The Characterisation of Atmospheric Particulate Pollution around Airports

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Abstract

There are a wide range of sources of atmospheric particulate matter at airports. The ability to identify characteristic particulate 'fingerprints' which would allow source attribution has proved difficult. In the present study, we use environmental magnetic measurements to characterise and differentiate dusts from commercial aircraft engines and brakes. The results suggest that the analysis of 'magnetic fingerprints' could be applied more widely to particulate source apportionment in the airport environment.

1. Introduction

The global demand for air travel has increased exponentially during the last 50 years. International air passenger figures between 1960 and 2005 have, on average, increased by more than 8% year on year. This trend appears set to continue with a predicted rise of between 4.5 and 6% of passengers over the next 20 years (Stettler et al., 2011).

Alongside the increasing demand for air travel, concerns have been raised regarding the potential impact of atmospheric particulate matter (PM) emissions on health and the environment (Spassov et al., 2004; Saragnese et al., 2011; Stettler et al., 2011). The airport environment consists of a wide range of potential PM sources including aircraft (engines, brakes and tyres); vehicles; ground support equipment and buildings. In order to investigate the potential problems it is important to be able to isolate the individual emission sources. One approach would be to identify characteristic particulate 'fingerprints', which would facilitate source attribution. Whilst some studies have attempted to achieve this, predominantly through the use of geochemical analysis (Herndon et al., 2005; Amato et al., 2010) the identification of such 'fingerprints' remains elusive and has been identified as a research priority for the aviation industry (Webb et al., 2008; Wood et al., 2008).

Environmental magnetism is a non-destructive, inexpensive and relatively rapid technique involving the application of non-directional, rock magnetic measurements to a wide range of natural materials (Walden et al., 1999). These measurements can provide information about the type, grain size and concentration of magnetic minerals in the material. Magnetic minerals are produced and transformed by a range of environmental and anthropogenic processes (Oldfield, 1991). In previous studies relating to atmospheric PM, environmental magnetism has been used successfully as a technique for distinguishing between different emission types and PM sources in the environment. Hunt et al. (1984) found distinctive magnetic mineral contrasts between vehicle-derived and fly-ash particulates from an electricity generating power station. The vehicle emissions were dominated by ferrimagnetic (i.e. magnetite-type) minerals, whilst the fly-ash samples showed different magnetic behaviour consistent with a significant antiferromagnetic (i.e. haematite-type) content. The different combustion processes and fossil fuels give rise to particulate emissions of contrasting mineralogy and grain size.

Oldfield et al. (1985) and Hunt (1986) used magnetic mineralogy and grain size parameters measured on a range of atmospheric dust samples to distinguish particulates arising from fossil fuel combustion and other industrial processes and those derived from natural sources such as through soil erosion. Similarly, Lecoanet et al. (2003) applied the techniques to surface soils to identify and differentiate particulates deposited from sources including road traffic, airport and steelwork emissions. Other research has focused on the use of magnetic measurements to monitor the deposition of atmospheric particulate pollution on surface soils (e.g. Lu and Bai, 2006; Hu et al., 2007; Blundell et al., 2009). However, the interpretation of such data is often complicated by the 'in-situ' formation of magnetic minerals through weathering and pedogenic

processes. Increasingly, magnetic measurements are being applied to sinks of atmospheric particulates such as tree leaves and surface vegetation (including moss) and road surfaces (e.g. road dust) to provide quantification of atmospheric particulate sources and urban pollution (e.g. Matzka and Maher, 1999; Makholm and Mladenoff, 2005; Maher et al., 2008; Bucko et al., 2010).

This paper reports on the preliminary stages of a study to investigate the potential use of environmental magnetic measurements as a technique for discriminating between atmospheric PM from different emission sources in the airport environment and thus establishing distinctive 'magnetic fingerprints'.

2. Methodology

2.1 Sampling

Engine and brake dust samples were collected from a range of different jet aircraft at the British Airways (BA) engineering facility at London Heathrow Airport, UK between August 2010 and August 2012. The aircraft sampled included Boeing 747-436; 767-336; 777-236 and Airbus A319-131 and A320-232 (Table 1). Engine dust samples were obtained from various engine types (Table 1), collected from the mixer shroud surrounding the turbine blades, onto which exhaust emission particulates had impacted. Brake dust samples were collected from the wheel hubs of the aircraft. Bennett et al. (2011) suggest that samples collected from the undercarriage and wheel hubs would contain PM from a range of sources including tyres, brakes, runways and taxiways. However, BA engineers (pers. comm.) suggest that the concentration of sampling in the wheel hub area would largely restrict the sample to brake-derived material. Samples were obtained using a clean wooden spatula and/or small paint brush and transferred to clean, self-sealed polythene bags.

Table 1: Aircraft

Manufacturer	Type	Engine
Airbus	A319-131	V2522-A5
Airbus	A320-232	V2527-A5
Boeing	747-436	RB211-524G2-T-19
Boeing	767-336	RB211-524H-36
Boeing	777-236	RB211 Trent 895-A

2.2 Magnetic measurements

Samples were packed into 10ml plastic containers for measurements. Low-field magnetic susceptibility (χ) was measured at two frequencies (0.47 kHz and 4.7 kHz) using a Bartington Instruments (Witney, Oxon OX28 4GE, UK) MS2B sensor and meter. The values used here are low frequency mass-specific magnetic susceptibility (χ_{lf}). An anhysteretic remanent magnetisation (ARM) was induced in the samples using a peak alternating field (AF) of 100 mT and a direct current (DC) biasing field of 0.04 mT, provided by a Molspin Demagnetiser. The resultant remanence was measured using a Molspin magnetometer. The ARM was then recalculated as susceptibility of ARM (χARM) by normalising the ARM for the DC biasing field used. Isothermal remanent magnetisation (IRM) measurements were carried out using a Molspin pulse magnetiser and magnetometer. The IRM acquired in the initial forward field of 1 T is assumed to be equivalent to a Saturation Isothermal Remanent Magnetisation (SIRM). Reverse field ratios were determined by placing a previously saturated sample successively in reverse fields of increasing strength (-20 mT; -40 mT; -100 mT; -300 mT) and measuring the isothermal remanence at each stage. The data are expressed as a ratio IRM_{-xmT}/SIRM. Table 2 summarises the magnetic parameters used in this study.

Table 2: Magnetic parameters referred to in this study

Magnetic parameter	Interpretation
χARM/χ	Where there is little variation in magnetic mineral type, the ratio of these two parameters can be diagnostic of magnetic mineral grain size.
χARM /SIRM	The ratio of these two parameters is diagnostic of variations in magnetic mineral grain size in samples where the magnetic mineral type remains relatively constant (Units: 10^{-5} Am^{-1}).
IRM_{-xmT}	Reverse field ratios obtained by applying one or more reverse magnetic fields to a previously magnetically saturated sample. The loss of magnetisation at the selected reverse fields is expressed as a ratio of the SIRM and can be used to discriminate between ferrimagnetic and antiferromagnetic mineral types and/or magnetic mineral grain size.

3. Results

3.1 Magnetic properties

Table 2 summarises some of the results of the magnetic measurements completed on the engine and brake dust samples. The engine dusts are characterised by higher χARM/χ and χARM /SIRM ratios than those for the brake dusts. Both ratios show a significant difference between the sample sets at the p = 0.05 rejection level using the Mann-Whitney U statistic. The higher χARM/χ and χARM /SIRM ratios of the engine dusts are indicative of finer ferrimagnetic mineral grain sizes.

Table 3: Summary of magnetic parameters of engine and brake dusts.

Magnetic parameters		Brakes	Engines
χARM/χ	Range	9.90 – 29.73	36.02 – 68.77
	Mean ± SD	19.72 ± 5.2	53.42 ± 9.53
χARM /SIRM	Range	87.92 – 152.16	166.7 – 331.8
	Mean ± SD	122.57 ± 17.44	260.8 ± 50.1
IRM_{-20mT}	Range	0.48 – 0.65	0.60 – 0.80
	Mean ± SD	0.58 ± 0.05	0.70 ± 0.02
IRm_{-300mT}	Range	-0.98 - -0.95	-0.93 - -0.88
	Mean ± SD	-0.97 ± 0.01	-0.90 ± 0.02

The contrast in the magnetic mineral characteristics of the engine-derived and brake-derived particulates is further illustrated in Figure 1, which plots IRM_{-20mT}/SIRM versus IRM_{-300mT}/SIRM for both sets of samples. Whilst there is only a slight variation in the range of the lower reverse field ratios (IRM_{-20mT}/SIRM), the higher reverse field ratio (IRM_{-300mT}/SIRM) discriminates between the two samples more effectively. The engine dust samples have significantly less negative IRM_{-300mT}/SIRM ratios, suggestive of a much higher antiferromagnetic component, than the brake dusts with more negative higher reverse field ratios.

Cluster analysis was used to classify all the samples into groups using the four magnetic parameters presented here. An agglomerative method was applied to all the data, normalised to eliminate differences in magnitude between the variables. The analysis classified the

samples into two major groups, one group containing all the engine dust samples and the other group including all the brake dust samples.

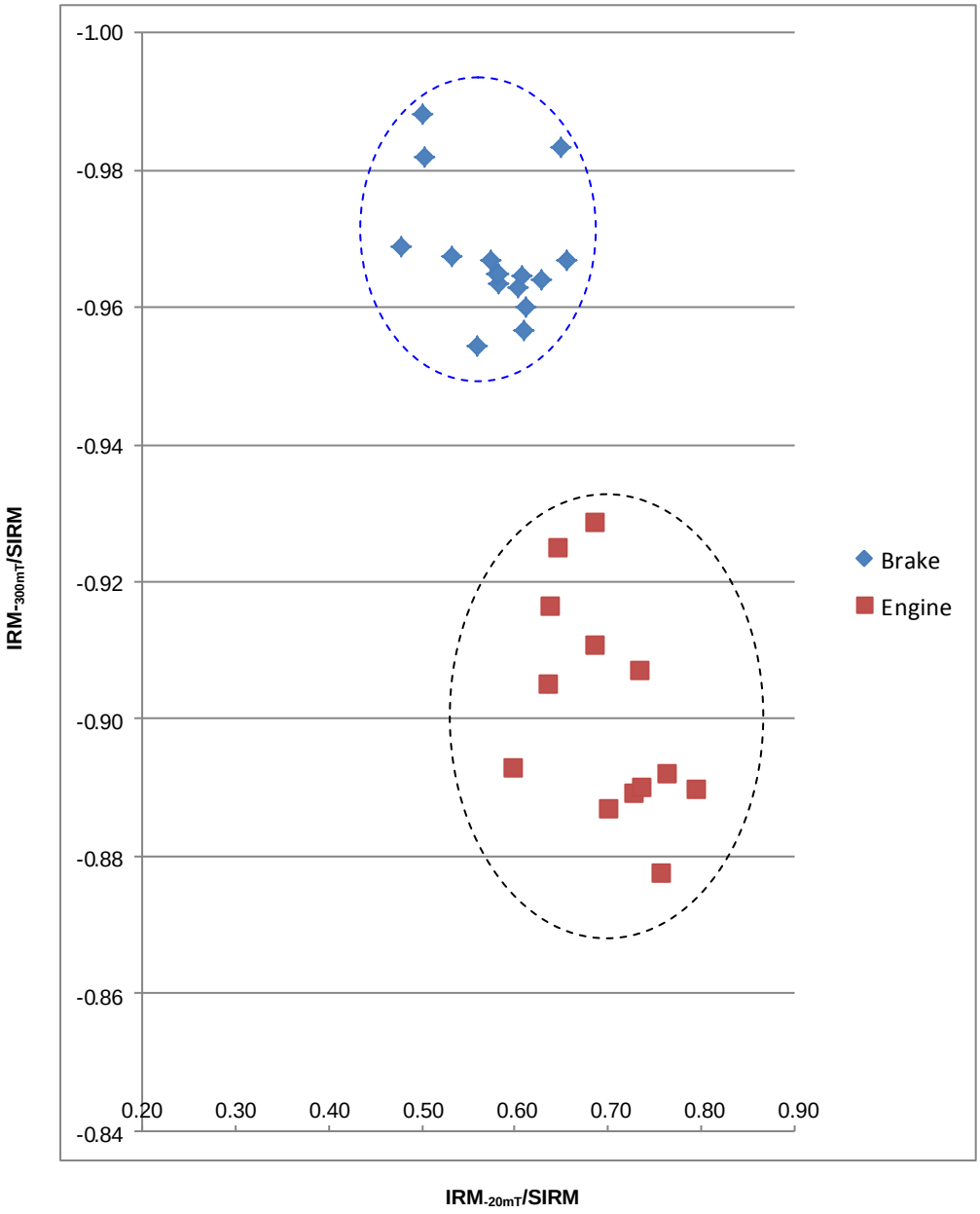

Figure 1: $IRM_{-20mT}/SIRM$ versus $IRM_{-300mT}/SIRM$ for a range of aircraft engine and brake dust samples.

4. Discussion

The results show a clear distinction in the magnetic mineral grain size and assemblage between the engine dust and brake dust samples. A definitive explanation of why such differences exist is not known but most probably relates to different processes and conditions at the point of formation of the magnetic minerals. Ultrafine particulates are a component of aircraft exhaust emissions and generally form from the incomplete combustion of jet fuel in the combustion section of the jet engine (Webb et al., 2008; Starik, 2008). Iron impurities in the commonly used aviation turbine fuel, Jet A-1, are probably converted into magnetic minerals during high temperature combustion processes and are a component of the emitted particulate matter. The

significant antiferromagnetic mineral content possibly relates to the specific nature of chemical reactions involving iron impurities during the combustion stage.

Brake dust largely arises from mechanical/chemical reactions on sliding surfaces during brake operation when aircraft are taxiing, on landing or during undercarriage retraction on take-off (Rietsch et al., 2009). Modern aircraft brakes consist of carbon-carbon combinations due to their high temperature behaviour characteristics. Chemical relations on the brake surface involving any iron impurities within the matrix of the C-C brake may lead to the formation of coarse-grained ferrimagnetic forms of magnetic minerals at the lower operating temperatures (ca. 300°C).

5. Conclusion

Atmospheric particulate dust samples collected from commercial aircraft engines and brakes have been shown to differ significantly in terms of the nature and grain size of the magnetic minerals they contain. The 'harder' magnetic mineral component related to the presence of antiferromagnetic minerals, together with finer ferrimagnetic mineral grain sizes in engine dust distinguish it from aircraft brake dust which displays mainly coarser-grained ferrimagnetic mineral properties. The varying magnetic assemblages may be related to differences in the processes and conditions under which the magnetic oxides developed.

The results demonstrate that relatively rapid and non-destructive magnetic measurements have the potential to identify and differentiate particulates in the airport environment. On-going research is focusing on the magnetic measurements of contemporary environmental samples including runway surface dusts, and vegetation and surface soils sampled from directly adjacent to runway 23L at Manchester International Airport, UK, to investigate atmospheric particulate source-link relationships.

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