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On the determination of the shock and steady state parameters of gelatine from cylinder impact experiments

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ABSTRACT

For a soft body projectile striking a target or the shock loading of a soft body material, the determination of the interface shock pressure, shock speed and applied steady state pressures is important but has been hindered by technical challenges even with the use of sophisticated embedded pressure sensors in the target surface. Difficulties interpreting the results render the accuracies sometimes questionable or impossible to reproduce. Here we propose a simple impact experiment using a force sensor and an analysis procedure to derive the interface pressure from the force/time history. The results are compared to those obtained from shock Hugoniot and penetration equations. We came upon the presence of a dynamic pressure that is significantly higher than the expected stagnation pressure. This method could be used to determine and characterise the shock and steady state pressures of a wider range of materials under impact and shock loading conditions.

1. Introduction

Low strength materials such as water, gelatine, rubber, wax or even emulsions are used for a broad range of applications involving impact and shock loading conditions. Apart from being used as shock absorbers or in energy dissipating systems, these materials, such as gelatine and rubber, are used as surrogates for human body tissues, organs, biological liquids, animals and birds to examine the effects that may occur due to impact or shock. Examples range from the use of extra-corporeal shock wave lithotripsy [1] in the non-invasive disintegration of urinary tract stones or ultrasounds for the denaturing of deep seated cancerous cells [2] to the studying of trauma [3] caused to the human body due to impact or shock loading or the damage to aircraft structures due to bird impact [4–12]. In all these examples, the shock and steady state pressures are important loading parameters that are needed to understand the response of the materials and these parameters are normally measured at the impactor/target interface. In an impact problem, especially in the case involving a soft body material, the simultaneous deformation of the projectile and target makes uncoupling the response of each material very difficult so to decouple and understand the responses, studying cylinders made out of a particular material striking rigid targets provides researchers with a very useful means to characterise a material under shock loading condition whether it is used as an impactor as in the case of a bird strike problem or a target as in the case of a human surrogate struck by a projectile. Studies [13–19] on the deformation of solids by liquid impact at supersonic speeds examined flat-ended cylinders striking a rigid target and described the interface pressure as the water hammer pressure, $P = \rho c_0 u_0$ where ρ is the density, c_0 is the wave speed and u_0 is the impact velocity. Further studies [24–28] on the issue have shown that the water hammer equation pressure works well only for low velocity impact but for higher velocities, c_0 must be replaced by the shock velocity, U_s, to get what is called the shock or Hugoniot pressure, $P_h = \rho U_s u_0$. These studies have all shown that when a projectile strikes a target (Fig. 1) a shock is generated at the center of the projectile and propagates towards the outside surface and on reflection, forms release waves that propagate towards the center at a lower pressure which causes the material to flow. The pressure at the interface begins to decrease and after several reflections the projectile flow will approach a steady state condition where the pressure becomes the stagnation pressure, $P_{stagnation} = \frac{1}{2}\rho u_0^2$. Many studies [4,7–9,13–24] have validated this theory of the shock and steady state regimes govern, respectively, by the shock Hugoniot and the steady state pressure and from the literature cited there is general agreement on this. Many researchers [4–12] in measuring these pressures use pressure transducers embedded in the surface of the target where the projectile first strikes. However, in all the work cited for soft body impact, although good shock and steady state pressure results are obtained, there are many difficulties, such as the limitation of the pressure gauges that rendered the accuracies of the data sometimes being questionable or difficult to reproduce.

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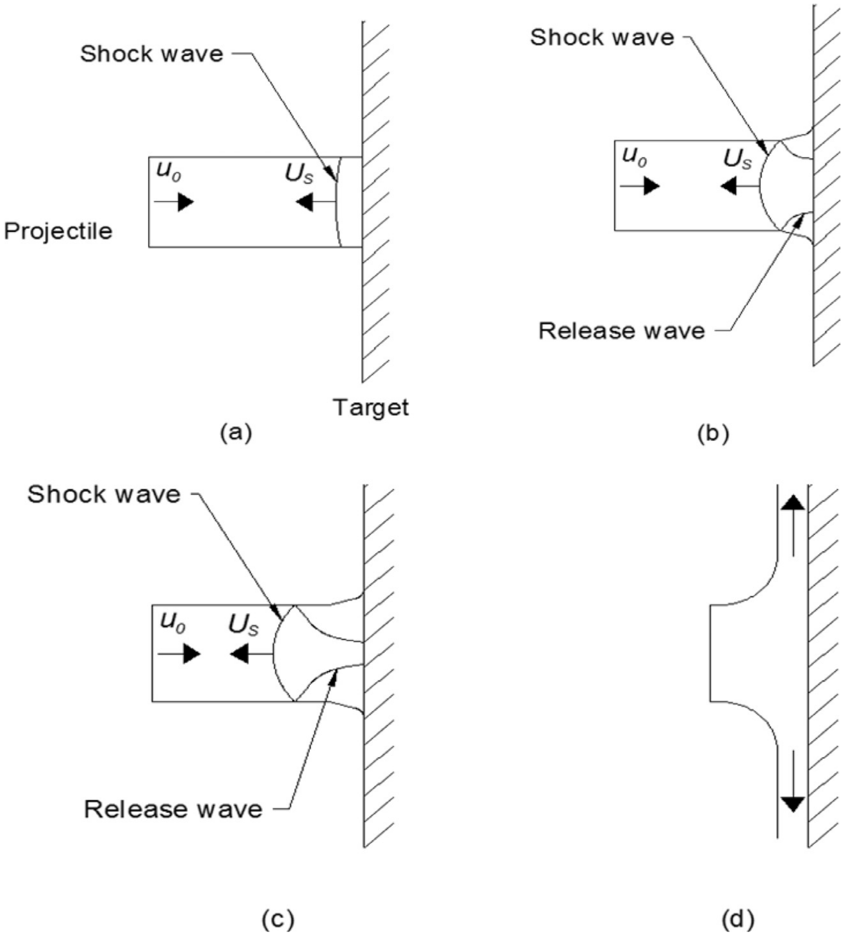

Fig. 1. Illustration of the four stages of a soft body projectile striking a rigid target.

Studies [4–6,10,11] spanning the last three decades have highlighted these limitations and this led us to re-look at the issues of the impact problem and examine whether reliable shock and steady state pressures could be obtained from a simple more repeatable experiment that could be used to examine a broad range of soft body materials.

2. Experiments

Here we propose using a force ring transducer, instead of a pressure gauge, sandwiched between a rigid target disc and a clamped support plate to determine the interface pressure using the force-time history. An air gun impact facility (Fig. 2(a)) was used to conduct the experiments. The air gun itself consisted of a 1.8-m long, 40-mm diameter launch tube that is coupled to a compressed air reservoir. The pressure of the air in the reservoir determines the exit velocity of the projectile. A phototron high speed camera recording at 20,000 frames/s, was used to record the projectile release from the launch package, its flight to and interaction with the target. The data acquisition system integrated with the gun firing mechanism, was used to trigger the camera and acquire the force history. To launch projectiles with the air gun, a sabot (Fig. 2(b), Appendix A.2 - Sabot development and Appendix B - Fig. B. 1) was required to hold the penetrator in place during its travel in the launch tube and then stripped away before striking the target. The basic projectile (Fig. 2(b)) was a 28-mm cylindrical 10% gelatine rod with a hemispherical tip and a nominal length of 102 mm and was prepared using a standard 10% gelatine recipe [1,9] (Appendix A.1 - Gelatine preparation). The target was a 120-mm diameter, 19-mm thick steel disc with a solid 28-mm diameter cylindrical support at the center that was attached to the center of a 330-mm, 35-mm thick square steel plate sandwiching a force ring sensor (Fig. 2(c)). The force transducer used was a PCB Piezotronics Quartz Force Ring Sensor Model 207C (Fig. 2(d)) with a force measurement of up to 445 kN and a sensitivity of ± 1.5%.

3. Results - experimental data reduction and discussion

Of the many tests conducted, four at different impact velocities, 74, 105, 115 and 119 m/s, were chosen to conduct the analysis. Fig. 3 shows a sequence of the projectile/target interaction in time for the 119 m/s impact velocity case, starting with the projectile striking the target until it was completely eroded. A closer look at the sequence of pictures reveals that as the material goes from the initial shock phase and into deformation due to the large compressive forces, the front of the projectile mushrooms and then there appears to be considerable shearing and fissuring of the material into fragments and subsequently entering into the radial flow which remains parallel to the target. This tearing or shearing of the material into fragments are also very evident from the pieces of the gelatine (Appendix B - Fig. B. 2) gathered after the test. This appears to be different than the flow of water or a liquid striking the target. The solid line of the force histories shown in Fig. 4 are the raw force data as acquired from the tests and significant oscillations were observed in the results. A Fourier transform [21] on the