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Polyurea coated aluminum plates under hydrodynamic loading: Does side matter?

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ABSTRACT

We report on the dynamic behavior of a polyurea-coated 6061 aluminum plate under hydrodynamic loading condition. The plate's deflection was measured using ultra-fast stereoscopic photography, and analyzed using 3D-DIC (digital image correlation) technique. The residual deformation of the plate after several shocks was measured using conventional cameras and the DIC technique. The experimental results show the benefits of the polyurea coating, with a clear indication that polyurea will better mitigate the shock if positioned on the side in contact with water.

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1. Introduction

Wave slamming endangers the structural integrity of planning boats [1]. The eventuality of hull breaching increases significantly with the speed of the boat, and therefore becomes of prime concern for the design of fast vessels. To decrease this risk, one must reduce the impulse inflicted to hull plates during wave slamming. A viable solution is to consider flexible boats capable of deforming during slamming. Yet, when considering the somewhat flexible structures instead of fully rigid ones, one must take into account the inherent risk associated with hull plates that are thinner than in conventional design, and are therefore prone to experience larger strains. To reduce this risk, lightweight and flexible polyurea coating of the aluminum hull plates can be considered as a means to reduce the potential breaching, keeping the vessel impervious for some time. This may perhaps impair the sailing capability of the vessel in terms of speed on one hand, but will allow its safe return to harbor on the other hand.

Polyurea has long been considered as a potential component of blast-mitigation systems.

Polyurea, which was first considered in the late 1980s as a coating layer designed to reduce corrosion damage, regained the attention of the scientific community with the work of Amirkhizi et al. [2]. Those researchers formulated a constitutive model focusing on polyurea's mechanical capabilities, namely its pressure sensitivity and visco-hyper-elasticity. The work included experiments showing the increased performance of polyurea coated metal plates. It also revealed the potential of polyurea as a protective layer increasing the survivability of structures under extreme conditions such as impact, blasts, ballistic penetration etc. This work generated a vast interest in polyurea. Sarva et al. and Yi et al. [3,4] shed some light on the microstructural origins of PU behavior. PU is a block copolymer composed of both "hard" and "soft" segments which are scattered intermittently (Fig. 1). The bi-segmented chains form a structure of soft segment matrix, with the hard segment domains scattered through it acting as a crosslink between polymer chains. Experiments were conducted to study both the quasi-static and dynamic response of polyurea to compressive loadings and show its strain rate sensitivity. The latter is explained through a glassy transition occurring in the hard segments. The glassy transition consumes energy thus conferring the PU its ability to dissipate stress waves induced by dynamic loadings.

Roland [6] studied the dynamic behavior of polyurea with respect to the effects of stoichiometry on the mechanical behavior. The dynamic behavior of polyurea under dynamic tensile load was shown with emphasis on yield strength variations due to strain rate. The experimental results of Sarva et al. and Yi et al. [3,4] with those of Ronald et al. [6] inspired other researchers to try and develop constitutive models for polyurea which can be implemented in finite elements codes. Several researchers [7–9] proposed various constitutive models capable of describing the behavior of polyurea by superposing a rate dependent visco-elastic model with hyper-elastic model describing the large deformation material behavior

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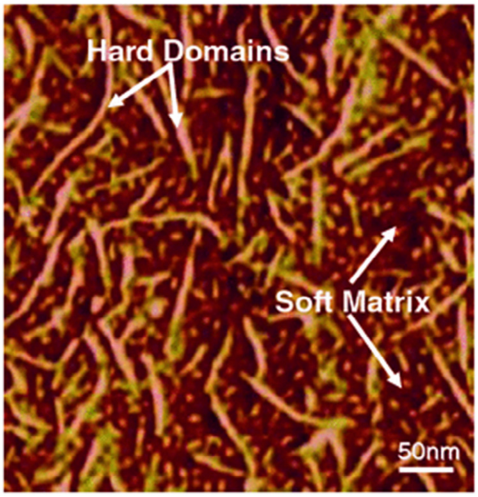

Fig. 1. AFM image of polyurea reprinted from Ref. [5].

at low strain rates. Further insights in the molecular level were suggested by Grujicic [5,10,11], discussing the physical origins of the attenuation capabilities of polyurea.

This study of the behavior of polyurea was accompanied by experimental attempts to use this material as a protective layer, increasing the survivability of structures. An effort to design sandwich structured plates as armor plates continued over the last decade or so, including it as an interlayer candidate for this purpose. Bahei-El-Din [12] proposed and studied fibrous laminates sandwich plates with a polyurea interlayer as a blast resistant structure using FE simulations.

Simulations and experiments of ballistic impact of polyurea–steel composite plates were conducted by El Sayed et al. [13] with great attention paid to developing a valid constitutive model [9]. Xue et al. compared the performance of coated vs. uncoated plated under ballistic penetration to show the energy absorption capabilities of polyurea [14]. LeBlanc et al. [15,16] and Amini et al. [17] investigated the increased capabilities of polyurea coated metal plates under hydrodynamic shocks.

It appears that in order to overcome the risks involved with wave slamming (a hydrodynamic shock), one should further explore the potential of a polyurea coating over boat's aluminum hull plates.

This experimental study examines the performance of polyurea coated vs. uncoated 6061 aluminum alloy plates. The study shows the potential of the polyurea as an active load-carrying member in case of hydrodynamic loads. It is observed that the nature of the fluid–structure interaction between the water and the tested plate affects the overall momentum history absorbed by the plate due to shocks in the water. This interaction emphasizes the importance of the *selection of the coated side of plate*. The interaction between the water and the plate takes place at their interface, and it is therefore crucial to characterize the resultant structural behavior when the hydrodynamic load encounters either the layer of (initially) soft polyurea or the tougher aluminum side. We will show that, just by flipping the coated side, one can significantly improve the performance of the hull plates. This experimental research aims at providing insights to designers and improving the efficiency of polyurea coatings for hydro-dynamically loaded structures.

The study consists of experiments aimed at simulating violent hydrodynamic loads that mimic wave slamming at high cruising speeds. First, we introduce the experimental setup and numerical model used in this work. Next, experimental results are presented; those detail the plate deflections and strains pertaining to each tested configuration. A short discussion follows, ensued by concluding remarks.

2. Experimental setup

2.1. Loading device

The experimental setup is shown schematically in Fig. 2. The test plate obturates a water-filled cylinder, the latter being shock loaded by an instrumented bar-piston system.

A compressed air gun was used to accelerate a 20 cm long, 25 mm diameter C300 Maraging steel projectile onto a 150 cm long incident bar of the same material and diameter (Hopkinson bar setup). The impact induces an elastic stress wave which propagates along the incident bar. The latter is positioned in contact with the back side of a stainless steel, 19 cm diameter, piston confined by a pressure cylinder. As the stress wave reaches the piston, it compresses the water inside the cylinder thus creating a hydrodynamic shock wave. The shock wave propagates through the water, and the pressure history is measured via a fast response pressure sensor (PCB model 113B22). It then almost immediately hits the target plate. The setup is shown in Fig. 3. Note that similar setups have been used in the past, e.g. by Deshpande et al. [18] to study the response of metallic foam cores sandwich plates under hydrodynamic shocks. Espinosa and Mori [19,20] used a similar setup with a conical pressure cylinder to study the behavior of I-core sandwich structures subjected to water blasts. In the absence of actual data from sea-experiments, the current experiments are meant to mimic the reality to some extent and the actual inflicted shocks can be adjusted at a later stage to closely replicate the sea-reality.

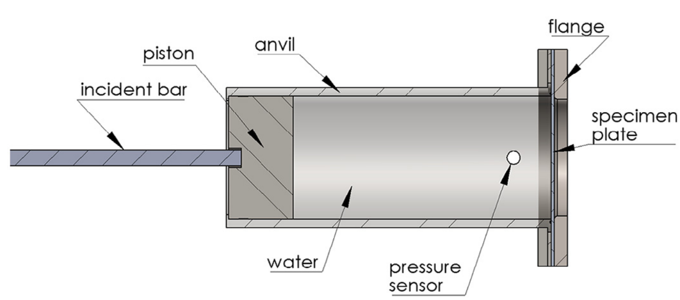

Fig. 2. Section view of the setup.

Fig. 3. Incident bar in contact with piston (inserted in the pressure cylinder).

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