Multi-frame synchrotron based radiography of wire explosions in water

In 2018 we performed the world's first high current pulsed power experiments coupled to a synchrotron and now, whilst the ESRF synchrotron is being upgraded, we have been performing detailed analysis of the results and planning our next campaigns.

On the ID19 beamline at ESRF we explored the explosion of aluminium, copper and tungsten wires in water baths driven by a ~30kA, 500ns current source. The synchrotron provided 20-30kV radiation pulses, each ~0.1ns in length, which were recorded via a scintillator and high speed camera. The resultant multi-frame, phase contrast radiography images enabled absolute density measurements of the expanding wire material and surrounding water at high spatial and temporal resolution.

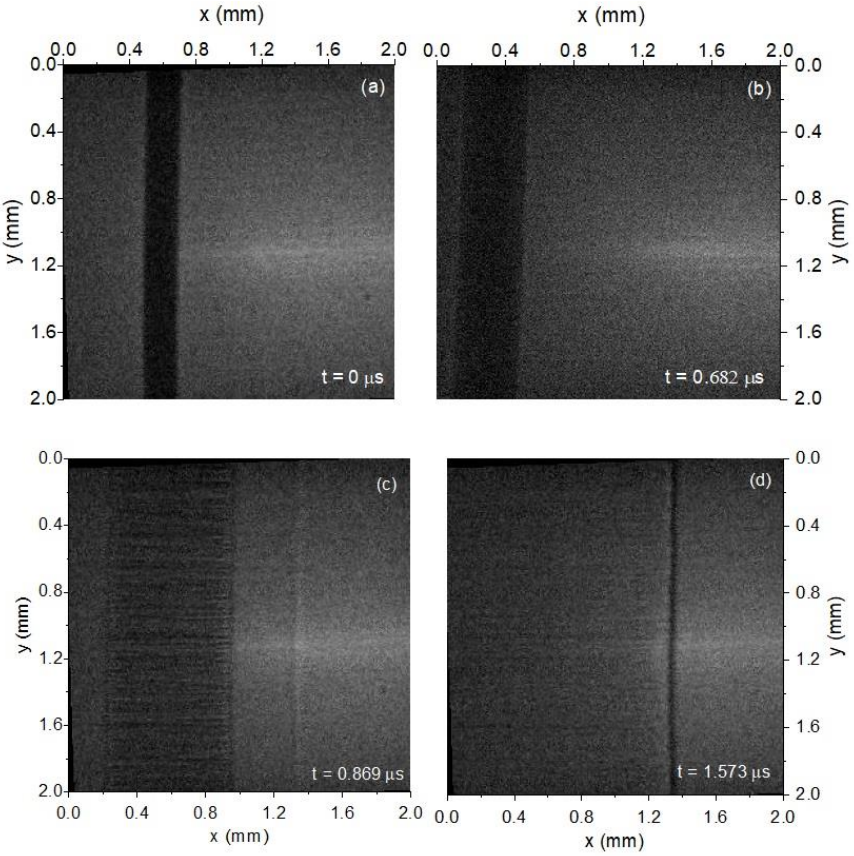

Fig. 1. High magnification images of explosion of 160μm copper wire in water

As the wires expanded and ionized unexpected instability growth was observed inside the dense wire material (fig. 1), resulting in prominent axial striations. This electrothermal instability might help explain some of the unexpected features in conductivity measurements of warm dense plasmas, which have previously required 'empirical' adjustments to theory, and made cold start calculations of wire explosions problematic.

As seen previously in underwater wire experiments, the rapid expansion of the wire launched a strong shockwave into the water surrounding it. In experiments with 2 closely spaced wires,

the shockwaves launched into the water interacted with the expanding wire material and Richmeyer Meshkov instability growth was observed. The development of the instability was likely seeded by the electrothermal striations in the expanding wire, and appears to follow classic growth rates. Method to alter the level of the R-M instability are now being explored and three-dimensional MHD simulations are planned in the future to compare to these experimental results.

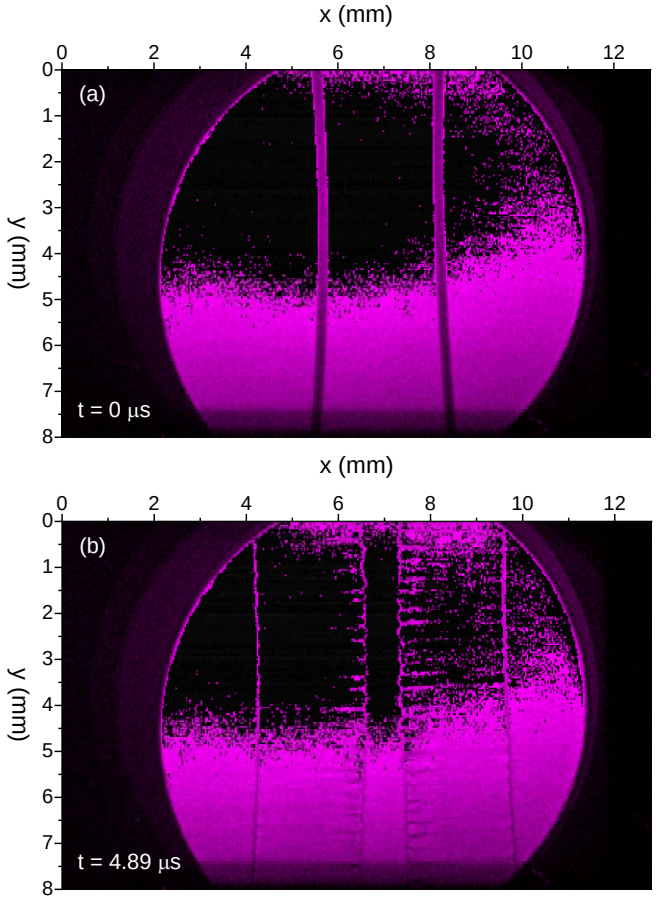

Fig. 2. Radiography images of explosion of two copper wires.

In experiments with cylindrical arrays of wires (fig. 3) radiography enabled the interaction of shockwaves launched from adjacent wires to be studied as they formed a highly symmetric convergent shockwave that travelled at multi-kms^{-1} towards the axis. For the first time the increased density on axis due to arrival of this shockwave could be measured – in previous experiments, limitations of optical diagnostics meant only the speed of the shockwave could be observed, and no information on the state of the water could be recovered after its passage. The increased density agreed well with theory, helping validate the use of our hydrodynamics simulations to estimate pressures produced in experiments with MA current drives and in other 3D convergent geometries.

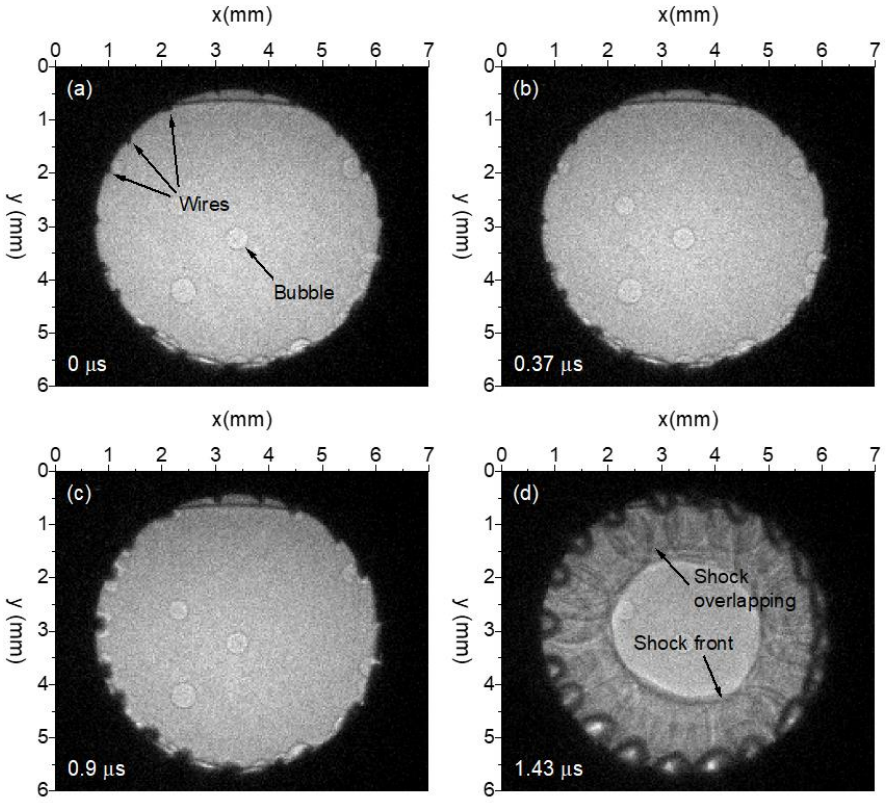

Fig. 3. Radiography images of cylindrical wire array explosion at ESRF

4 journal papers have so far been published based on the results, with 2 getting editors pick, and one the cover of a journal.

1) Use of synchrotron-based radiography to diagnose pulsed power driven wire explosion experiments S. P. Theocharous, S. N. Bland, D. Yanuka, A. Rososhek, M. P. Olbinado, A. Rack, Ya. E. Krasik,, Review of Scientific Instruments 90, 013504 (2019).
2) Synchrotron based X-ray radiography of convergent shock waves driven by underwater electrical explosion of a cylindrical wire array, D. Yanuka, S. Theocharous, S. Efimov, S. N. Bland, A. Rososhek, Ya. E. Krasik, M. P. Olbinado, A. Rack, Journal of Applied Physics 125, 093301 (2019).
3) Multi frame synchrotron radiography of pulsed power driven underwater single wire explosions, D. Yanuka, A. Rososhek, S. Theocharous, S. N. Bland, Ya. E. Krasik, M. P. Olbinado, A. RackJournal of Applied Physics 124, 153301 (2018)
4) X-ray radiography of the overheating instability in underwater electrical explosions of wires, D. Yanuka, A. Rososhek, S. Theocharous, S. N. Bland, Ya. E. Krasik, , M. P. Olbinado, A. Rack and E.V. Oreshkin, Physics of Plasmas 26, (2019).

2 more papers are in the process of being written. In addition 2 invited talks and multiple contributed talks at international conferences have been based on the results.