Searching for Elusive Solitons: Optical Detection of Strain Waves Generated by Pulsed Laser Ablation in Acrylic Bars

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Abstract

The study of the dynamic properties of Polymethyl Methacrylate (PMMA) and similar polymers is currently an important area of research, due to the vast range of possible applications of these materials. Recent work has studied the propagation of undular bores produced at small to moderate strain rates via natural and induced fracture [1, 2] but these waves failed to produce solitons. Our research aims to investigate similar undular bores in PMMA bars generated at much higher strain rates, to extend it to consider waves in PMMA rods as well as bars, and study the conditions required for the generation of solitary waves. We increased the strain rate by 3 orders of magnitude compared to the previous work [1, 2] to observe the mutual effects of nonlinearity, dispersion and viscoelasticity, as this may allow the bore to develop faster and potentially develop into a solitary wave at the front of the bore. Researchers at the Ioffe institute in Russia have investigated the propagation of longitudinal strain waves in PMMA bars that arise after a shockwave impacts the end of the bar. They used a high-power laser pulse to locally ablate a thin foil target submerged in a water tank. The shock wave generated in the water is coupled to the PMMA bar inside the tank, as the bar acts as a waveguide for the strain wave, which is observed using pulsed holographic interferometry outside the tank [3]. Interesting results were produced, including the strain wave propagating tens of centimetres at a constant speed; suggesting that the strain waves produced are solitons [4]. However, the setup used can only capture snapshots of the spatial bore at different times after impact, and separate snapshots are required to observe how these waves evolve in time. In our experiment we use a high-power Nd:YAG pulsed laser (250mJ per pulse, 5ns pulse duration, 10Hz repetition rate) to directly excite the end of a PMMA bar and produce a shock wave that propagates along it. To detect the strain wave, we use a Mach-Zehnder interferometer with compensation to remove the effect of residual birefringence of the material. Fast photodetectors in quadrature allow the determination of unambiguous phase changes related to compressive and tensile strain with microsecond temporal resolution – see Figure 1. Sliding the interferometer along the bar enables the visualization of passing strain waves at different distances from the excitation point.

Various waveguides have been used: rectangular cross sections of 3mm x 10mm and 3mm x 3mm. We compare the strain wave in these different waveguides and how the wave develops as it propagates. Previous works have derived models to describe strain waves propagating through a cylindrical rod [5,6], which can be used to approximate a square cross section bar. Experimental results for constant cross section are compared to mathematical models and experimental results for tapered waveguides are given.

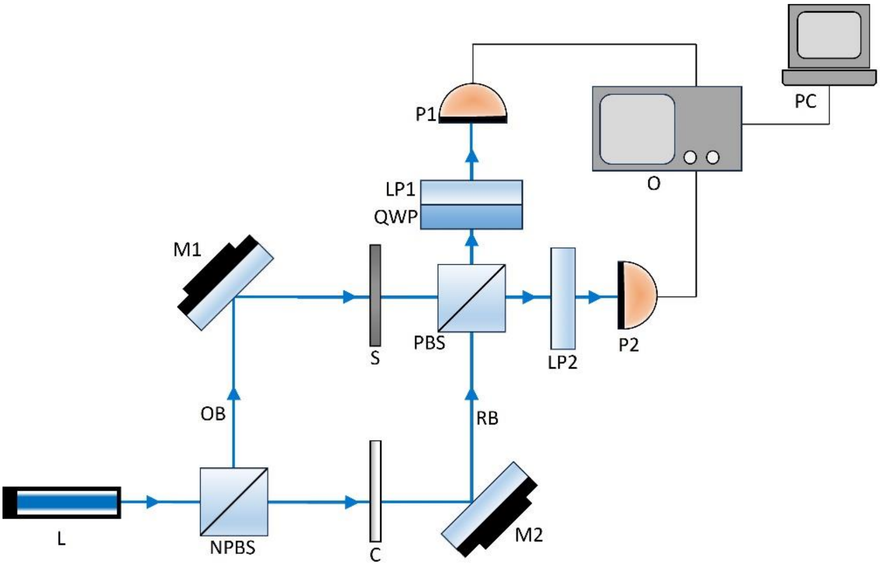

Figure 1: Mach-Zehnder interferometer with compensation and in-phase quadrature. L – Laser, NPBS – Non-polarising Beam Splitter, OB – Object Beam, M1 – Mirror 1, S – Sample, C – Compensator, M2 – Mirror 2, RB – Reference Beam, PBS – Polarising Beam Splitter, QWP – Quarter Waveplate, LP1 – Linear Polariser 1, LP2 – Linear Polariser 2, P1 – Photodetector 1, PD2 – Photodetector 2, O – Oscilloscope, PC – Computer.

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