Effect of polyurea on the dynamic response of steel plates

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Abstract

The dynamic response of circular plates subjected to impulsive loads has been investigated experimentally. In the present paper we report the procedure we have employed and the results we have obtained, through our recently-developed *reverse ballistic* experimental technique.

A convenient option to enhance the energy absorption capability of steel plates and to improve their resistance to fracturing in dynamic events is to spray-cast a layer of polyurea on the plates. We have examined the effectiveness of this approach, focusing on the question of the significance of the relative location of the polyurea layer with respect to the loading direction, *i.e*., whether the polyurea cast on the *front face* or on the *back face* of the steel plate would provide the optimal blast mitigation.

We have found that the polyurea layer can have a significant effect on the response of the steel plate under dynamic impulsive loading both in terms of failure mitigation and energy absorption, only if it is deposited on the back face of the plate. And, remarkably, when polyurea is placed on the front face (*i.e.,* the blast-receiving face) of the plate, it may actually enhance destructive effect of the blast, promoting (rather than mitigating) the failure of the steel plate.

Introduction

A convenient technique to enhance the energy absorption capability of steel plates and to improve their resistance to fracturing in dynamic events is to spray-cast a layer of polyurea on the plates. Recent studies show that applying a layer of polyurea backing to steel plates significantly enhances the resistance of the bilayer plate to the impulsive loading. Various experiments (Mock and Balizer, 2005) show this improvement can change the response from full penetration of the projectile to full fracture mitigation under similar test conditions.

Experimental studies of plates subjected to impulsive loading using various test techniques have been widely reported in the literature. These include experiments in which the structure is subjected to air pressure waves created by explosive devices, underwater explosive forming, shock loading by mean of metal foam projectile impact, and direct impulsive loading using plastic sheet explosives and spring loaded arms. Nurick and Martin (1989) have reported a comprehensive review on the experimental works on the deformation and failure of thin plates subjected to impulsive loads.

Recently, a reverse ballistic experimental technique has been developed at CEAM/UCSD. Using this method, one can apply a controlled dynamic load on a simply supported plate. The experimental results are reproducible and reliable.

In the present paper, we report the procedure and results of investigating the effect of polyurea on the dynamic response of steel plates, using the reverse ballistic technique.

Experimental Procedure and Results

The reverse ballistic tests on DH-36 steel plates were performed at UCSD's Center of Excellence for Advanced Material's gas gun facilities laboratory. In this study, an aluminum projectile, carrying a DH-36 steel plate, is propelled by a gas gun at a controlled velocity toward a polyurethane target that rests against a 3-inch Hopkinson bar. A number of tests were performed at various projectile velocities, using plates of slightly different thicknesses. The steel plates were designed with a built-in thick ring on its edge, to allow large deformation and ensure failure to occur within the central part of the plate; see Figure 1.

Figure 1. Un-deformed DH-36 steel plate

A number of the tests were conducted on steel plates with polyurea cast on its dish side. The experiments were performed in four different configurations: Monolithic steel plate loaded on the *flat-side,* monolithic steel plate loaded on the *dish-side,* bilayer plate loaded on the flat-side, and bilayer plate loaded on the dish-side. For each configuration we calculated input energy per unit thickness of the plate. Due to geometrical asymmetries that the thick ring causes, the plates that are loaded on the similar side, i.e. dish-side or flat-side, are compared with one another. Figure 2 shows the final deformed profile of the plates for different configurations tested at similar input energy per unit plate thickness for each loading direction (i.e. dish-side or flat-side).

The comparison of Figures 2-a and 2-b, reveals that the polyurea layer has no significant effect on the fracture resistance and energy absorption of the plate when it is placed on the loading face of the plate. However, when the polyurea is cast on the face opposite to the loading face and loaded with the same input energy per unit thickness (about 21,000J/cm), the polyurea backing significantly mitigates the failure of the steel plate; see Figures 2-c and 2-d.

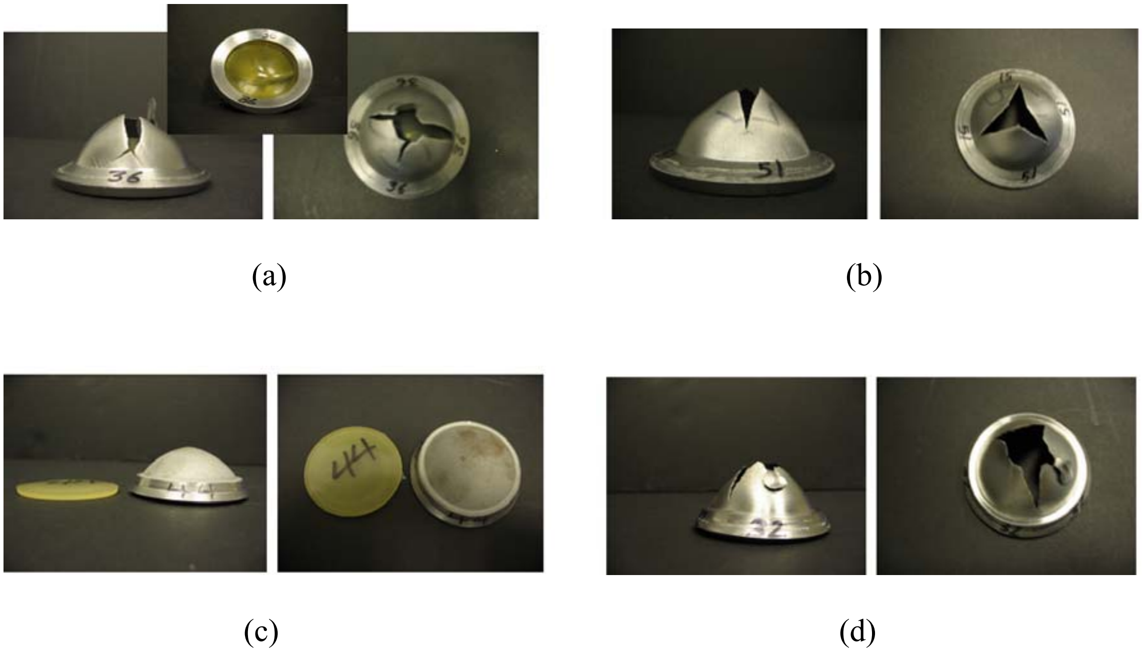

Figure 2. Side and top view of the deformed DH-36 steel plates tested in different configurations: (a) steel plate with polyurea cast on dish-side and loaded on dish-side (input energy per unit thickness, 16,128J/cm); (b) monolithic steel plate loaded on dish-side (input energy per unit thickness, 16,379J/cm); (c) steel plate with polyurea cast on dish-side loaded on flat-side (input energy per unit thickness, 21,016J/cm); and (d) monolithic steel plate loaded on flat-side (input energy per unit thickness, 21,013J/cm).

Conclusion

A new reverse ballistic experimental technique is developed to investigate the effect of polyurea on the dynamic response and failure of steel plates. It is found that a polyurea layer can have significant effect on the response of the plate under dynamic impulsive loading, both in terms of failure mitigation and energy absorption, only when it is cast on the back face of the plate. And, remarkably, when polyurea is placed on the front face (*i.e.,* the blast-receiving face) of the plate, it may actually enhance destructive effect of the blast, promoting (rather than mitigating) the failure of the steel plate.

Reference

1. Teeling-Smith RG, Nurick GN. The deformation and tearing of thin circular plates subjected to impulsive loads. Int J Impact Engng 1991; 11:1:77-91
2. Nemat-Nasser S, Guo WG. Thermomechanical response of DH-36 structural steel over a wide range of strain rates and temperatures. Mechanics of Materials 2003; 35:1023-1047.

3. Hutchinson JW. Notes on necking retardation in metal-elastomer bilayers. Personal communication 2005.
4. Nurick GN, Martin JB. Deformation of thin plates subjected to impulsive loading-a review, Part II: experimental studies. Int J Imact Engng 1989; 8:2:171-186.
5. Rudrapatna NS, Vaziri R, Olson MD. Deformation and failure of blast-loaded square plates. Int J Impact Engng 1999; 22:449-467.
6. Olson MD, Nurick GN, Fagnan JR. Deformation and rupture of blast loaded square plates-predictions and experiments. Int J Impact Engng 1993; 13:2:279-291.
7. Nurick GN, Gelman ME, Marshall NS. Tearing of blast loaded plates with clamped boundary conditions. Int J Impact Engng 1996; 18:7-8:03-827.
8. Menkes SB, Opat HJ. Tearing and shear failure in explosively loaded clamped beams. Expl Mech 1973; 13:480-486.
9. Thomas B, Nurick GN. The effect of boundary conditions on thin plates subjected to impulsive loads. In plasticity 95- Dynamic Plasticity and Structural Behaviors, Eds Tanimura S, Khan AS. Gordon and Breach Publishers, 1995: 85-88.
10. Nurick GN, Shave GC. The deformation and tearing of thin square plates subjected to impulsive loads-an experimental study. Int J Impact Engng 1996; 18:1:99-116.
11. Bonder SR, Symonds PS. Experiments in viscoplastic response of circular plates to impulsive loading. J Mech Phys Solids 1979; 27:91-113.
12. Shenoy VB, Freund LB. Necking bifurcations during high strain rate extension. J Mech Phys Solids 1999. 47:2209-2233.