Shock Compression of Simulated Adobe

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Abstract. A series of plate impact experiments were conducted to investigate the shock response of a simulant for adobe, a traditional form of building material widely used around the world. Air dried bricks were sourced from the London brick company, dry machined and impacted at a range of velocities in a single stage gas gun. The shock Hugoniot was determined ($U_s = 2.26u_p + 0.37$) as well as release information. The material was found to behave in a manner which was similar to that of loose sand and considerably less stiff than a weak porous sandstone. The effect of any cementing of the grains was examined by shocking powdered samples contained within a cell arrangement.

INTRODUCTION

Adobe is a traditional building material [1] that is extensively used throughout the world. While the exact composition varies from place to place, the general format is of air/sun dried mud that is used to form either structures themselves, or bricks which are then used in construction. Owing to the prevalence of the material it is often encountered in military situations, for example during the recent conflicts in Iraq and Afghanistan [2]. Understanding the properties of the material are therefore important, as it is necessary to assess the effectiveness of defenses made from such material.

Owing to the likely variability in abode from different areas of the world, it is important that the material used in any experiments is well characterised. It is also necessary to compare to other materials which are perhaps simpler in constitution, as there is a lack of data on comparable adobe type materials in the literature at the pressures of interest. There is a reasonable amount of data taken at lower strain rates [3, 4, 5, 6], however this is not directly comparable.

EXPERIMENTAL

Material

In order to obtain a large amount of material for experimental purposes, it was not deemed to be practical to source this material from a country where abode is used on a regular basis. Additionally, such material would potentially suffer from a lack of quality control and repeatability, bearing in mind the nature of the material. An alternative was found in asking the London Brick Company to supply a number of air dried bricks based on the standard bricks that they produce (these bricks would normally be kiln fired). In this way a good level of reproducibility could be expected, as well as the ability to obtain further material in the future, if required. Subsequently this material will be referred to as adobe simulant.

As the material was unfired, all of the samples in this paper were produced by dry cutting with a diamond saw and hand lapping on abrasive paper. This was done to avoid the samples becoming damaged from contact with water or cooling fluids, which preliminary investigations demonstrated caused the bricks to disintegrate.

Various static property measurements were conducted on the material. Density was measured using a volume method as being 1.73 ± 0.01 g cm^{-3}. Given the make-up of the material (see table 1), this suggests a porosity of around 34%. Longitudinal and shear sound speeds were measured using a time of flight method and ultrasonic transducers.

The measurements indicated the longitudinal speed was 1.92 ± 0.09 km s^{-1} and the shear speed was 1.12 ± 0.05 km s^{-1}. In order to better understand the make up of the bricks x-ray diffraction was conducted on a sample, giving the mineralogical make-up shown in table 1. In order to make measurements of the constituent grain sizes within the material, a sample was tumbled extensively in a 3 axis turbulent mixer, which broke it down gently into the constituent grains. The majority of the bricks are made from a fine grained material, however approximately 3% by mass of the bricks is larger, defined by not passing a 600 micron sieve. This larger material has not been extensively analysed, but appears to contain a variety of aggregate material including flint, pieces of fired bricks, and glass. As the amount of this material compared to the bulk is low, it is not expected that this will have a substantial effect on the macroscopic properties under shock loading. Figure 1 shows a particle size analysis of the small size fraction material, as determined by a Malvern Mastersizer laser based particle size analyser. While the peak of the distribution is around 40 microns, there is a significant fraction of sub 10 micron and sub micron particles.

TABLE 1. Percentages of different minerals identified by x-ray diffraction in the adobe simulant. It is noted that there may be a small clay fraction which is not identified by the x-ray diffraction, but this is likely to be around 5% by weight at the maximum.

Quartz	Orthoclase	Albite	Calcite
73.4 ± 0.9 %	7.6 ± 0.7 %	10.8 ± 0.7 %	8.2 ± 0.5 %

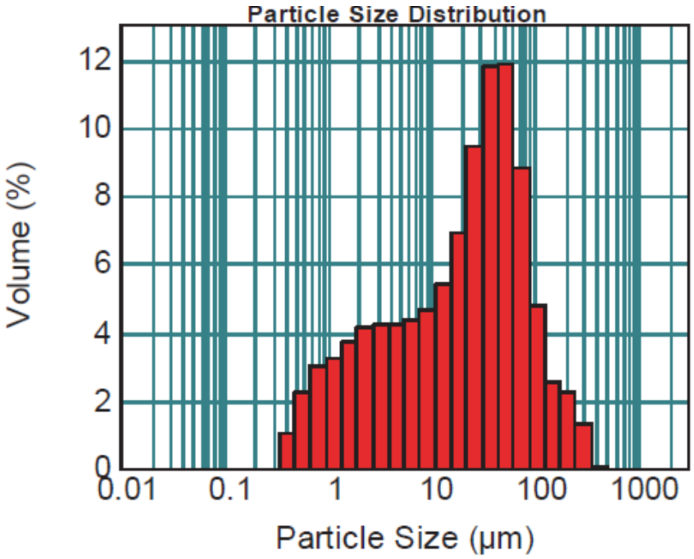

FIGURE 1. Particle size distribution for crushed adobe simulant as determined by laser diffraction in a Malvern Mastersizer.

Plate Impact Experimental Set-up

All of the experiments were conducted at the Cavendish Laboratory plate impact facility, which consists of a single stage light gas gun with a 2 inch bore, capable of firing projectiles at velocities in the 200-1100 m s^{-1} range. Two different experimental geometries were used. For the majority of the samples which were solid pieces of adobe simulant, a front plate was attached to the samples, which was PMMA with an embedded stress gauge. This gave a time of arrival for the shock front. The rear of the samples were monitored with a PDV probe, which gave release information as well as a time of flight measurement for determination of shock velocity. The Hugoniot points were calculated using an impedance matching technique. A single experiment was conducted with the crushed material, and this was held in a PMMA cell design similar to the one described by Braithwaite et. al. [7]. This again allowed for time of flight and release measurements to be made. The amount of material added to the cell was determined by a desire to achieve the same level of porosity in the crushed sample as in the intact sample.

RESULTS AND DISCUSSION

Seven experiments were conducted on the intact material, allowing for a good description of the Hugoniot of the material to be determined. Releases were determined at the rear surface, giving a single point on the release path. Figure 2 shows the Huginots in stress-particle velocity (a) and shock velocity-particle velocity space (b). The release paths are shown as straight lines in the figure, and for the higher stress experiments this is likely to be a good approximation to the release path, owing to the release being dominated by the release in the constituent minerals [7]. It is difficult to determine accurately whether the sample has reached full compaction owing to the fairly large errors that are present when converting the points to a pressure-density space, something which could in future be addressed by conducting more experiments. The release is substantially different to the Hugoniot owing to the high level of irreversible compaction that is occurring in the samples. In the lower stress regime the release paths are a simple straight line joining the Hugoniot point to the final release state. As at this point the material is probably behaving elastically (at least in part), the release path is probably closer to the Hugoniot, as is typical in shock data (however this has not been explicitly measured). The single experiment on the crushed material is shown in fig. 2b, and can be seen to be very different to the intact material, indicating that the cementing of the material does seem to play a role in the shock properties. It should be noted in addition however, that for the crushed material, the large particle size fraction was removed whereas it was present in the intact material.

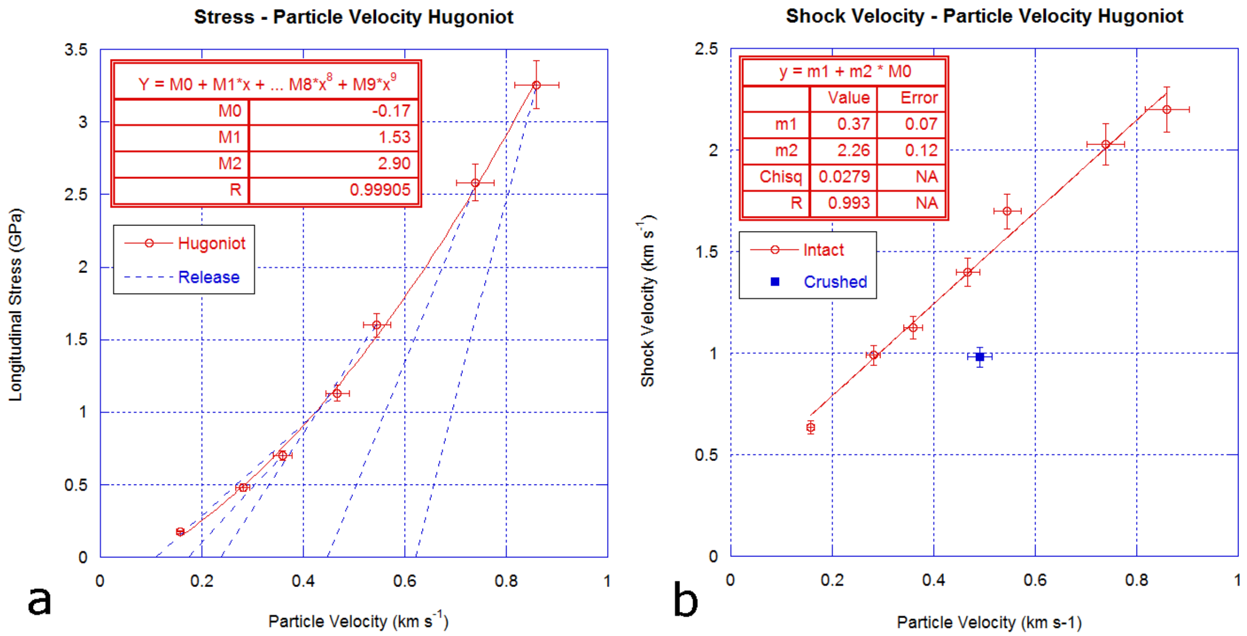

FIGURE 2. Hugoniots for the simulated adobe in a) stress - particle velocity space and b) shock velocity - particle velocity space. It can be seen that there is a clear difference between the intact and the crushed samples (b). Release paths are shown in a and are largely inelastic at high stresses.

The general form of the Hugoniot and release are similar to those found in other materials such as sand and sandstone[7]. Figure 3 shows the U_s-u_p Hugoniots of two of these materials, from [7]. It can be seen that the Hugoniot of the simulated adobe is comparable to that of a loose uncompacted sand, despite having a higher initial density (the sand density is approximately 1.45 g cm^{-3}), and some level of cementing between the grains. The fact that this is the case, in addition to the fact that the tumbling was sufficient to break the material apart, suggests that the intergranular cementing is weak, though not insignificant when considering the response of the broken material. The sandstone which has a density of 1.93 g cm^{-3} is stiffer than both of the other materials, though the overall porosity of the material is lower, so this is to be expected.

A number of aspects of the behavior of the simulated adobe are still under investigation. The first is the response of the material to ballistic impact, which is a more realistic loading scenario that is likely to be encountered in the field. In addition the cementing may have a larger effect on the material in this loading geometry as it is inherently three dimensional. The second is a comparison of the simulated adobe to a genuine adobe, and possibly a fired version of the London brick used in the current investigation.

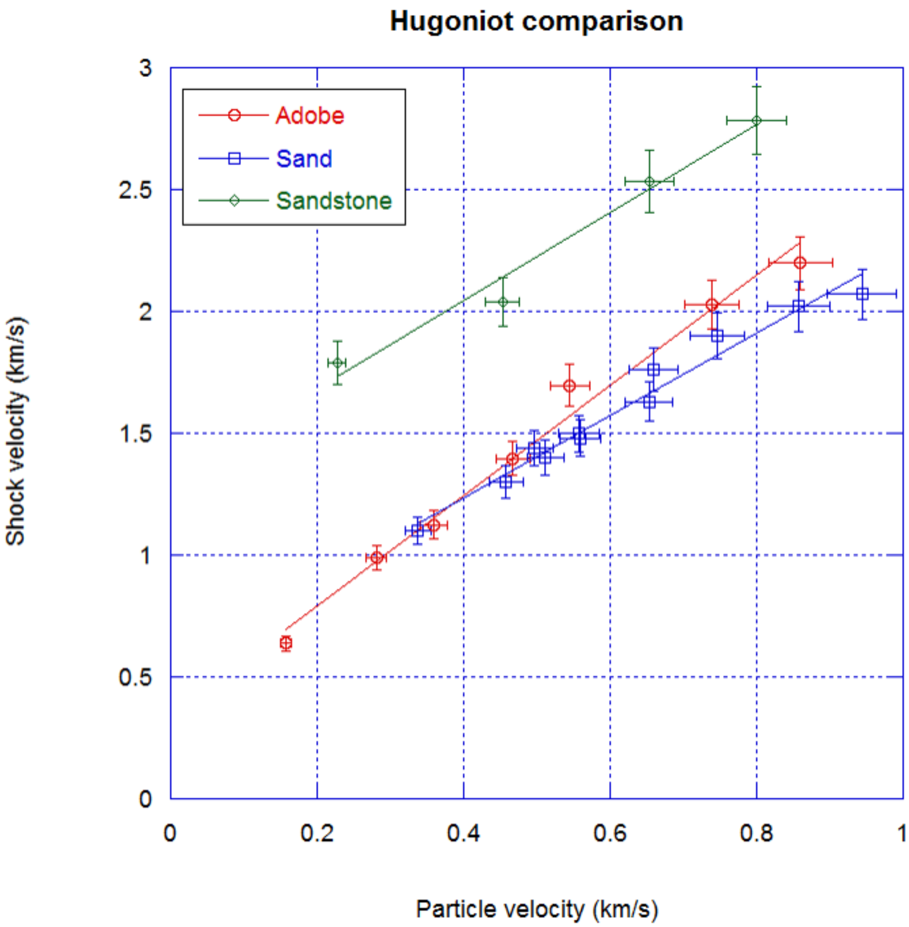

FIGURE 3. Hugoniots for the simulated adobe compared to data for both sand and sandstone from [7]. It can be seen that the adobe behaves similarly to the sand despite being denser.

CONCLUSIONS

A well controlled simulant for adobe had been identified and produced. A number of simple tests were carried out to characterize the simulant. Density was measured as being 1.73 ± 0.01 g cm^{-3}, a porosity of around 34%. The material had around 3% by weight aggregate with the remainder being a matrix of particles mostly (73%) composed of quartz. Longitudinal sound speed was 1.92 ± 0.09 km s^{-1} and the shear speed was 1.12 ± 0.05 km s^{-1}. The material has been examined under a plate impact geometry both in the as-received state, and after reduction to powdered constituents. The shock Hugoniot was determined ($U_s = 2.26u_p + 0.37$) as well as release information. Release was found to be largely inelastic (for the adobe material, though the release is likely well characterised by the elastic release of the constituent mineral species) at high stresses, and more elastic as the impact stress was reduced. The material was found to behave in a manner which was similar to that of loose sand and considerably less stiff than a weak porous sandstone.

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