Effect of Volcanic Ash Characteristics on their Adhesion in Gas Turbines

C Taltavull, J Dean & TW Clyne

Department of Materials Science and Metallurgy, University of Cambridge
27 Charles Babbage Road, Cambridge CB3 0FS, UK

The Gordon Laboratory

Introduction

Ingestion of Volcanic Ash (VA) into gas turbine aeroengines can cause serious damage, ranging from blockage of cooling chanel to complete inhibition of combustion. Even at the concentration level currently classified by the CAA as "safe" (2 mg m^{-3}), gram quantities can be ingested into an engine in a matter of seconds. Such quantities, if adhered within the turbine, would cause severe damage. The key issue is therefore the proportion of ingested particulate that adheres. VA is of special concern because in many cases they have low softening temperatures and hence are more likely to adhere. The factors affecting adhesion of VAs thus need to be understood in some detail.

Volcanic Ash Characteristics

Four VAs have been used, all from volcanoes in Iceland: ***Laki***, ***Eldgja***, ***Hekla*** & ***Askja***.

These cover 2 different types. ***Laki*** & ***Eldgja*** are ***fissure*** types, with fluid magma close to the surface. ***Hekla*** & ***Askja*** are ***strato-volcanoes***, with more viscous lava, leading to conical peak shapes.

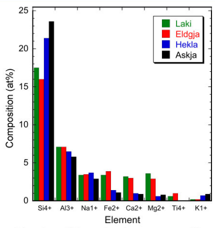

Fig.1: Chemical composition (excluding oxygen) of the 4 VAs, obtained by EDX.

Chemical compositions (Fig.1) are consistent with this: while ***Laki*** & ***Eldgja*** have high contents of low valence (*network-modifying*) ions, such as Fe^{2+}, Ca^{2+} and Mg^{2+}, ***Hekla*** and ***Askja*** are high in silica and hence expected to be more viscous.

This expected viscosity difference is not, however, apparent in T_g (or T_m) values, which are similar (and low) for all four ashes - see Fig.2. All four are largely glassy.

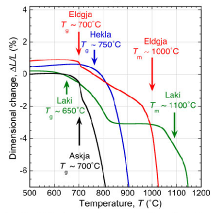

Fig.2: Dilatometry data for the four ashes, revealing T_g and T_m.

Particle Adhesion Rates

A Vacuum Plasma Spray (VPS) facility has been adapted for measurement of the fraction of particles incident on substrates that adhere to them. By correlation of these adhesion rates with numerical modelling of the acceleration and heating of particles during flight, conditions for adhesion have been explored.

Fig.3 shows adhesion rates for different thermal (gas flow) conditions. Rates become high when particle temperatures exceed T_g (~700°C), which happens when T_{sub}>~500°C.

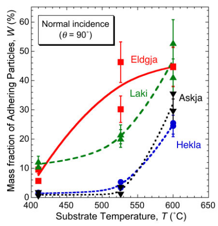

Fig.3: Mass fractions of adherent VA particles, as a function of substrate temperature.

However, ***Laki*** & ***Eldgja*** ashes clearly adhere more readily than ***Hekla*** **&** ***Askja***. This can also be seen from the micrographs in Fig.4. This suggests that the viscosity of these VA particles (at high strain rate and temperature) also affects adhesion.

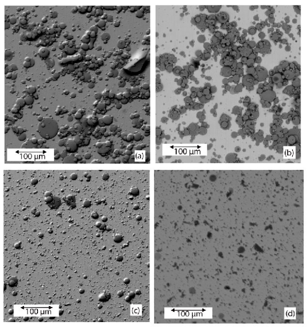

Fig.4: SEM micrographs of substrates after injection of (a) ***Laki****, (b)* ***Eldgja****, (c)* ***Hekla*** *and (d)* ***Askja*** *powders, for T_{sub} ~ 400°C. The average particle size in each case was about 30 μm.*

Pellet Impact Behaviour

Small (~6 mm) pellets were made by sintering of the four VAs. These were heated to ~1200°C and then projected in a gas gun onto cold substrates, at ~100 m s^{-1}. A high speed camera was used to record the outcome.

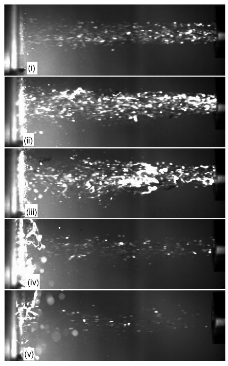

Fig.5: Video stills from an ***Eldgja*** *pellet, after approximate times of 1, 2, 3, 4 & 6 ms.*

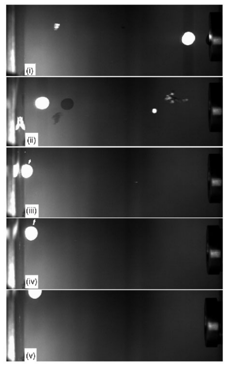

Fig.6: Video stills from an ***Askja*** *pellet, after approximate times of 1, 2, 3, 4 & 5 ms.*

It's clear from Figs.5 & 6 that the responses of pellets from fissure-type volcanoes and strato-volcanoes were markedly different. The former (***Laki*** & ***Eldgja***) behaved like conventional liquids, but the latter (***Hekla*** & ***Askja***) responded like visco-elastic polymers. This difference in (high strain rate) viscosity between the two types is evidently responsible for the observed adhesion rate differences.

In summary, this work suggests that simply monitoring the concentration of VA particulate in the air is not an adequate approach to assessing hazard levels. Not only the *particle size distribution* (known to be important), but also the *composition*, and hence, at least approximately, the viscous flow characteristics during particle impact in the turbine, should also be established. This should be relatively quick and easy to do, using drones to collect samples.