Impact pressures generated by spherical particle hypervelocity impact on Yorkshire Sandstone

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IMPACT PRESSURES GENERATED BY SPHERICAL PARTICLE HYPERVELOCITY IMPACT ON YORKSHIRE SANDSTONE

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Abstract. Hypervelocity impact tests were carried out at 4.8 km/s using the Open University's All Axis Light Gas Gun (AALGG) in the Planetary and Space Sciences Research Institute (PSSRI)'s Hypervelocity Impact Laboratory. A first estimate of the peak loading pressures was made using preliminary hydrocode simulations, supported by calculations. Following a review of existing published quartz and sandstone data, our previously published plate impact data were combined with high pressure quartz data to produce a synthetic Hugoniot. This will form the basis of future hydrocode modelling, as a linear U_s-U_p relationship does not adequately represent the behaviour of sandstone over the pressure range of interest, as indicated by experimental data on Coconino sandstone. This work is a precursor to investigating the biological effects of shock on microorganisms in sandstone targets. This paper also contains the first presentation of results of ultra high speed imaging of hypervelocity impact at the Open University.

Keywords: Sandstone, Hugoniot, Particle Impact, Microbial Life, Hydrocode.
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INTRODUCTION

Recent research has evaluated the conditions for the development of microorganisms in impact structures. Our understanding of present-day microbiology of these impact structures is limited. There is also little understanding of about how impact heating and shock alter the suitability of rocks as sites for microbial colonization, nor of the effects of non-lethal impact on the microbial life. For example, shock processing of rocks at the Haughton impact structure (impact shocked gneiss) in the Canadian High Arctic has made them more colonisable by cyanobacteria [1]. Following a review of existing published quartz and sandstone data, our plate impact data were combined with high pressure quartz data to produce a synthetic Hugoniot. This will form the basis of future hydrocode modelling. A first estimate of the peak loading pressures was made using preliminary hydrocode simulations, supported by impedance matching and analytical calculations. Experimental particle impact data was also produced using the All Axis Light Gas Gun (AALGG) in the Planetary and Space Sciences Research Institute (PSSRI)'s Hypervelocity Impact Laboratory This work is a precursor to investigating the effects of shock on microorganisms in sandstone targets.

EXPERIMENTAL PROCEDURE

The Open University's All Axis Light Gas Gun (AALGG) (Fig. 1) was used to accelerate a 1 mm diameter spherical stainless steel projectile at a velocity of 4.8 km/s, which was measured using laser velocimetry. The target, consisting of Yorkshire sandstone plate assemblies, was mounted 30° (from the horizontal) to the line of flight (Fig. 2). A DRS Ultra High Speed Camera (Ultra 8), with velocity calculation and camera triggering by MS Instruments equipment, was used for high speed imaging. One 500 J flash head was used for illumation, triggered from the laser velocimetry equipment. An overview of the Open University's Hypervelocity Impact Laboratory including the AALGG, is reported elsewhere [2].

Figure 1. OU's AALGG. The Ultra 8 camera was mounted to image inside the chamber, via a small mirror.

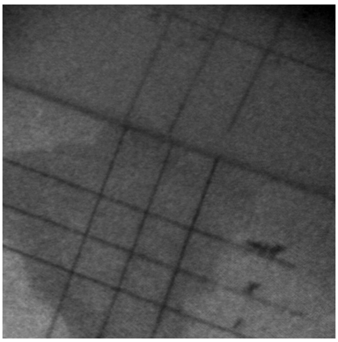

Figure 2. Target configuration, showing FOV of ultra high speed camera and the target measurements made (grid cell is 1x1 cm). The darker area indicates location of *B. subtilis* bacteria doping.

EXPERIMENTAL RESULTS

A total of 13 shots were carried out. As other work was ongoing in parallel (e.g. varying stop plate diameter of hole; testing a burst disk (or petal valve) design), only 1 test produced a clean single impact on target (Fig. 3a). Some other targets showed two impacts (e.g. Fig. 3b). A profilometer was used to measure the depth of the crater. Examination of the craters on the stop plate craters suggests that the second impact may be due to a part of whole of the burst disk (largest dimension 0.5 mm thick, 4.5 mm diameter flat disk) impacting the target. A further four impacts were captured using ultra high speed imaging. These clearly show two impacting projectiles and the ejecta plume (Fig. 6, Fig. 7 shown on the last page). Further work on burst disk design is planned. Exploratory research on *the cyanobacterium Chroococcidiopsis sp.* has identified that the organisms near the crater rim on ejected fragments have survived the impact.

(a) (b)

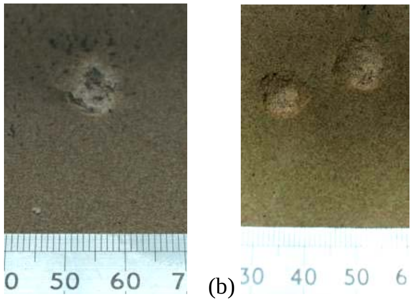

Figure 3. (a) Single impact (b) Two impacts.

HYDROCODE SIMULATIONS

The AUTODYN hydrocode was used for the simulations of spherical particle impact to calculation the pressure generated. Previously determined C_0 and S values were used [3]. A simple Drucker-Prager formulation was used for strength calculations. Data from lateral stress gauges provided the parameters for the strength model [4].

Previously published Coconino sandstone data, including upper and lower bands indicated by measurement errors are plotted in P-V space (Fig. 5 shown on the last page). A high pressure quartz Hugoniot, derived from the high pressure quartz data in Ref. 6, is also plotted in Fig. 5 (P de Carli, personal communication). The C_0 and S values for this high pressure quartz Hugoniot are reported in Table 1.

The peak pressures calculated for normal incidence were compared with impedance matching calculations and analytical solutions in Table 2 [7, 8], and show agreement within 15-20%.

Note that the plate impact data in Ref. 3 hint at a porosity crush in Yorkshire sandstone. It is clear that the linear U_s-U_p derived from the experimental measurements may be only a first approach. More detailed work is needed to resolve any two wave shock structure. It is possible that at least some of the differences (in the pressure-volume plane) among the various porous quartz (sand and sandstone) crush curves may simply be due to single shock versus multiple shock interpretations of the data (P de Carli, personal communication). As a first step, a synthetic Yorkshire sandstone Hugoniot was constructed by interpolating between the two, as shown in Fig. 4.

Material	Density [g/cm^3]	C_0 [km/s]	Slope, S
Sandstone [3]	2.24	2.07	1.94
Quartz (pers comm.)	2.65	1.67	1.78
Stainless steel (SS) [9]	7.86	4.61	1.73

TABLE 1. Hugoniot data

Approx peak P [GPA]	Cav_SHOCK [8]	LE [7]	Hydro -code
Sandstone/ SS	70	98	55
Quartz/ SS	73	105	N/A

TABLE 2. Peak pressure (4.8 km/s, normal incidence)

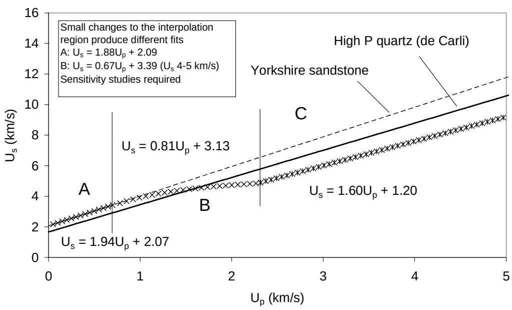

Figure 4. Derived U_s-U_p data for Yorkshire sandstone.

DISCUSSION AND FURTHER WORK

The results presented here are only an initial estimation of pressures generated on spherical particle impact. The synthetic Hugoniot presented in Fig. 4 will be implemented into AUTODYN and CAV_KO to provide updated predictions of pressures (including time duration of pressures). Spall models – also an area of ongoing research - will be used to estimate pressures experienced by ejected fragments. Waste heat generated will provide a first estimate of temperature [10]. However, modelling of the release behavior of sandstone is a challenge and even though the porosity crushup can be modeled more easily, the hysteretic high pressure transformation will require implementation of new sub-routines.

CONCLUSIONS

A first estimate of the peak pressures on spherical particle impact has been made. Synthetic sandstone Hugoniot presented in this paper will be implemented in AUTODYN and CAV_KO to improve the predictions of peak pressures. More work is needed before conclusions can be drawn on the pressures experienced by *B. subtilis*.

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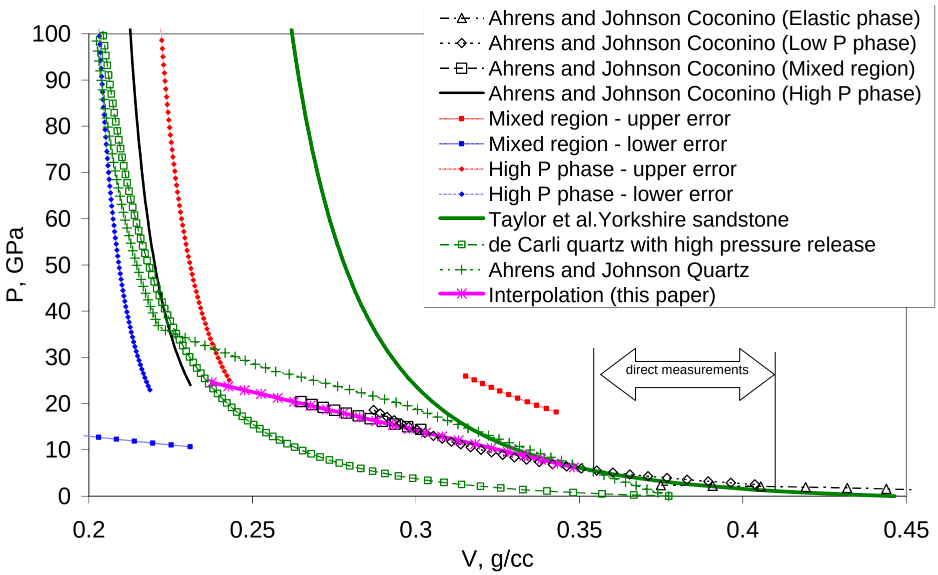

Figure 5. P-V data for quartz and sandstone [3, 4, 5, 6].

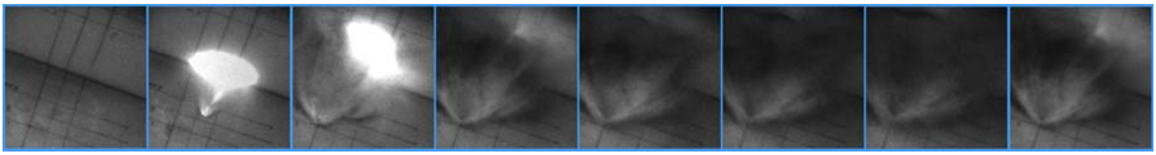

Figure 6. High speed imaging sequence for impact #12. The frame exposure was 2 μs and the interframe rate 20 μs.

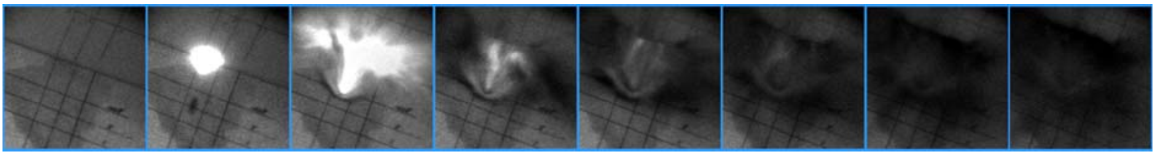

Figure 7. High speed imaging sequence for impact #13. The frame exposure was 2 μs and the interframe rate 20 μs.

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