Applicability of Pre-heating Techniques for Recovery of Minerals from Rocks

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Abstract

In mineral processing industry, liberating of minerals is the most important involvement because it can enhance the purity of the mineral. However, if we can initiate micro-cracks in rock pieces in advance to these operations, it would be more economically viable. Hence, there is a trend in the world to investigate less energy-consuming methods for propagating micro cracks within rock grains. Previous studies show that preheating techniques such as heating in muffle furnace, microwave preheating can enhance micro-cracks propagation in rocks and samples. Microwaves have several advantages over standard heat application methods namely that they heat only "responsive" phases. Microwaves also heat considerably faster than conventional heating methods as the heating on radiation and conduction heat transfer mechanisms. Therefore, in this scientific investigation, we applied microwave pre-heating technique to liberate Garnet from Garnet Biotite Gneiss for which samples were collected from Boulder Mix Pvt. Ltd quarry in Meepe. To create a weak zone in between graphite and its gangui rock in graphite bearing rocks which were collected from Bogala Mines in Aruggammana have also tested. Industrial price of garnet vary with the particle size. In general, higher the particle size, higher will be the value. Hence, the recovery of Garnet in this study was considered focused on industry needed particle size which is less than 850 μm. The analysis revealed that there is a possibility to produce low cost garnet sand which is cheaper than in the international market with high purity, by means of microwave technology,. Also it is proved that creating a weak zone along the grain boundary of graphite and its gangue rock is possible with microwave pre-heating.

Keywords: Garnet , Graphite, Micro cracks, Weak zone, Microwave Pre-Heating, Thin sections

1. Introduction

Liberating minerals is the most important involvement in processing industry, because it increases the purity and value of mineral. Therefore, various methods are used for this criteria having high processing costs and consume lot of energy. To recover this extra cost, manufacturer has to increase the price of the product which he introduced to the market.

One method is to liberate the minerals from rocks before the secondary crushing of metals. Crushing costs can be reduced substantially by using this method.

Pre-heating techniques like microwave has shown promising results. So results over several years of time and can be used successfully to liberate minerals from rocks. This would improve the efficiency of various mineral processing units such as leaching, coal grinding and gold ore treatment [1].

Previous studies involving traditional thermally assisted liberation have concluded that whilst the benefits are particularly attractive, the overall energy balance is unfavorable [2]. Microwaves have several advantages over standard heat application methods namely that they heat only "responsive" phases. Microwaves also heat considerably faster than conventional heating methods as the heating is in situ rather than relying on radiation and conduction heat transfer mechanisms. The speed at which materials heat has been shown to be particularly important in both conventional and microwave thermally assisted liberation Rapid heating has been shown to be particularly effective in applied microwave fields as differential expansion due to different rates of the constituent minerals encouraged, creating stress in the mineral lattice [3].

Therefore the intention of this research is to find the ability of microwave as a cheaper, low energy and reliable method in mineral liberation. Especially to liberate garnet from garnet biotite gneiss, and to liberate graphite from its gangue rock. Another expectation is to find the ability of microwave in reducing crushing and grinding costs in metal industry.

2. Methodology

- Garnet rich Biotite Gneiss rock samples were collected from Meepe quarry site [6°51'35.1"N 80°06'04.3"E], which belongs to Boulder Mix Pvt. Ltd.
- Graphite bearing rock samples were collected from Bogala mines [7.014476N, 79.9544029E], which belongs to Bogala Graphite Lanka PLC.

2.1 Test Procedures

2.1.1 Garnet Extraction

Rock cores, of diameter 43mm were prepared from the samples collected from Meepe quarry site by means of 'HILTY' rock coring machine followed by rock cutting machine. Rock disks were prepared by means of rock cutting machine and rock polishing machine for Point Load Index test by means of 'MATEST' point load tester to identify the strength deterioration of rock samples which were pre-heated in Microwave oven.

Table 1 - Microwave settings for Garnet Recovery

Sample No	Power Level of Microwave(W)	Time (Minutes)
1	180	2
2	180	4
3	180	6
4	300	2
5	300	4
6	300	6
7	450	2
8	450	4
9	450	6
10	600	2
11	600	4
12	600	6

For Garnet extraction process, rock cores having (height: diameter) ≥ 2 were prepared for testing. Then rock cores were pre-heated in the Microwave oven and quenched, crushed by jaw crusher, ground by Ball Mill, and finally from sieved samples Garnet was extracted using Wilfly Table. For optimizing the recovery there are various energy levels and different temperature ranges were used when heating in Microwave oven as given in Table 1.

Some thin sections were prepared from rock samples which were pre-heated in Microwave Oven and quenched separately. Then thin sections were analysed using petrological microscope, in order to identify the propagation of micro cracks as micro fracturing is a dominant deformation mechanism in the process of deterioration of rock strength.

2.1.2 Pre-heating of Graphite

Some graphite mineralization is quite impossible to separate from gagne rock, due to very strong bond getting them. Graphite baring rock samples which were collected from Bogala Mines were also subjected to heat treatment process using Microwave Oven however one sample was not heated in order to identify the degree of decomposition (weakening) along the grain boundary of graphite and its gangne rock with the heat. Pre-heating process was done as summarized in Table 2.

Table 2 - Microwave setting for Graphite Pre-heating

Sample No	Power Level of Microwave (W)	Time(min)
1	None	None
2	300	3
3	450	3

Some thin sections were prepared from rock samples which were pre-heated in Microwave oven and quenched separately. Then the thin sections were analyzed using petrological microscope, in order to identify the decomposition (weakening) along the grain boundary.

3. Results and Discussion

3.1 Point Load Index Test

Point Load Index (P.I) values obtained for microwave heat treated and quenched rock from Meepe quarry site are given in Figure 1.

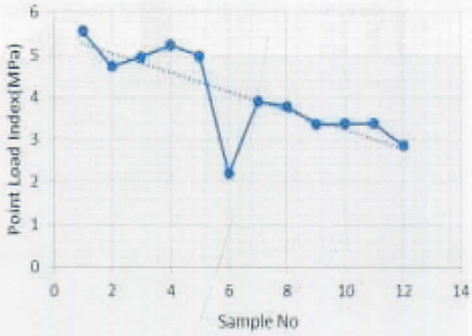

Figure 1 - Comparison of P.I test results for microwave heat treated samples

According to Figure 1, it is clear that the point load index value is getting decreased gradually with the increase of the temperature of rock specimens except in one occasion that they have been exposed. It means that the compressive strength of garnet biotite gneiss rocks is decreased with the increase of exposure temperature. The sample number 6 had some minor fractures in the as received sample, and that could be the reason for showing a significant drop in P.I of the same sample. Most of the samples were tested in 4 minutes exposure time in each energy level shows that remarkable strength deterioration than the two other samples of each group.

3.2 Garnet Recovery from Microwave Pre-heating and Quenching

Garnet recoveries from the rock samples collected from Meepe quarry site after microwave pre-heating and quenching are show in figure 2 to 5.

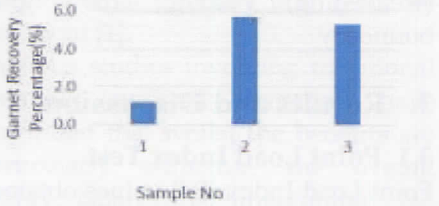

Figure 2 - Comparison of garnet recovery at 180W energy level

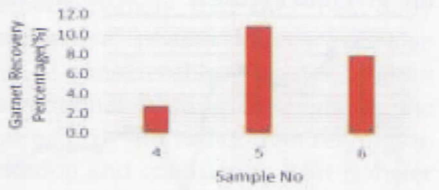

Figure 3 - Comparison of garnet recovery at 300 W energy level

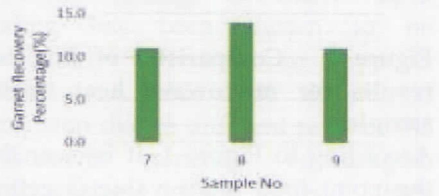

Figure 4 - Comparison of garnet recovery at 450 W energy level

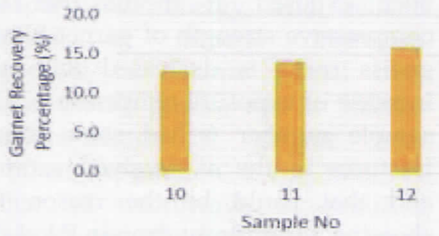

Figure 5 - Comparison of garnet recovery at 600 W energy level

It can be seen that most of the energy levels show higher recovery in 4 minutes exposure time, than other two exposure times in the same group. Test results are strictly correlating with the results of point load strength test. It can clearly assume that, strength reduction can yield higher recovery. The reason for this could be the micro fracture propagation within the rock grains and it broke the inter molecular bonds between garnet mineral and gneiss.

3.2.1 Full Comparison of Recovery

Figure 6 shows the full comparison of results which we have got throughout this microwave pre-heating process.

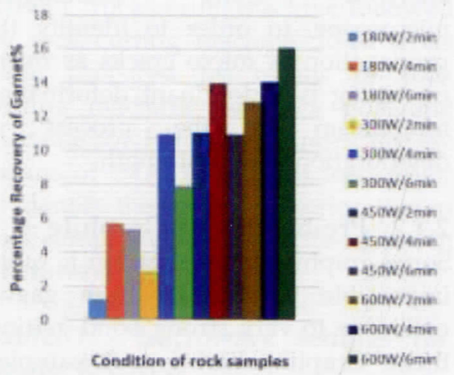

Figure 6 - Overall Garnet Recovery

It can be seen that, recovery was higher with the temperature obviously. However using higher energy (temperature) could be economically advisable, therefore it is important to select an energy (temperature) range with more energy efficient and economically viable in order to use microwave pre-heating technology in industrial scale. Then, it is enough to heat the samples up to 4 minutes and there is no need to heat up to 6 minutes which consume more energy and waste more as well. It would also be economically feasible using microwave in qualitative production of garnet. Another outcome of this study as seen from Figure 6 in the 300W/6 min to 600W/2 min could be effective for the industrial-scale applications. Although that would be a better range further it can reduce up to 450W/2 min and 450W/4 min as the most preferable energy intervals by looking the figures of recovery. A 450W/4 min sample could be used as the reference sample for all the calculations in this study.

3.3 Thin Section Analysis

According to Figure 7 there is no any lager fracture propagation throughout the grain structure of thin section prepared with rock sample exposed to 300W energy level within 2 minutes, comparing with other samples in its own group.

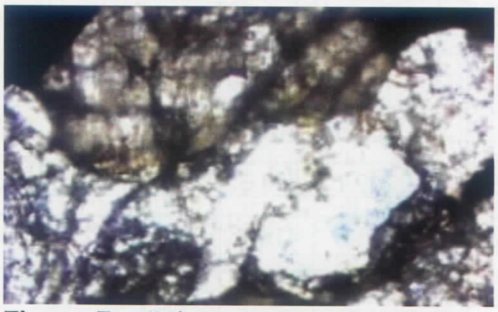

Figure 7 - Microscopic view of the thin section prepared from heated in microwave in 300 W within 2 minutes

Higher micro fracture intensity was observed in the thin section prepared from rock samples pre-heated in microwave oven at 300W/4 min and quenched as shown in Figure 8.

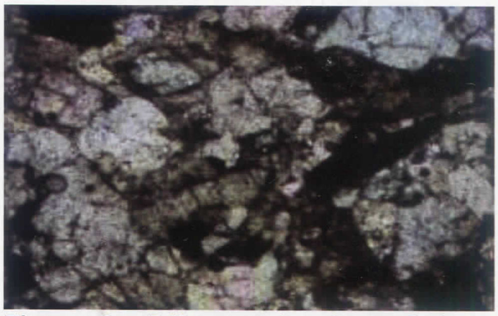

Figure 8 - Microscopic view of the thin section prepared from heated in microwave in 300 W within 4 minutes

However, comparing with the 300W/4min sample, fracture propagation is comparatively less than in 300W/6 min remarkably. It can be clearly seen in thin section analysis.

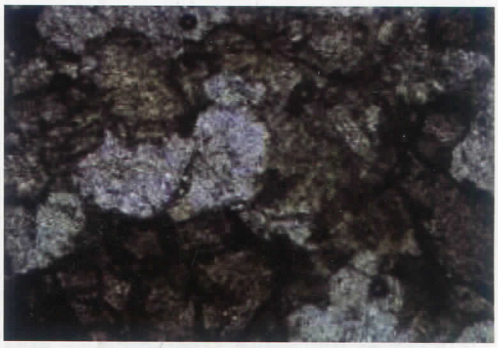

Figure 9 - Microscopic view of the thin section prepared from heated in microwave in 300 W within 6 minutes

According to the above analysis it is clearly assumed that it is enough to heat only up to 4 minutes in every energy level and it would be more economically viable than heating up to 6 minutes.

3.4 Importance of Producing Garnet Locally

According to the United States Geological Societies' Annual review, Sri Lanka in not a major producer of garnet in world, except as a gem producer[4]. However world's garnet requirement is nearly 440,000W at present and it would be expected to grow 3-5% within next 5 years [5]. Garnet is used as a blasting media for cleaning drill pipes in Petroleum Industry, for blast cleaning and finishing[6] of metal surfaces and for use in waterjet cutting. Hence, it is important to produce garnet in Sri Lanka in industrial scale.

3.5 Quantitative Analysis of Garnet Recovery from Microwave Oven followed by Quenching

3.5.1 Cost Estimation

Since Sri Lanka is not a Garnet producer, importing Garnet would be necessary for starting a local garnet industry.

When importing, it costs nearly Rs.36,174 per ton after adding local tax on revenue (0.5%) which is imposed by Mines and Minerals Act (Act no 66 of 2009) and transportation costs for per ton delivery from port to factory (assumed factory situated within 20km of radius from the port).

When producing locally, costs for energy is the major cost category and it can be calculated as per Table 3 (All the costs were based on the operations which have to be done according to our scientific study)

Table 3 - Total energy consumption in lab scale (microwave + jaw crusher + ball mill + sieving+ wilfly table energies)

Sample No	Total Energy (Wh)	Initial weight (g)	Recovery weight (g)	Total energy/ Recovery(Wh/g)	Total energy/Initial weight (Wh/g)
1	136.7	401.5	26.5	5.16	0.34
2	143.5	395	18	7.97	0.36
3	153.7	377.5	14.5	10.60	0.40
4	146.5	356.2	7	20.93	0.41
5	157.3	401.5	33	4.77	0.39
6	169.1	394.5	22.5	7.52	0.42
7	153.8	416	32	4.81	0.36
8	176.5	415	37.5	4.71	0.42
9	196.9	441	38.6	5.10	0.44
10	162.4	423	38.6	4.20	0.38
11	192.3	439	46.5	4.13	0.43
12	220.9	453.5	59.3	3.73	0.48

Table 4 - Total energy consumption per ton of Garnet

Sample No	Total energy/ Recovery(Wh/g)	Total energy for a ton (KWh)	Total energy/Initial weight (Wh/g)	Total energy for a ton (KWh)
1	5.16	5160	0.34	340.47
2	7.97	7970	0.36	363.29
3	10.60	10600	0.41	407.15
4	20.93	20930	0.41	411.29
5	4.77	4770	0.39	391.78
6	7.52	7520	0.43	428.64
7	4.81	4810	0.37	369.71
8	4.71	4710	0.43	425.30
9	5.10	5100	0.45	446.49
10	4.20	4200	0.38	383.92
11	4.13	4130	0.44	438.04
12	3.73	3730	0.49	487.10

3.5.2 Energy Consumption Calculation

All of the energies which may use in industrial scale would be electricity. Therefore when perform an energy calculation it should be based on electricity. All of the calculations were done according to the standards of Ceylon Electricity Board.

Table 5 - Comparison of Electricity bill with Recovery of Garnet

Sample No	Electricity Cost (Rs.)	Recovery weight (g)	Electricity charge per gram of recover (Rs/g)
1	10744.79	26.5	405.46
2	12311.6	18	683.98
3	13475.34	14.5	929.33
4	13391.37	7	1913.05
5	13053.65	33	395.57
6	14713.38	22.5	653.93
7	12060.54	32	376.89
8	14562.05	37.5	388.32
9	15515.33	38.63	401.64
10	12700.08	38.63	328.76
11	15135.35	46.55	325.14
12	17343	59.3	292.46

Major variations of energy against the recovery can be clearly seen by studying the Figure 9.

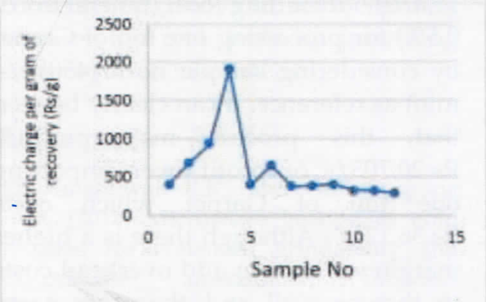

Figure 9 - Comparison of Electricity bill with Recovery

According to above variation we can strictly refuse the sample number 4 which was heated for 2 minutes at 300 W energy level. There are possible samples we could obtained as reasonable for producing garnet sand: however sample no's 7,8,10 and 12; but comparing with qualitative analysis we can neglect sample no 12 directly. Also sample no 10 is not much compatible with qualitative analysis results. Then, we can select sample no's 7 and 8. However, most preferable would be sample no 8 according to qualitative analysis. However still sample no 7 also laid in preferable area in graph given in Figure 9.

3.5.2 Labour Cost Calculation

Labour is the next major cost other than the electricity hence to be calculated accordingly energy calculation has proved that sample no8 which is 400W/ 4 min would be the most preferable setting over industrial scale production, then labour should be produced accordingly. Here it is considered one labour would be sufficient for whole production (according to our practices). The labours should be preferable with working for 8 hours per day for Rs.1500/- then it comes to Rs.172/- for recovering 01 ton of Garnet sand.

Then the overall cost would be Rs. 15,470/- (including local mineral tax of 0.5%) for processing one ton of Garnet by considering sample no 8 (450W/4 min) as reference. It can clearly be seen that, this process may produce Rs.20,703/- of profit over importing one ton of Garnet which costs Rs.36,174/- Although there is a higher margin we have to add overhead costs to that as well and there are some practical problems as well such as we want to develop a microwave chamber in industrial scale because there is no such a technology in the world in industrial scale and we have to buy all the equipment as this is a new industry to Sri Lanka. We have to find buyers in international market as well as in local market and the capital is much higher which have to use at the beginning of the project. Therefore these kind of matters would affect to this gross profit. However there could be a higher probability to success this project even in industrial scale even with a low profit margin.

3.6 Garnet Pre-heating

3.6.1 Thin Section Analysis

Following figures show the polarized microscopic view of the rock samples of the microwave pre-heated and quenched and the normal sample.

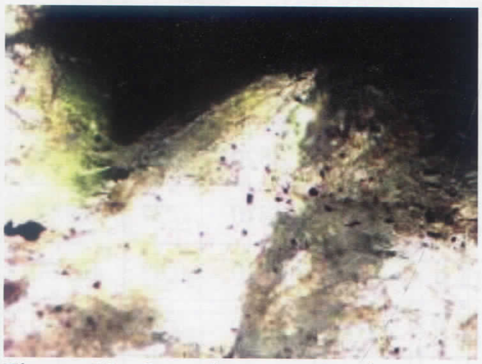

Figure 10 - Sample as received

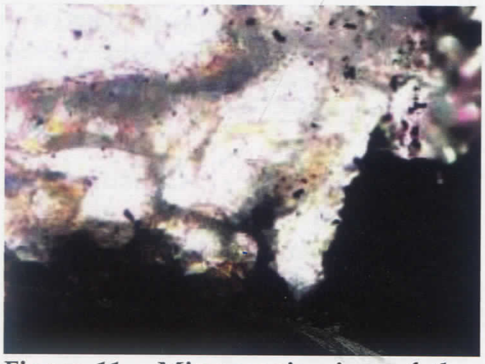

Figure 11 - Microscopic view of the thin section prepared from heated in microwave in 300 W within 3 minutes

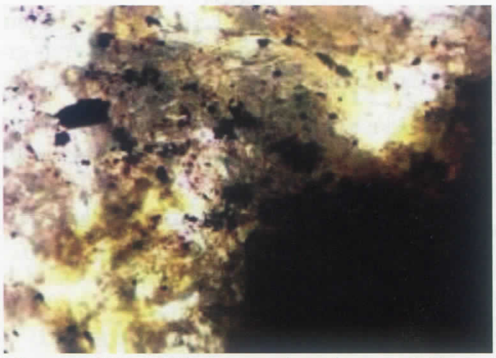

Figure 12 - Microscopic view of the thin section prepared from heated in microwave in 450 W within 3 minutes

According to the figures 10-12 we can clearly see decomposing of the mineral boundary is getting higher with the temperature. Then it is clear that microwave preheating can enhance the recovery of graphite.

4. Conclusions

- Microwave preheating and quenching process gives more effective compressive strength deterioration (compressive strength reduction).
- Microwave preheating process reduce crushing and grinding costs in metal industry.
- There is a remarkable result obtained at the middle range of exposure time (4 min) rather than highest range of exposure time. (6 min) which is significant strength deterioration.
- Results of the recovery closely correlates to the strength deterioration.
- Sri Lanka is not a garnet producer currently, even though the garnet plays significant role in the world economy. Hence, still there is a potential for Sri Lanka to join with the Garnet world market.
- As per the results of this study, producing garnet by processing of garnet biotite gneiss would be more economically feasible by means of microwave technology
- Producing garnet locally in Sri Lanka would be more economically feasible than importing garnet from world market for local industrial applications.
- Microwave pre-heating can also successfully be used in recovery of graphite bonding hard with gangue rock which cannot be recovered by general graphite recovery techniques.

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