navielle, 1983) and high temperatures (Manesh, 2002). Normal air curing technique had been used and the briquettes were subjected to test on the 28 day.

2.3 Chemical composition of raw material, rock wool waste and briquette
The chemical composition of briquette and percentage of binder play significant role in recycling the rock wool waste. They should be within the control range and should be maintained to get desired quality of briquette. Table 1 shows the chemical composition of raw material, drop waste and briquette with cement binder using Philips PW1480 Spectrometer.

2.4 Compressive strength
The most common method of testing briquette were using compressive test. However when the briquette was subjected to the drop condition this test considered unsuitable and time consuming. In practice Tumble drum test had been used, however this had many standards (Kortmann and Bughardt, 1977) and considerable amount of material required for the test. Besides that the briquette also had many different shape and size due to their different material and briquette machine. The compressive strength of briquette were conducted using Universal Testing Machine Hung Ta HT-9501 S/N 1135.

2.5 Abrasion test
Abrasion test was conducted based on ASTM C 241-90. Abrasion of stone was subjected to traffic. The test was conducted to determine the strength of surface of briquette due to friction.

2.6 Drop test
Drop test was conducted according to the ASTM D440- Standard Method of Drop Shatter Test for Coal. Two sample from each test were used and drop at 2 meter height and the remains were sieved using BS 410-2cdm square sieve.

Figure 1: Compressive strength for 250g briquette over a period of 28 days.

3. Result and Discussion
Table 1 shows the chemical composition of raw material, drop waste, OPC, reject rock wool and briquette. The results show that chemical composition of drop waste, reject rock wool and briquette with 12% OPC have much lower SiO\textsubscript{2} than the main raw material, i.e. Basalt. This indicates that briquette derived from waste with suitable binder can be used for recycling.

Figure 1 show the compressive strength for a sample of 250g briquette over a period of 28 days. The graph shows that briquette strength increases steadily from day 1 to 7 and start to stabilize from day 7 to 28. The strength mostly depends on the properties of cement.

3.1 Abrasion test
Figure 2 shows the comparison of the results of abrasion tests on briquette of two different and percentages of rock wool. As could be seen from the figure, the values of the abrasion tests for both samples were found to be slightly different due to small changes in rock wool content. The results of the abrasion tests demonstrated that the slight inconsistency in the values of the abrasion for both briquette samples probably influence by the occurrence effect of rejected rock wool at the surface of the briquettes.

3.2 Effect on cement content component by drop test
Figure 3 shows the results of drop test of briquette mixing with different percentage proportion of cement binders (8%, 10 %, 12%, and 14%). The analysis of sample with 8% binder (cement) show that the weight of briquette lost per drop was found to be 25.6 % which indicates that the briquette was unsuitable for recycling. From the drop test analysis,
it was found that when the binder proportion increases from 8% to 14%, the rate of briquette weight lost per drop decreases from 25.6% to 6.6%. This indicates that the addition of cement binder improved the strength of the briquette significantly. However, the increase in cement binder would also increase the cost of briquette production.

![Figure 2: Samples of briquette with two different weights and percentage of rock wool contents by abrasion test](image)

![Figure 3: Result of drop test on briquette strength having different percentage of cement as binder](image)

**3.4 Effect of drop height on briquette in drop test**

Figure 5 shows the result of 260 g briquette being tested at three different heights. The results show that the weight lost of briquette per drop increases linearly and its weight per drop increases when the drop height increases. Based on this relationship weight lost per drop from briquette making, delivery, transfer and charging could be estimated according to number of drops and the height it encounters during handling and charging sequences.

Weight lost of briquette due to multiple drops from different heights in an actual briquette production line is a significant parameter for assessment of the quality (physical strength) of briquette. Linearity drop tests were conducted on six samples of briquette weighing 210, 220, 230, 240, 250 and 260 g for each consecutive three fixed heights (1, 1.5 and 2 m). Mean value of 10 drops of these experimental runs are reported. The test was conducted at a condition of 12% binder (Ordinary Portland Cement) and with water to cement ratio of 2. The results of the corresponding drop tests conducted for ten drops show that each briquette would lose its weight consistently corresponding to its weights and drop heights. The change in the weight of briquette remaining with respect to drop number (lost factor) was always constant. Thus, these results demonstrated that number of drop tests could be minimized to a reasonable number, preferably at least 3. Also, the ratio of the weight lost with different height was found to be represented by only the maximum height instead of other lower heights. Additionally, by plotting the slope (lost factor) of each curve (percentage of weight of briquette remaining per drop versus drop number for different weight of briquette according to a fixed height) versus the drop height would represent a summary on trend of briquette quality (in terms breakage index) with drop height. Thus, the empirical models are established in
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Plate 1: Rock wool production and waste source.

Figure 4: Drop test for 200 g and 250g briquette with 2% and 4% reject rock wool
Recycling of rock wool waste:

Plate 2: Good briquette quality analyzed in this study (small particle disintegrate at point of impact)

Plate 3: Total failure of briquette as observed in this study

Plate 4: Partial failure of briquette during early curing time as observed in this study

Plate 5: Common split after drop due to non-homogenized mixture of the briquette

Plate 6: Split surface with rock wool bud observed on the internal portion of briquette during drop test
Recycling of rock wool waste: this study which can be used for prediction of the different weight lost of briquette subject to different weights. These models also could be used to predict the total weight lost of briquette production for recycling it in the actual production scale. Figure 6 shows a plot of breakage index (lost factor) for different weights of briquette versus corresponding drop heights. From the figure, the breakage index at 1 meter height for the corresponding briquette weights of 210 and 260g were found to be 4.5 and 1.0 respectively. The higher the briquette weight, the lower the index. Thus the index shows that the heavier briquette would have better physical strength.

By applying the drop test results the estimation can be made by using the following general formula:

$$W_t = N_1 \sum k_1 W_1 + N_2 \sum k_2 W_2 + N_3 \sum k_3 W_3 + ...$$

where $$N$$ = number of drop from height, $$h$$

$$k$$ = respective constant

Step 1 : From pellet to hopper by front loader height in 1.0 meter in height
Step 2 : From material hoper to batch weight shuttle 1.0 meter in height
Step 3 : From weight shuttle to bucket elevator is 1.5 meter in height
Step 3: From bucket elevator to cupola furnace is 2.0 meter in height.

So the total loss of 250gm briquette was

$$W_t = 2 \times 2.3 + 1 \times 4.5 + 1 \times 6.8 = 16.1\%$$

Figure 6 also demonstrates that for 260g briquette weight start to break when dropped height was more than 0.6m and becomes lower for lower weight briquette. The 210g briquette were considered not acceptable briquette due to negative value. In general, after substitution of the drop height of each briquette and analysis of the data using curve-fitting software, the breakage index can be generalized to the following formula

$$k_{vh} = a + b\ln M_b$$

where $$k_{vh}$$ = briquette index for corresponding height in meter
$$M_b$$ = mass of briquette in gram ($$M_b$$ greater 210g)
$$a$$ &$$b$$ = constant

3.5 Differential thermal analysis of briquette and raw material

Figure 7 shows the results of the differential thermal analysis for the samples of basalt, andesite, and briquette. Differential Thermal analysis which was conducted in this study to provide clues on the oxidation process the status of melting temperature of the briquette and compared to the raw material used for the rock wool production especially at temperature above 1000°C. The analysis shows that
all the samples (basalt, andesite and briquette) start melting at temperatures above 1000 °C. The samples also did not show endothermic peak till 1250 °C. Thus, the raw samples composing of basalt and andesite were found to melt at 1050 °C and 1070 °C respectively. However, briquette, melted at 1140°C. These results also show that the briquette was suitable for recycling into feedstock for rock wool production as it started melting later than raw material. Smaller briquette size than raw material was desired so that complete melting can be achieved at the same melted bath zone.

4. Conclusion
Successful recycling of waste requires the waste material should have similar chemical composition and physical properties as that of raw material. Cube briquette were the simplest briquette in shape, cheap, easily to produce and evaluate. Briquette degradation during transfer and charging can be estimated by drop tests. Briquette with 12% cement had sufficient strength for recycling. Differential thermal analysis shows that briquette melting point was less than raw material.

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References


