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Interaction of a spark-generated bubble with a two-layered composite beam

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ABSTRACT

This paper deals with interaction between a spark-generated bubble and a two-layered composite beam (constrained at its two ends) which consists of an aluminum sheet coated by an elastic layer. Both numerical and experimental approaches are employed to investigate the dynamics of bubble collapse near the two-layered composite beam. A good agreement between the numerical simulation and experimental observation is achieved, which reveals that the bubble collapse time is greatly influenced by the nearby two-layered composite beam. The numerical model is then extended to examine the dynamic response of the two-layered composite beam induced by the bubble growth and collapse; and also to explore the correlation between the energy density of the two-layered composite beam and its coating layer stiffness. The results from this study may provide some insights on the protection of submerged marine structures exposed to bubble collapse arising from an underwater explosion.

1. Introduction

An oscillating bubble interacting with a deformable structure has been a subject of considerable interest and concern for many years. Gibson and Blake (1982) and Blake and Gibson (1987) conducted some of the earliest studies on the interaction between bubbles and an elastic material (both theoretically and experimentally). They observed that the bubble migrates away from an elastic surface and suggested that it could be useful to consider applying a deformable coating to prevent erosion on ship propellers. They further found that the surface stiffness and inertia had a profound effect on the motion of the bubble based on their experiments of a sparked-generated bubble near a rubber-coated boundary (Blake and Gibson, 1987). Shima et al. (1989) and Tomita and Kodama (2003) observed similar phenomena in subsequent experiments and found that the migration of the bubble depends on bubble size and relative position to the surface (besides the properties of the surface). Brujan et al. (2001a, b) used an elastic boundary (polyacrylamide gel) in their study of laser-induced bubble dynamics. They observed 'mushroom-shaped' bubbles, but also the splitting up of bubbles and the movement of the interface, which can be either towards or away from the bubble. Duncan and Zhang (1991) and Duncan et al. (1996) simulated numerically similar cases to the experiments (Shima et al., 1989; Tomita and Kodama, 2003) and modeled the coating material as a spring foundation with parameters such as spring mass, spring stiffness and coating radius. Their simulation results qualitatively agreed with the experimental observations (Shima et al., 1989; Tomita and Kodama, 2003).

Subsequent experiments and simulations have been carried out on the interaction of an underwater explosion bubble with a nearby compliant structure (Kalumuck et al., 1995; Geers and Hunter, 2002; Chahine et al., 2003; Klaseboer et al.,

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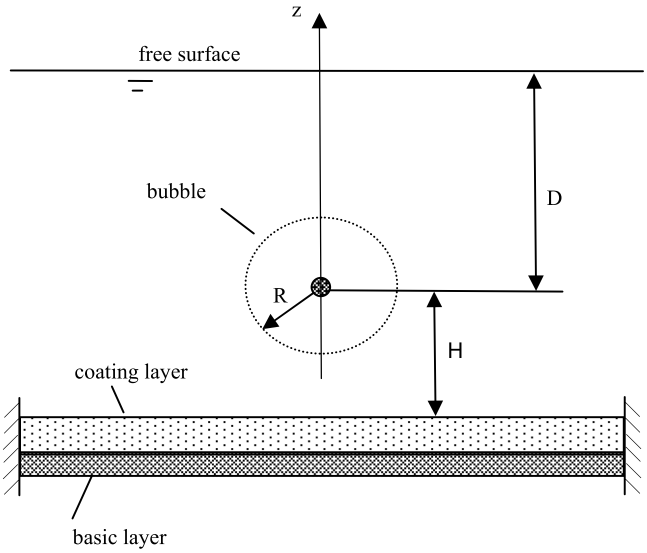

Fig. 1. The configuration of a spark bubble and a two-layered composite beam. The bubble is situated initially at a depth D at a distance H away from the structure ($H << D$ initially). The bubble radius R and H are of comparable magnitude.

2005a,b; Zong, 2005; Zhang and Zong, 2011; Hsiao and Chahine, 2015), which is motivated by the fact that an underwater explosion bubble is one of the major causes leading to structural damage duo to the formation of a high speed jet which can impact on the structure (combined with the shock wave of the explosion). Chahine and co-workers (Kalumuck et al., 1995; Chahine et al., 2003) developed a fully three dimensional boundary element method (BEM) code assuming the liquid to be inviscid and incompressible, and coupled it to a finite element structural code. A free-floating surface piercing body interacting with a bubble was thus simulated and they also studied the response of the solid structure to an underwater explosion bubble. Klaseboer et al. (2005a, b) investigated bubble dynamics in an underwater explosion, while interacting with a flat plate using a finite-element method (FEM) structural code and boundary-element method code. Their study was subsequently extended to study a composite structure to an underwater explosion bubble (Gong and Khoo, 2015). In view that a spark-generated bubble enables high quality observations of bubble dynamics at relatively low cost compared to experiments involving explosives, it has been used extensively as validation tool for laboratory-scale models of an underwater explosion bubble (Chahine et al., 1995). Gong et al. (2012) also studied the behavior of a spark-generated bubble and an elastic rubber beam. Separately, a scaling law, relating spark and underwater explosion bubbles (Gong et al., 2010), was established by the same group to derive the scaling parameters and relationship linking the spark-generated bubble to the underwater explosion bubble.

The physics associated with the interaction of an underwater explosion bubble and layered surface whose coating layer is supposed to attenuate the erosion damage (Gibson and Blake, 1982; Blake and Gibson, 1987; Shima et al., 1989; Tomita and Kodama, 2003; Gong and Lam, 2006) has not yet been fully explored but might have a lot of potential applications, we therefore extend our study to numerically and experimentally investigate the interaction of a spark generated bubble and a two-layered composite beam (which comprises an elastic coating layer attached to an aluminum sheet) in an effort to determine the trend and optimize the overall structural response.

This paper is organized as follows. Details concerning the numerical implementation are given in Section 2. The analysis of the bubble collapse near the two-layered composite beam is carried out in Section 3, where the modified bubble collapse time is presented considering the influence of the nearby composite beam. Section 4 describes the spark-generation bubble experimental setup. Section 5 discusses the numerical and experimental results and finally Section 6 summarizes the main findings.

2. Numerical methods

2.1. On fluid part

Consider a spark-generated bubble with its initial center situated at a distance H from the upper surface of a two-layered composite beam as shown in Fig. 1. The beam is constrained at its two ends and an xyz coordinate system is used with the z-axis pointing oppositely to the gravity acceleration vector. After the shock wave is gone, the subsequent flow dynamics surrounding the initial bubble are essentially governed by fluid inertia (compressibility and viscosity effects are negligible). Therefore the fluid is assumed to be inviscid, irrotational and incompressible and a velocity potential Φ that satisfies Laplace's