1321 Experimental study of underwater shock wave attenuation for medical application

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The present research aims to study underwater shock wave propagation and attenuation in tissue models to understand mechanisms of tissue damages during shock wave therapies. In order to simulate interaction of shock waves with intercellular structures, thin porous layers of cotton immersed in water were exposed to underwater shock waves. Shock waves were generated by explosion of 10 mg silver azide pellets, which were ignited by irradiation of a pulsed Nd:YAG laser beam. Peak overpressures were measured with hydrophones at various stand-off distances. The motion of shock waves was quantitatively visualized by using double exposure holographic interferometry.

1. Introduction

Applications of underwater shock waves have been extended to various clinical therapies [1]. It has been a common practice for treatment of kidney stones for more than a decade [2]. In orthopedic surgery shock wave has been successfully used for bone formation. Its effects to cancer cell lines have been studied. In cancer therapy, clinical studies revealed enhancement of chemotherappeutic effects when it was combined with shock waves exposure [3]. Beside of the successful contribution of Extracoporeal Shock Wave Lithotripsy (ESWL) in clinical therapies, side effects of ESWL have been noticed, for instance, in the areas where shock waves were exposed tissue damages and bleeding were reported. These side effects are believed to be due to the shock wave / tissue interaction and cavitation production. Although shock waves in gases have been intensively studied, those in liquids or media with a complex non-uniformity and shapes have not been investigated.

2. Experiments

In our earlier study, equal-diameter gelatin spheres and cylinders packed in water, silicon oil and caster oil have been used as experimental models of tissue [4]. In order to simulate interaction of shock waves with intercellular fibrillar structures, such as cell cytoskeleton, in the present research thin porous layers of cotton immersed in water were exposed to underwater shock waves. The layers had 60%, 39.5%, and 16.5% opening area for one, two, and four cotton layers set-up, respectively. Shock waves were generated by explosion of 10 mg silver azide pellets (AgN_3; Chugoku Kayaku Co., Ltd., Japan), which were ignited by irradiation of a pulsed Nd:YAG laser beam. A stainless steel chamber equipped with observation windows was used and it made exact lateral, horizontal, and vertical alignment of the pellet and pressure transducers to be possible. PVDF needle hydrophone with 0.5 mm sensitive dia. and 50 ns rise time (Imotec Messtechnik, Germany) was used.

Double exposure holographic interferometry was used for quantitative flow visualization [5]. Figure 1 shows a schematic diagram of the optical set-up. The light source was a holographic double pulse ruby laser (Apollo Laser Inc. 22HD, 25 ns pulse duration, 1 J per pulse). The first ruby laser exposure was carried out before ignition of the pellet and the second exposure was synchronized with the propagation of the shock wave at the test section with a proper delay time. The whole sequences of the phenomenon were successfully observed.

3. Results and discussion

The attenuation of underwater shock waves was measured with needle hydrophones at various stand-off distances. The strength of incident shock waves was changed by adjusting the distance between the pellets and the layers (d1). The distance between the layers and the hydrophone was constant (d2=10.0 mm). All of the measurements were repeated with the same initial conditions and each time a new porous layer was used. A good reproducibility of experimental data was obtained. Figure 2 shows pressure histories at stand-off distance D=25 mm (d1=15 mm, d2=10.0 mm). The attenuated pressure traces for the different number of porous layers have a similar pattern as the underwater explosion wave. The attenuation ratio of overpressures, (Pw − Pa) / Pw, where Pw is underwater overpressure and Pa is attenuated one, is shown in Fig. 3. In Fig. 3 the experimental result corresponds to a nearly liner variation for different porous layers.

Figure 4, at 23 μs, shows infinite fringe interferogram the underwater shock wave after interaction with a single porous layer at d2=20.0 mm. A conical precursor wave was produced due to the stress wave propagation through the optical fiber. A clear wave reflection from the layer was observed which refers to splitting of the incident shock wave to a reflected and a transmitted wave and resulting attenuation in transmitted shock pressure.

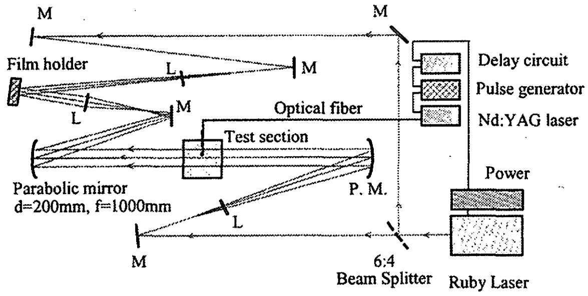

Fig. 1. A schematic diagram of holographic interferometric optical arrangement.

4. Conclusions

Effects of non-uniform structures on underwater shock wave propagation and attenuation created due to the interaction of shock waves with porous layers were clarified. The obtained results can be used as benchmark data to tune and validate CFD codes, which are useful to simulate the complex shock / tissue interaction.

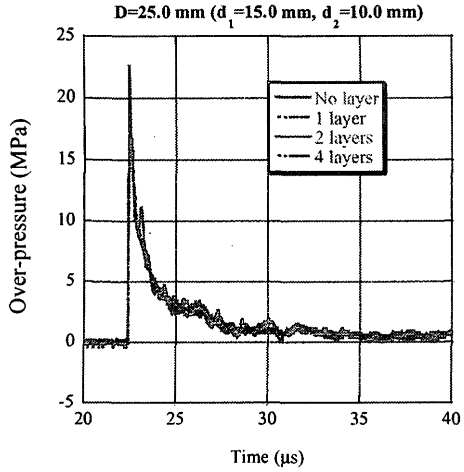

Fig. 2. Pressure histories for no layer and 1, 2, and 4 layers experiments measured at D=25 mm.

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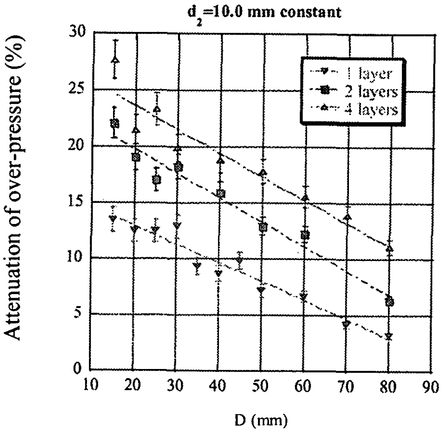

Fig. 3. Variation of shock overpressure attenuation ratio with total stand-off distance.

Fig. 4. Infinite fringe holograms of underwater shock wave induced by explosion of 10 mg silver azide pellet after interaction with a single cotton layer, d1=20 mm, at 23 μs.