Determination of magnetite grain-size using the Hopkinson effect - examples from Botswana rocks

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Abstract

The Hopkinson effect is the increase of magnetic susceptibility with temperature from near room temperature to near the Curie point. Although this effect has been known for more than a century, it has not been effectively utilised as an analysing tool in palaeo, rock and environmental magnetic studies. This is partly due to the poor understanding of the influence of magnetite (Fe_3O_4) grain parameters on the Hopkinson effect. In an attempt to study the effects of grain size on the Hopkinson effect, magnetite samples with well-defined grain sizes have been used. It was found that in general, magnetic susceptibility enhancement factor (SEF) obtained by heating the sample in a non-oxidising environment, increase with decreasing grain size. The relation of SEF to grain size is linear when plotted on a log-log scale. This relation has been used to infer grain sizes (hence magnetic domains) for some selected Botswana rocks. The inferred magnetic domains are consistent with independent predictions from hysteresis measurements for the same samples.

Keywords = magnetite, magnetic susceptibility, magnetic domains, Hopkinson effect, Botswana rocks.

Introduction

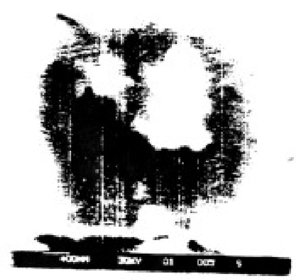
Hopkinson first reported the increase in magnetic susceptibility with temperature till near the Curie point in 1889 for the element iron (Collinson, 1983). This phenomenon (the so-called Hopkinson effect) has also been observed in other minerals e.g. magnetite (Radhakrishnamurty and Likhite, 1970). Previous attempts at utilising the Hopkinson effect in rock magnetic studies include the determination of magnetic domains of magnetite (Radhakrishnamurty and Likhite, 1970 & Dunlop, 1974). Radhakrishnamurty and Likhite (1970) observed a gradual increase followed by a gradual decrease in magnetic susceptibility with increasing temperature for basalt samples. They interpreted this observation as being typical for single domain magnetite grains. In contrast, Dunlop (1974) observed a sharp increase in magnetic susceptibility near the Curie point using single domain and smallmultidomain grains of magnetite. In an attempt to systematically determine the effect of grain size of magnetite on the Hopkinson parameter SEF, samples with well-defined grain sizes have been used in this study.

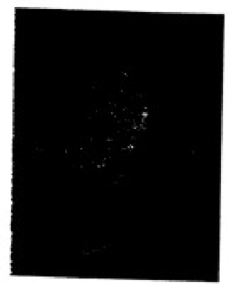
Sample description

(a) Artificially produced magnetite particles.

SEM (scanning electron microscope) pictures of magnetite samples with well-defined grain sizes used in this study are shown in Figure 1. The method of production of the samples and their characterisation as magnetite have be described elsewhere (King and Williams, 2000 and King, 1996). Such characterisation included XRD (X-ray diffraction) the low temperature magnetic transition (the so-called Verwey transition, Verwey, 1939) that occur near 120 K for stoichiometric magnetite, and the Curie point.


(a)


(b)


(c)


(d)

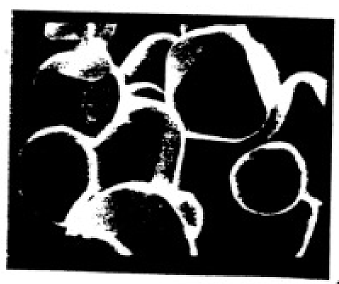

(e)

Fig. 1. SEM pictures for the following magnetite samples: (a) JG0.1 = 0.1 μm, (b) Gei0.2 = 0.2 μm, (c) JH0.5 = 0.5 μm, (d) JH1 = 1 μm and (e) JH40 = 40 μm.

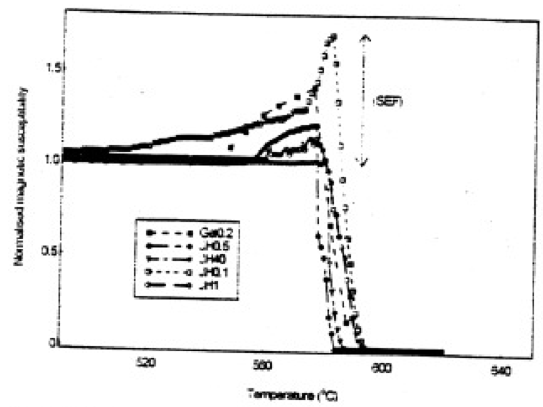


Fig 4 (b) which is a zoomed section of Fig 4 (a). An increase in SEF with descreasing grain size is evident.

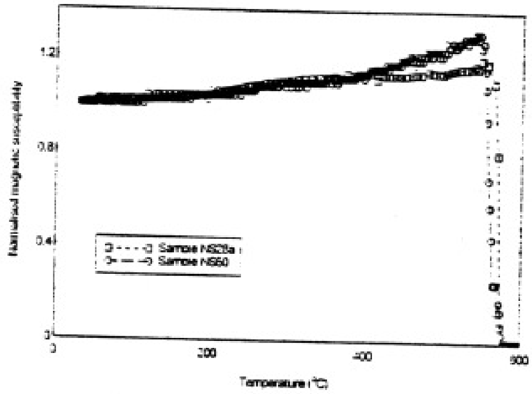


Figure 5 Magnetic susceptibility normalised to room the temperature value as a function of temperature for samples NS28a and NS60.

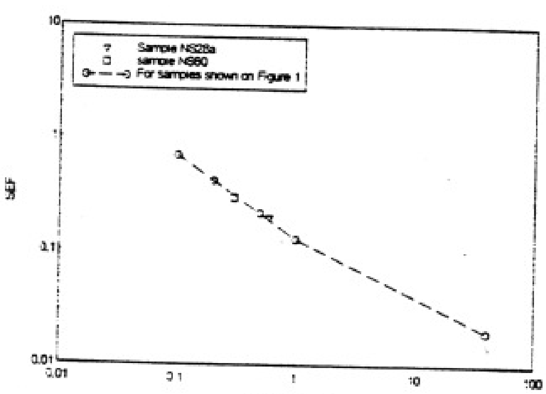


Figure 6. Plot of susceptibility enhancement factor (SEF) as a function of grain size on a log-log scale is to a good approximation, linear. Values of SEF for samples NS60 and NS28a was used in this figure to determine their grain size

Magnetic hysteresis loops

As a check on the magnetite domain inferred using the Hopkinson parameter SEF for samples NS28a and NS60, magnetic hysteresis loops for the two samples were obtained (Figure 7). The Physics Department (UB) Alternating Gradient Magnetometer (AGM-micromag) equipment from Princeton Measurements was used to get the hysteresis loops for these samples. It can be seen from Figure 7 that these samples readily saturates in fields of about 250 mT. This is typical magnetite behaviour (King, 1996). From Figure 7 (inset), it can be seen that the coercivities for samples NS28a and NS60 are 5.5 mT and 10 mT respectively. These coercivity values are typical for pseudo-single domain magnetite. It is clear that the magnetic domain prediction from hysteresis loop parameters concurs with prediction from the Hopkinson parameter SEF for these two samples.

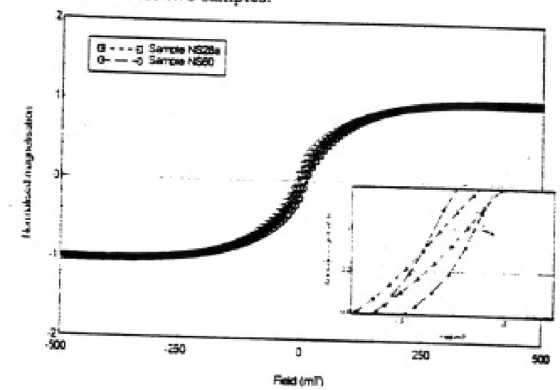


Figure 7: Hysteresis loops for the two samples NS28a and NS60. Inset is a zoomed section of the hysteresis near the axes of origin. From this zoomed section, the coercivities can be seen to be 10 mT for NS60 and 5.5 mT for NS28a.

It is emphasised here the application of the Hopkinson parameter SEF to grain size determination works well if samples have been heated in a non-oxidising environment. In oxidising environment (e.g. heating in air), chemical alteration can occur and hence the method may not work very well. The gradual increase and gradual decrease of magnetic susceptibility observed in the study of basalts by Radhakrishnamurty and Likhite (1970) are most likely a result of chemical alteration.

Conclusions

Using magnetite samples with well-defined grain sizes, it was found that in general, magnetic susceptibility enhancement factor (SEF) obtained by heating samples in a non-oxidising environment, increase with decreasing grain size. The relation of SEF to grain size is linear when plotted on a log-log scale. This relation was used to infer grain sizes (hence magnetic domains) for some selected rocks from Botswana. The inferred magnetic domains are consistent with independent predictions from hysteresis measurements for the same samples. The Hopkison parameter (SEF) method of determining magnetic domain is more appealing than other methods such as hysteresis loop parameters because it includes the determination of the Curie point at the same time.

Sample name	Average grain size (μm)	SEF
JGO.1	0.1	0.70
Ge10.2	0.2	0.42
JH0.5	0.5	0.22
JH1	1	0.13
JH40	40	0.02
NS60	*0.3*	0.30
NS28a	*0.6*	0.02

Table 1. Susceptibility enchantment factor (SEF) for magnetite samples with various grain samples with various grain sizes. Except for samples NS60 and NS28a whose average grain sizes were inferred from the plot of figure 6, the average grain sizes of the samples were determined from SEM pictures.

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