Applicability of Pre-heating Techniques for Recovery of Garnet from Garnet Biotite Gneiss

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Abstract

In mineral processing industry, the highest energy is consumed by crushing and grinding operations. However, if we can initiate micro cracks in the hard rock pieces in advance, we should be able to reduce the crushing energy and liberate useful minerals economically. Various pre-heating techniques have been tried by the scientists around the world to liberate minerals from rocks. In this investigation, pre-heating techniques were used to liberate Garnet from Garnet Biotite Gneiss. The market price of Garnet varies with the particle size. Hence, the samples were crushed and sized into industry needed three size fractions: (+250-850) µm, (+180-250) µm and (-180) µm. Afterwards, by means of Wilfley Table, Garnet was separated from rocks. Final Garnet recovery percentage was recorded for different temperatures. Furthermore, energy calculation was done for each sample to get an idea about the power consumption. It was observed that the crushing strength decreases with the temperature increment and it has been proven by identifying propagation of micro cracks in thin sections, prepared from rock samples pre-heat treated in Muffle Furnace and Microwave Oven. The analysis reveals that the pre-heat treated and quenched samples give higher Garnet recovery than Garnet recovered from as-received samples of Garnet rich Biotite Gneiss.

Keywords: Garnet recovery, Micro cracks, Pre-heat treatment, Thin sections

1. Introduction

The current demand for minerals and metals is being increased. However, it is proved and stated that the impact of mining and mineral processing operations has to be reduced in order to meet the future sustainability requirements. Mining operations may bring down their impact with the evolving of science and technology. Out of most of the techniques used to liberate minerals from rocks, pre-heating techniques including Microwave heating techniques has shown promising results to improve the efficiency of various mineral processing unit operations including: refractory gold ore treatment, grindability and liberation [1], grinding of Granite rocks [2], leaching of chalcopyrite & tetrahedrite, and coal grinding [3]. The main objective of this research is to apply pre-heating techniques and liberate Garnet from a taken rock sample and analyze the feasibility for industrial use of the method. Minerals have different heat absorption characteristics, and thus selective heating of individual minerals in a rock matrix can be achieved. In some rocks, differential heating of constituent minerals generates thermal stresses, which cause the mineral particles to fracture. Fracturing may occur along grain boundaries, leading to complete or partial physical separation of the components which in turn improves grindability and mineral recovery [1]. However, grindability of pre-heated rocks are influenced by the specific mineral species present, particle size of the specific mineral and the degree of dissemination [4].

It is known that mechanical size reduction in a mineral processing is extremely energy intensive [2]. Pre-heating has the ability to alter the properties of an ore to reduce the mechanical strength and improve liberation of minerals thus reducing the energy required for size reduction [1]. Hence, we adopt Muffle Furnace and Microwave pre-heating methods to liberate Garnet from Garnet Biotite Gneiss in this investigation.

Industrial price of Garnet varies with the particle size such that larger the particle size, higher will be the market price. In this study, we have focused on three size ranges of Garnet which are generally needed by different industries; (+250-850) µm, (+180-250) µm and (-180) µm. Garnet belongs to these size fractions has various industrial uses such as water jet cutting, abrasive blasting, water filtration and abrasive powders are some of them. Hence, the Garnet we recover from the rock samples can be categorized into three particle size ranges based on its each industrial use. Thin section analysis is a mandatory requirement for the identification of micro cracks, and this phenomenon has been used in this study to contrast the intensity of propagation of micro cracks in the rock samples, pre-heat treated in Muffle Furnace and Microwave.

2. Methodology

Garnet rich Biotite Gneiss rock samples were collected from the quarry sites at Galpatha [6°38'07.8"N 80°01'35.2"E] and Meepe [6°51'35.6"N 80°06'04.5"E], which belong to Metal Mix (Pvt) Ltd.

2.1 Test Procedures

Rock cores, of diameter 55mm were prepared from the samples collected from each quarry site by means of ‘HILTY’ rock coring machine followed by rock cutting machine. Garnet was recovered from as-received rock samples from both of the quarries. Rock discs 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 Muffle Furnace and pre-heated in Muffle Furnace followed by quenching.

For Garnet extraction process, rock cores having (height : diameter) ≥ 2 were prepared for testing. Then, the rock cores were pre-heated in the Muffle Furnace and quenched, crushed by Jaw Crusher, ground by Ball Mill, and finally from sieved samples Garnet was extracted using Wilfley Table. Garnet was also recovered from the as-received (non-heat treated) rock samples, in order to compare the Garnet recovery values.

Point Load Strength test was carried out for rocks pre-heated in Microwave and quenched, and Garnet also recovered from another set of rock cores pre-heated in Microwave followed by quenching. A "Samsung" Microwave Oven of 2.45 GHz and maximum power output of 800 W was used for this study.

Some thin sections were prepared from rock samples which were pre-heated in Muffle Furnace and quenched, and from rock samples pre-heated in Microwave and quenched separately. Then, thin sections were analyzed through 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 [5].

3. Results and Discussion

3.1Garnet recovery from as-received rock samples

As seen in Figure 1, more Garnet rich Biotite Gneiss rocks are found at Meepe site.

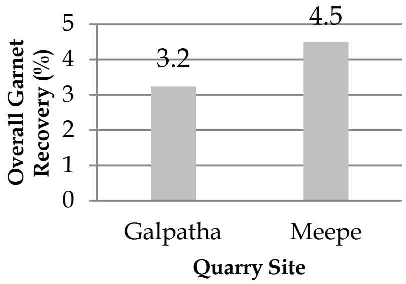

Figure 1 - Comparison of Garnet recovery from samples taken from two quarry sites

3.2 Variation of Point Load Index of rocks due to heat treatments

According to Figure 2, it is clear that the corrected point load index (C.P.I.) value is decreased gradually in both cases with increase of temperature of the rock specimens that they have been exposed. The compressive strength of Garnet Biotite Gneiss should also be decreased with the increase of exposed heat accordingly.

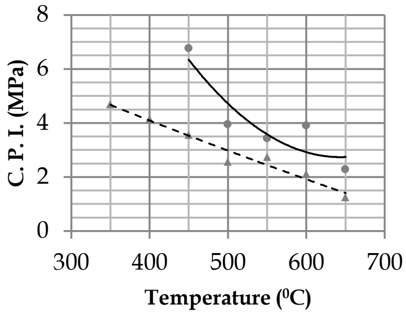

Figure 2 - Deterioration of strength of rocks due to Muffle Furnace assisted pre-heating

——— Muffle Furnace pre-heated
- - - - - Muffle Furnace pre-heated and quenched

More importantly, it can be seen that the point load index values of Muffle Furnace pre-heat treated, followed by quenched rock specimens are lesser than that of only heat treated rock specimens which implies that the compressive strength of rock is significantly reduced when it is heat treated in Muffle Furnace followed by quenching than only heat treating at the same temperature conditions. Therefore, it is true that quenching process of rocks is much effective for formation of cracks, and thereby to reduce rock strength than just heat treating. As quenching is a low cost process, it was adopted in this investigation.

3.3 Garnet recovery from rock samples pre-heated in Muffle Furnace and quenched

According to Figure 3, it can be seen that the highest Garnet recovery can be obtained using (-850+250) µm fraction for all the temperatures, where as for (-180) µm fraction the Garnet recovery is lowest. Garnet recovery within the particle size range of (-250+180) µm is slightly lower than that of (-850+250) µm, however, significantly greater than (-180) µm size fraction, except for the sample heat treated at 350°C. For the sample treated up to 350°C, the Garnet recovery percentages for all the fractions have decreased and especially the recovery of (-250+180) µm fraction has been decreased even below the room temperature recovery value. Hence, it can be considered as a low grade sample. Therefore, (-850+180) µm fraction is consisted of significant amount of Garnet and (-180) µm fraction has very less amount of Garnet.

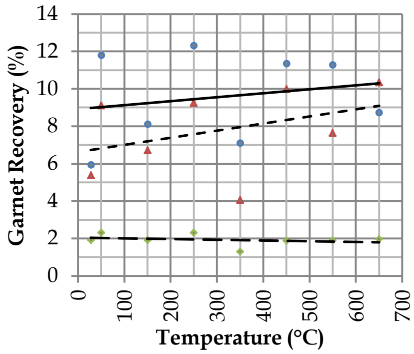

Figure 3 - Size classification of Garnet recovery with temperature

– – – – (-180)µm fraction

- - - - - - (+180-250)µm fraction

——— (+250-850)µm fraction

Further, it is clear that both (-850+250) µm and (-250+180) µm fractions exhibit an increasing trend of Garnet recovery with the increasing temperature, whereas for (-180) µm size fraction, Garnet recovery decreases with the increasing temperature.

According to Figure 4, it is clear that the overall Garnet recovery shows an increasing trend with the increasing temperature. The overall Garnet recoveries from heat treated rock samples are greater than that from non-heat treated rock samples.

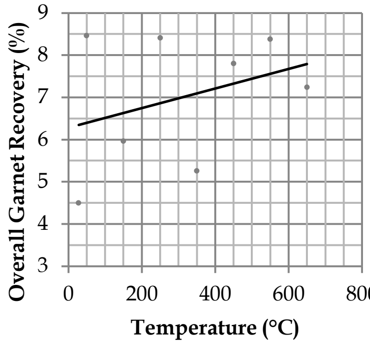

Figure 4 - Overall Garnet Recovery variation with temperature

Therefore, the Garnet recovery is more effective from heat treated rock samples than from as-received rock samples tested under Room Temperature (RT) conditions.

3.4 Garnet recovery from rock samples pre-heated in Muffle Furnace and quenched and comparison with Garnet recovery from As-received rock samples

Garnet recoveries from rock samples pre-heated in Muffle Furnace at 50°C, 150°C and 250°C are shown in Figures 5-7 respectively.

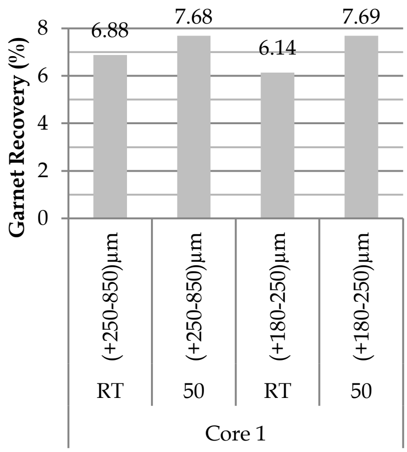

Figure 5 - Garnet Recovery from samples heated upto 50°C and quenched

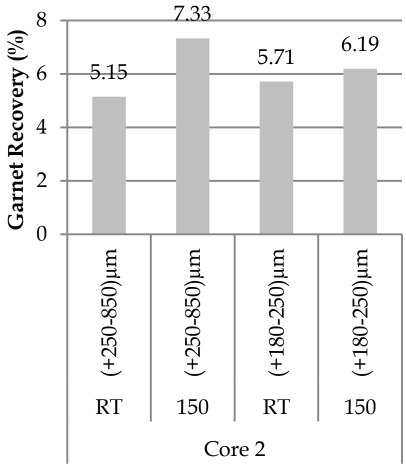

Figure 6 - Garnet Recovery from samples heated upto 150°C and quenched

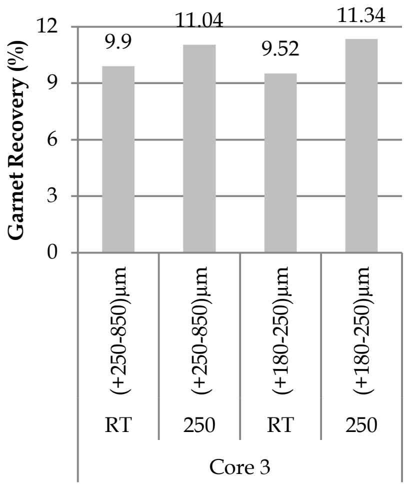

Figure 7 - Garnet Recovery from samples heated upto 250°C and quenched

It can clearly be seen that Garnet recovery percentage from Muffle Furnace pre-heat treated and quenched rock samples are always greater than the Garnet recovery percentage from as-received rock samples, for each temperature condition. Therefore, it is true that the Garnet recovery has been increased due to the effect of Muffle Furnace pre-heating and quenching process.

3.5 Point Load Index for rock samples pre-heated in Microwave and quenched

According to Figure 8, it is clear that the rock specimens pre-heat treated for three minutes in the Microwave show lower Point Load Index values where as the rock specimens pre-heat treated for one minute in the Microwave show higher Point Load Index values for each 180 W, 300 W and 450 W power levels.

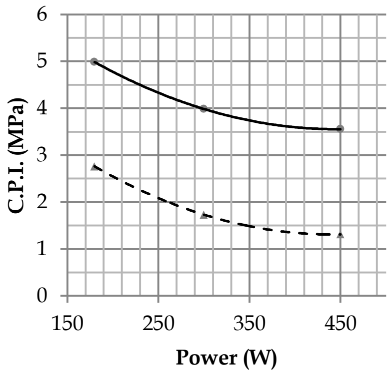

Figure 8 - Rock strength deterioration of Microwave pre-heated and quenched rock samples

——— 1 minute

- - - - - 3 minutes

Therefore, the specimens exposed for higher time duration in the Microwave at a particular power level shows greater compressive strength reduction, than that of samples treated for lower time duration at the same power level.

3.6 Garnet recovery from rock samples pre-heated in Microwave and quenched

According to Figures 9-11, it can be seen that the overall Garnet recovery has been increased in six minutes pre-heat treated samples than two minutes pre-heat treated samples for each exposed power level; 180 W, 300 W and 450 W.

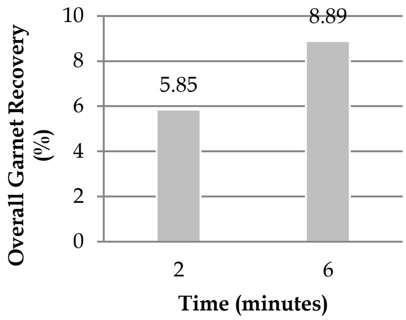

Figure 9 - Overall Garnet Recovery from samples pre-heated in Microwave at 180W

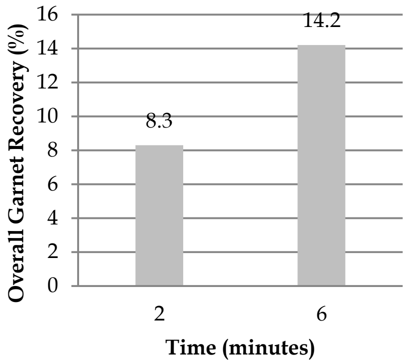

Figure 10 - Overall Garnet Recovery from samples pre-heated in Microwave at 300W

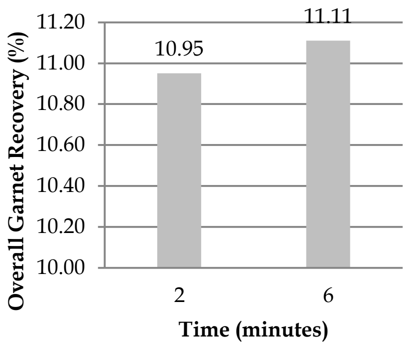

Figure 11 - Overall Garnet Recovery from samples pre-heated in Microwave at 450W

Therefore, it is true that the Garnet recovery can be increased with higher exposure time in the Microwave for each power level.

3.7 Summary of Garnet recovery by Microwave assisted pre-heating

Figure 12 shows the comparison of overall Garnet recovery from rock samples pre-heated in Microwave and quenched, with overall Garnet recovery from as-received samples.

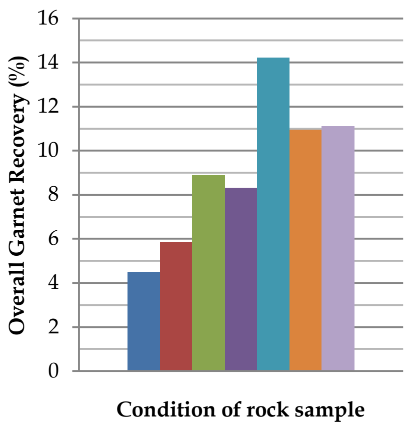

Figure 12 - Overall Garnet Recovery Comparison

It can be seen that all the overall Garnet recovery values from rock samples pre-heat treated in Microwave and quenched are greater than the overall Garnet recovery value from as-received rock samples. More importantly, the highest overall Garnet recovery which is 14.2% was obtained from 300W×6mins exposure condition. However, for 450W×6mins exposure condition which provides higher energy than 300W×6mins has given lower overall Garnet recovery than the 300W×6mins exposure condition. That means, by providing 450W×6mins is a waste of energy while recovering lower Garnet percentage. Hence, the optimum exposure condition in the Microwave for higher overall Garnet recovery is 300W×6mins.

3.8 Comparison of energy consumption for Garnet recovery

Table 1 shows the energy consumption for the production of one ton of Garnet from pre-heat treated rock samples by means of Muffle Furnace and the Microwave.

Table 1 - Comparison of energy consumption for Garnet recovery

Sample No.	Energy for pre-heating using Muffle Furnace (GJ/t)	Energy for pre-heating using Microwave (GJ/t)
S1	41.1	1.2
S2	118.8	2.3
S3	134.3	1.5

It can clearly be seen that the energy consumption for the production of one ton of Garnet by using Muffle Furnace pre-heating technique is significantly higher than that of for the production of one ton of Garnet by using Microwave pre-heating technique. Therefore, in the sense of pre-heating the Microwave assisted pre-heating technique is much more economically feasible than the Muffle Furnace pre-heating technique.

3.9 Thin Section Analysis

According to Figure 13, it is clear that no any visible cracks appear in the thin section prepared from the as-received (non-heated) rock sample.

Figure 13 - Microscopic view of the thin section prepared from as-received rock sample (Magnification : 10X)

A higher micro crack intensity was observed in the thin section prepared from rock samples pre-heated in Muffle Furnace at 650°C and quenched as shown in Figure 14, whereas thin sections prepared from lower temperature heated showed fairly less amount of micro cracks.

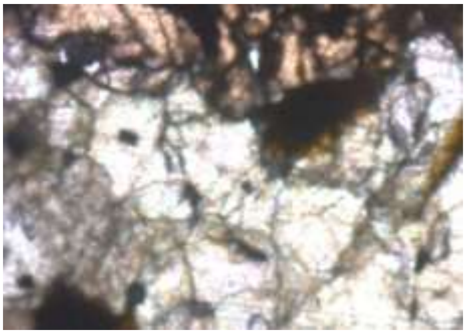

Figure 14 - Microscopic view of the thin section prepared from 650°C heated in Muffle Furnace and quenched rock sample (Magnification : 10X)

A much higher micro crack intensity was observed in the thin section prepared from rock samples pre-heated in Microwave for (450W×6mins) and quenched as shown in Figure 15, whereas thin sections prepared from samples with lower exposure conditions showed fairly significant amount of micro cracks than the Muffle Furnace heat treated and quenched rock samples.

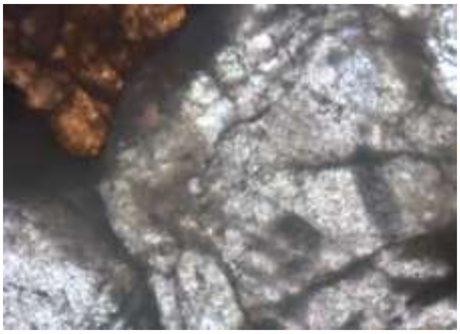

Figure 15 - Microscopic view of the thin section prepared from (450W×6mins) heated in Microwave and quenched rock sample (Magnification : 10X)

4. Conclusions

- Heat treating followed by quenching effectively deteriorates the strength of rocks than that of only heat treated rocks.
- The propagation of micro cracks in the samples which are heated in Muffle Furnace at low temperatures and quenched is negligible. However, for higher temperatures it is significant.
- The propagation of micro cracks in the Microwave heat treated and quenched rocks is highly significant than the micro crack propagation in the Muffle Furnace heat treated and quenched rocks.
- Garnet recovery can be increased when the rocks are pre-heated in the Muffle Furnace and quenched.
- Garnet recovery can be increased from the rocks pre-heated in the Microwave and quenched with the increase of power level and the exposure time duration.
- All the pre-heat treated and quenched rocks give higher Garnet recovery than that from the as-received samples.
- Garnet recovery with the use of Muffle Furnace pre-heating technique is uneconomical, whereas Microwave pre-heating technique gives more Garnet recovery by consuming less energy. Therefore, it can be considered as an economical pre-heating technique for recovery of Garnet from Garnet Biotite Gneiss.

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