Malaysian Feldspar: Evaluation and Processing of Selected Deposits

M. M. Alimon* and N. Ahmad

Mineral Research Centre, Minerals and Geoscience Department, Jalan Sultan Azlan Shah, 31400 Ipoh, Perak, Malaysia

*Corresponding author: muzayin@jmg.gov.my

Abstract: *Several known feldspar deposits in Peninsular Malaysia were evaluated in the present study, and the potential use of the feldspar in local industries was assessed. The main objective of the present investigation was to identify deposits that can be exploited and processed to reduce the reliance of the region on imported feldspar. The specimens were characterised, and suitable upgrading processing techniques were assessed. The deposits were characterised by chemical composition analysis, button-making inspection and grinding tests. The primary upgrading techniques evaluated in the current investigation include magnetic separation and physical-chemical processes. Based on the results of the present study, potential uses of local feldspar products were identified.*

Keywords: Malaysia, feldspar, processing, button making

1. INTRODUCTION

In Malaysia, the demand for feldspar as a raw material for industrial applications has increased continuously. Locally, feldspars are used in ceramic, glass, sanitary wares and porcelain, and the demand for feldspar is met by imports. Imported feldspars are favoured by many industries because the price of imported feldspar is competitive and the material can be used directly in production plants. However, to reduce the reliance of the region on imported feldspars and to sustain the demand for this mineral in domestic industries, local feldspar production must be developed.

The Minerals and Geoscience Department of Malaysia has identified several deposits that may be developed for the production of feldspars. Significant deposits are located in Tanah Putih (Gua Musang, Kelantan), Merapoh (Kuala Lipis, Pahang), Bukit Mor (Muar, Johor), Gemenceh (Negeri Sembilan) and the state of Perak (Simpang Pulai, Menglembu and Grik). Based on the findings of the Minerals and Geoscience Department of Malaysia and various initiatives from the private sector, the first feldspar mine was opened in Tanah Putih, Gua Musang in 2003.[1] Currently, three feldspar mines are operated in the study region; however, a small amount of feldspar is also produced as a by-product from a tin mine in Menglembu. In addition, feldspar is produced in the form of pottery stone in Gemenceh.[2]

The production and importation of feldspar in Malaysia in 2005 to 2007 is shown in Table 1. As shown in the table, the production of feldspar increased by 152% from 142385 tons in 2006 to 358585 tons due to the production from the three mines in Gua Musang.[1] However, almost all of the feldspar produced at these mines (mostly with minimal processing practices) was of low quality due to the low content of feldspar and the presence of impurities such as iron oxides, which prevent applications in high end products.

Table 1: Malaysian production and imported feldspar.

Year	Production		Import	
	Quantity (tonnes)	Value (RM)	Quantity (tonnes)	Value (RM)
2005	117,180	4,034,172	309,234	30,371,928
2006	142,358	9,079,040	113,411	31,804,934
2007	358,585	26,934,720	130,819	24,000,231

To better understand local feldspar deposits and their potential in industrial applications, the deposits were characterised, and suitable upgrading processing technique were evaluated in the present study.

2. EXPERIMENTAL

2.1 Sample Preparation and Characterisation Tests

Three representative samples of feldspar deposits were obtained from Tanah Putih, Merapoh and Bukit Mor. Geological studies on deposits located in Tanah Putih and Merapoh indicated that the feldspar from these areas is formed from the residue of incompletely kaolinised rocks.[3] Alternatively, the Bukit Mor deposit exists in the form of pegmatite, and sheets of grey mica were readily apparent.[3,4] In the current investigation, raw samples were completely sun-dried and crushed by a jaw crusher and a cone crusher to separate the grains. Subsequently, each sample was mixed several times to form a composite sample, which was subjected to further sampling. Finally, several fractions of samples from each deposit were prepared for the characterisation tests and further processing.

Samples from Tanah Putih and Merapoh were ground according to a dry grinding process (ball mill machine) to further liberate the feldspar minerals from other gangues, including iron minerals and quartz. Most of the mica sheets in the Bukit Mor deposit were liberated during the cone crushing process and were removed by hand prior to grinding. Ground samples were sieved by dry sieving into 600 μm grains for further processing, including magnetic separation and froth flotation.

The samples were characterised by mineralogical and grinding tests, chemical analyses and button inspections (Fig. 1). Mineralogical analyses using various types of microscopes were carried out on all of the raw samples (after the cone crushing process). The chemical analysis of raw materials and final feldspar samples was performed by X-ray florescence (XRF-1700, Japan). The iron content of the various grain size fractions was determined by atomic absorption spectroscopy (AAS, Shimadzu AA-6800, Japan). The buttons and various grain size fractions of the raw materials were also produced for visual observation.

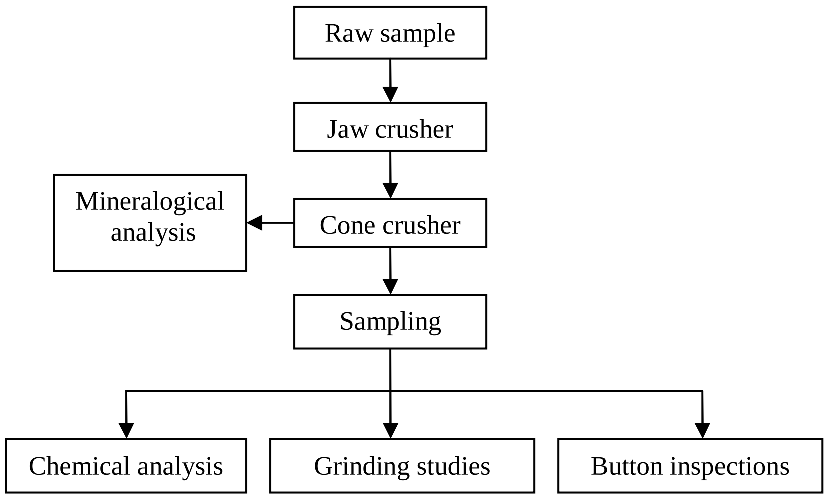

Figure 1: A flowchart of the sample preparation and characterisation procedure for the feldspar samples.

The grinding studies were carried out using a 300 mm x 450 mm grinding jar, and mild steel balls with a weight of 5 kg, 3 kg and 2 kg and a diameter of 50 mm, 40 mm and 28 mm, respectively were employed as the grinding media. For each test, 1 kg of the deposit was used, and the grinding time was set to 20 min.

Button-shaped samples for visual observation were prepared by mixing 24 g of pulverised sample, 0.2 g of carboxyl methyl cellulose as a binder and 7.5 ml of distilled water. The mixture was subjected to the proper mixing process and was oven dried at 200°C for 2 h. Subsequently, the dried mixture was pressed into a mould with a load of 18 tons. Finally, button-shaped samples were heated in a furnace at a rate of 4°C/min, maintained for 2 h at 1200°C and cooled for 6 h.

2.2 Beneficiation Tests

Magnetic separation was performed on the samples. Beneficiation tests were conducted with a hand magnet, wet high intensity magnetic separator (WHIMS, Boxmag Rapid, Birmingham, England), double disk high intensity magnetic separator (HIMS, Rapid Magnetic Machines Ltd., Birmingham, England) or a combination of these techniques. To remove iron minerals from the samples, the aforementioned separation processes were conducted in magnetic fields with specific intensities.

Froth flotation was used for the beneficiation of ground samples obtained from Bukit Mor. The tests were conducted using a Denver Cell Model D1 (Denver Equipment Co. Ltd., Colorado, USA) and 500 g of sample was evaluated in each test. The volume of slurry was fixed at 2.5 l, and the stirrer speed was maintained at 1300 rpm. A conditioning time of 5 min was applied to the slurry before and after the addition of the required reagents. The collecting time was set to 5 min, and sulphuric acid (H_2SO_4) and hydrofluoric acid (HF) were used to control the pH of the slurry. Tallow-hydrochloric acid (HCI) was used as a modifier, and Aerofroth 65 (Cytec Industries Inc., USA) was used as a frother cum collector. When required, a small amount of diesel was used as a dispersant. The selected flotation conditions and reagents are shown in Table 2.

Table 2: Selected conditions and reagents for the flotation tests.

Test	% solid	HF	H_2SO_4	Tallow HCl (g/t)	Diesel (drops)	Aerofroth 65 (drops)
1	20	Yes	Yes	100	2	2
2	20	Yes	Yes	200	2	2
3	20	Yes	Yes	300	2	2
4	20	Yes	–	300	–	2
5	20	Yes	–	400	–	2
6	20	Yes	–	350	–	2
7	20	Yes	–	350	–	2

3. RESULTS AND DISCUSSION

3.1 Sample Characterisation

The results of the chemical analyses are shown in Table 3. The iron oxide content of the Tanah Putih, Merapoh and Bukit Mor deposit were 0.39%, 0.62% and 0.70%, respectively. Based on the analytical results, the grade of feldspar and percentage of free quartz in each sample were calculated according to the Feldspar Convention guidelines.[5]

Table 3: Chemical compositions, feldspar grades and free quartz contents of selected samples.

Chemical compositions (%)	Raw sample		
	Tanah Putih	Merapoh	Bukit Mor
SiO_2	70.90	68.61	73.50
Al_2O_3	17.50	18.87	15.70
$Fe_2O_3^*$	0.39	0.62	0.70
Na_2O	6.25	4.23	3.01
K_2O	3.51	4.26	5.54
CaO	0.34	0.24	0.75
TiO_2	0.03	0.42	0.02
MnO	0.02	–	0.04
Loss on ignition, LOI	0.84	1.95	0.72
Feldspar grade (calculated)	73.59	60.97	58.21
Free quartz (calculated)	17.17	19.17	29.23

Note: *Analysis done by AAS

The feldspar grade and free quartz content are shown in Table 3. The primary constituents of the samples were feldspar and free quartz, and the average grade of feldspar for the Tanah Putih, Merapoh and Bukit Mor deposit were 73.59%, 60.97% and 58.21%, respectively. According to the aforementioned results and the calculated sodium and potassium oxide contents, the deposits obtained from Tanah Putih and Merapoh were in the form of N-feldspar, while the deposits obtained from Bukit Mor were in the form of K-feldspar.

Besides feldspar and free quartz, other components of the samples were determined (clay minerals were also present in the deposits obtained from Tanah Putih and Merapoh). Specifically, mica-based minerals were detected in all three samples. However, the mica content of the Tanah Putih and Merapoh deposit was considered insignificant (very low percentages).[6] Based on the amount of mica removed by hand sorting and observed in the microscopic evaluation, the Bukit Mor deposit contained more than 3% (by weight) mica minerals. Further analysis on the separated mica showed that the majority of iron in the Bukit Mor deposit was associated with mica.

After the grinding test, the particle size distribution of the samples was determined, and the results are shown in Figure 2. The particle size distributions of the Tanah Putih and Merapoh deposit were similar, and coarser particles were observed in the Bukit Mor deposit.[7] Relatively coarse particles may be present in the Bukit Mor deposit due to the large amount of mica and high content of free quartz.

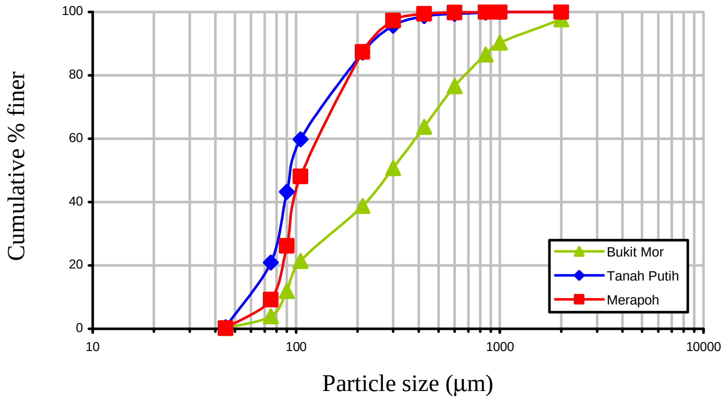

Figure 2: Particles size distribution of samples obtained from Tanah Putih, Merapoh and Bukit Mor after the grind ability tests (cumulative curves).

The button test results from different size fractions and the corresponding iron contents are shown in Table 4. Generally, for the Bukit Mor deposit, the buttons produced from different size fractions presented similar colours, indicating that the chemical composition of the sample was more evenly distributed through the fractions than that of the Tanah Putih and Merapoh deposits. Although slight differences in the iron contents of the three samples were detected, the colour of the buttons was significantly different. This phenomenon may be due to the different form of iron in the Bukit Mor deposit compared to the other samples.

3.2. Beneficiation

3.2.1 Hand sorting removal

Visual observation of the crushed sample of the Bukit Mor deposit showed that some of the mica sheets could be removed by hand sorting. The separation of mica by hand sorting was carried out on a 5 kg sample (after cone crushing). After the sorting process was complete, 91 g (approximately 1.8% of the sample) of mica was obtained.

Table 4: Relation between the colour of the button, size fraction and iron content.

Raw sample (µm)	Iron content, Fe_2O_3 (%)		
	Tanah Putih	Merapoh	Bukit Mor
Head (–600)	 0.39	 0.44	 0.70
–600 + 75	 0.33	 0.38	 0.78
–75	 0.21	 0.41	 0.79

3.2.2 Magnetic separation

The magnetic separation results for different size fractions of the Tanah Putih, Merapoh and Bukit Mor deposits are shown in Table 5, 6 and 7, respectively. Hand magnet separation was only suitable for the Bukit Mor deposit because most of the iron was associated with mica minerals. Most of the mica minerals were observed in the magnetic fraction, and the grinding process liberated the majority of iron-containing minerals from the samples. Thus, the results showed that the iron content could be reduced via magnetic separation.

Table 5: Magnetic separation results on Tanah Putih sample by WHIMS.

Size (µm)	Product	Weight (%)	Fe content (%)	Fe distribution (%)
Head (–600)	Magnetic	3.26	0.277	43.57
	Non-mag.	96.74	0.012	56.43
–600 + 75	Magnetic	2.42	0.231	9.43
	Non-mag.	97.58	0.055	90.57
–75	Magnetic	0.71	0.147	1.30
	Non-mag.	99.29	0.080	98.70

3.2.3 Froth flotation

A series of flotation tests were performed on the 600-µm size fraction of the Bukit Mor deposit to determine the feldspar concentration. The flotation test results are shown in Table 8.

Feldspar and quartz minerals were separated through the flotation of feldspar minerals and the depression of quartz minerals. Quartz minerals were depressed using tallow-HCI acid under strongly acidic conditions. The pH was controlled by the addition of HF and H_2SO_4. Aerofroth 65 was used as a frother cum collector, and a small amount of diesel was used as a dispersant when required.

As shown in Table 8, the feldspar grade concentrate was dependent on the flotation conditions. The lowest feldspar grade concentrate (60.80%) was obtained in Test 1, while the highest feldspar grade concentrate (94.96%) was obtained in Test 6. Specifically, in Test 6, 25% of the sample was used with 350 g/t of tallow-HCI. The feldspar grade and mass percentage recovery of feldspar were compared, and the results showed that the highest percentage recovery was obtained in Test 6.

4. CONCLUSION

The following results were obtained by characterising the deposits and evaluating several upgrading processing techniques:

- The Bukit Mor deposit was different from the other samples and showed several unique characteristics. In particular, some of the mica minerals could be removed by hand sorting (due to their large size), and iron could be removed with a hand magnet.

- The grinding process liberated iron-containing minerals from the samples, and the iron content was reduced using various magnetic separation techniques.
- The highest feldspar grade concentrate obtained by flotation was 94.96%, and 63.24% of feldspar was recovered when 25% of the sample was treated with 350 g/t tallow-HCI acid and Aerofroth 65, which was used as a depressant and frother cum collector, respectively.
- The results of the present study proved that high-grade feldspar can be produced by specific processing techniques. Thus, local feldspar deposits can be developed, and the reliance of the region on imported feldspar can be reduced.

5. ACKNOWLEDGEMENT

The authors would like to thank the Director of the Mineral Research Center, Dato' Hj. Zulkifly Abu Bakar, for his support in completing the manuscript and the staff of the Metallurgy Section for their assistance in making this research successful.

6. REFERENCES

1. Mineral and Geosciences Department. (2007). *Malaysian minerals yearbook.* Kuala Lumpur: Ministry of Natural Resources and Environment Malaysia.
2. Alimon, M. M., Ibrahim, I. & Baharuddin, S. (2004). *Kajian awal ke atas beberapa enapan feldspar yang berpotensi di Malaysia.* Kuala Lumpur: Pusat Penyelidikan Mineral, Jabatan Mineral dan Geosains Malaysia.
3. Sulaiman, Z. A. (2002). *Occurance of feldspar in Gua Musang, Kelantan.* Kuala Lumpur: Minerals and Geoscience Dept. Malaysia.
4. Alimon, M. M., Ibrahim, I. & Baharuddin, S. (2007). *Kajian potensi penghasilan feldspar dari Kuari Bukit Mor dan kesesuaiannya untuk digunakan dalam industri pembuatan tempatan.* Kuala Lumpur: Pusat Penyelidikan Mineral, Jabatan Mineral dan Geosains Malaysia.
5. Rau, E. (1985). Feldspar. In N. L. Weiss (Ed.). *SME mineral processing handbook.* New York: Society of Mining Engineers of the American Institute of Mining, Metallurgical and Petroleum Engineers.
6. Baharuddin, S., Ibrahim, I. & Alimon, M. M. (2005). *Indeks kerja (WI) dan kebolehkisaran pengisar bebola.* Kuala Lumpur: Pusat Penyelidikan Mineral, Jabatan Mineral dan Geosains Malaysia.
7. Alimon, M. M. (2008). *Kajian potensi penghasilan produk dari enapan feldspar di Bukit Kancil, Merapoh, Pahang.* Kuala Lumpur: Pusat Penyelidikan Mineral, Jabatan Mineral dan Geosains Malaysia.