PEER "Research Nuggets"

Title: Experimental and Numerical Investigation of Ballistic Impact Response of Polymethylmetacrylate

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Motivation: Polymethyl methacrylate (PMMA), known as acrylic or Plexiglas, is a popular transparent polymer valued for its lightness, high strength-to-density ratio, UV and heat resistance, and transparency. These properties make PMMA suitable for various applications, including construction and military uses like transparent armor and eye protection gear. While research on PMMA's impact behavior exists, it often focuses on limited loading conditions and specific damage modes, such as uniaxial tensile loads. Most studies examine mechanical properties under static or quasi-static conditions, which do not accurately represent real-world scenarios. Thus, there is a pressing need for more comprehensive investigations into PMMA's performance under practical loading conditions to enhance its application as a protective material.

Objectives: This research aims to gain fundamental insight on the impact response and failure behavior of PMMA plates from the point of view of energy conversion trends under ballistic impact considering variations in the plate-thickness and projectile velocity.

Methodology: For understanding characteristics of Polymethylmetacrylate (PMMA) under impact, the damage behavior of PMMA plates with various thicknesses (1.5 to 6.0 mm) subjected to ballistic impacts with various velocities (63 to 180 m/s) is experimentally investigated using a specialized testing apparatus. Moreover, numerical simulations using the Finite Element Method (FEM) are conducted for the corresponding experimentally studied cases. Furthermore, comparative results from the verified numerical model are interpreted to describe the impact behavior obtained using the FEM.

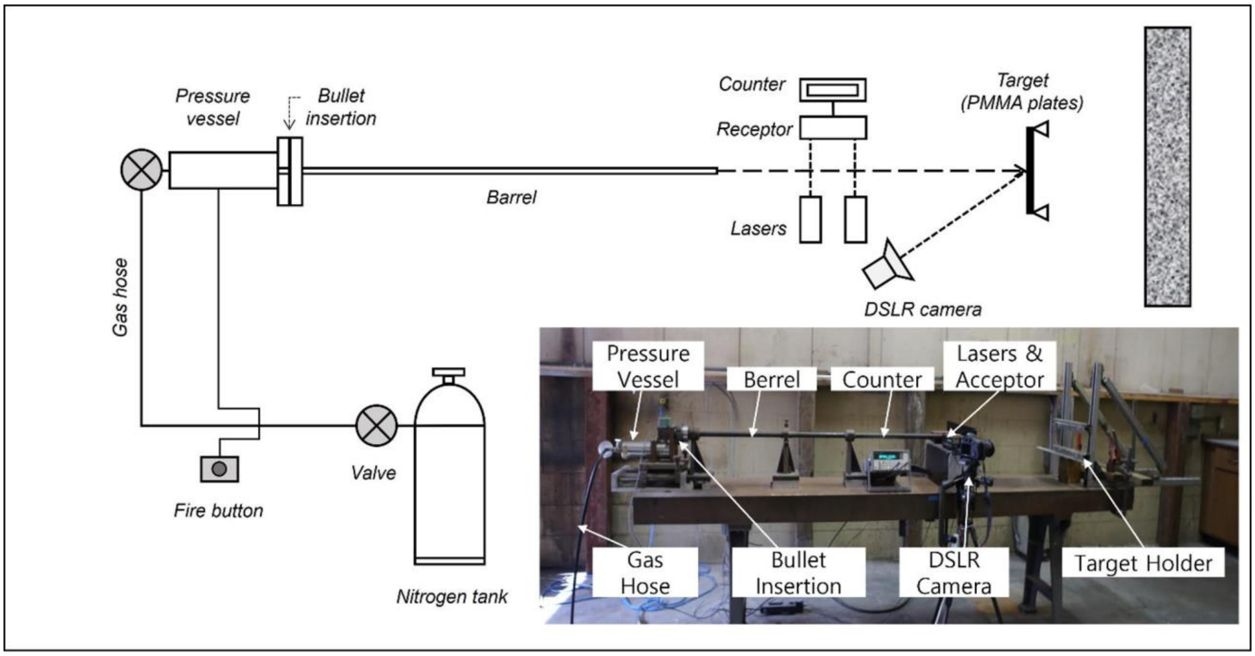
Results: Both experiments and simulations using the FEM are conducted on five plate-thickness cases for five impact-velocity values for a total of 25 studied cases. The crack patterns and perforations from each case during the experiments and simulations are compared verifying the computational models using the FEM. The main conclusions can be summarized as follow:

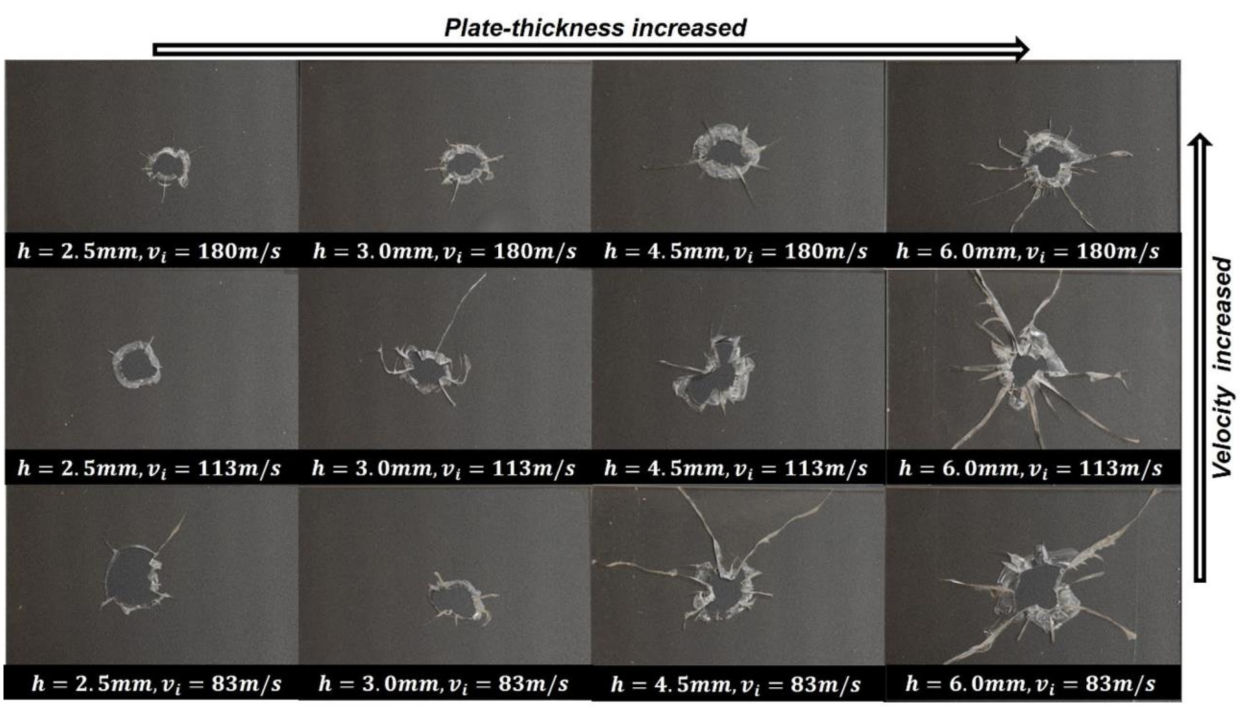
1) The ductile and tensile failure criteria considered in the FEM of the PMMA plate produced reasonable approximation to the experimental results throughout all considered cases with different plate-thicknesses and impact-velocity values.

2) The experimental and numerical results show that the PMMA plates become more brittle under the higher impact-velocity due to the rate-dependency and hardening effect.

3) The numerical approach using FEM offers considerable insight into the energy conversion during ballistic impact, and dependency of the damage behavior of the PMMA plate on the plate thickness and the projectile-velocity.

4) From the numerical simulations, it is observed that the kinetic energy loss of the projectile during the impact is linearly varying with the plate-thickness regardless of the initial velocity of the projectile (bullet).





Conclusions: Although the PMMA plates are generally brittle in the selected range of impact velocity, it is found that these plates exhibit ductile behavior under low-velocity impacts. Moreover, the numerical simulations imply that the kinetic energy loss of the projectile is linearly dependent on the plate-thickness while the impact velocity hardly affects this loss. This behavior obtained experimentally and numerically illustrates the usefulness of the PMMA material for the use as a protective layer in many applications involving ballistic (high velocity) impacts.

Future directions/References: The energy conversion of PMMA can be further studied with the quantification of experimental results, such as 3D-DIC analysis and the investigation of residual velocity of bullet after impact to estimate the out-of-plane deformation and ballistic limit, respectively. The continued investigation of PMMA with the numerical approach would establish future usage for PMMA to be a more suitable material substituting glass.

Keywords: Ballistic impact, Brittle behavior, Ductile response, Failure mode, FEM, PMMA.