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Using ceramic plates as shielding for concrete blocks against projectile penetration

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Abstract Numerical simulation of the response of concrete structures to impact loading is an important tool in both the design of hardened protective structures and in the planning for effective attacks against such structures. This paper presents the development of an accurate numerical model using AUTODYN to study the response of concrete structures shielded by ceramic (Al_2O_3-99.7%) plates exposed to 23 mm projectile. Concrete and ceramic are modeled using a combined mesh and meshfree numerical technique. The used meshfree Lagrangian technique (SPH) is to overcome problems of mesh tangling and remove the requirement for the use of erosion algorithms. The technique also allows an explicit representation of ceramic through (SPH) element formulation. In such a model, the concrete region local to the penetrator, which experiences large deformation, is represented using the SPH solver. The modeled penetrator and the concrete further away from the impact observed to undergo little or no deformation by using the Lagrange solver.

The aim of this paper was to study numerically the penetration resistance of concrete structures shielded by ceramic (Al_2O_3-99.7%) plates. The main findings show an enhancement in the penetration resistance of about 66% while using ceramic plates. Here, we used ceramic because of its electric, magnetic, and thermal insulation. Hence, we can use concrete structures shielded by ceramic in many types of medical, nuclear, power generating and electronic applications.

Introduction

In civilian and military applications, over the years concrete is used as a construction material for construction of protective structures. Great demand exists for designing of nuclear plants, power plants, military structures, water retaining structures, highway barriers, etc., to resist the penetration and perforation of concrete structure against kinetic projectile, generated both accidentally and deliberately, in various impact and blast scenarios. (e.g. failure of a pressurized vessel, failure

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of a turbine blade or other high speed rotating machines, and aircraft crashes, fragments generated by accidental explosions); terrorist attack and etc. Critical impact energy is the dominant cause of damage in dynamic of local impact phenomena [1,2,8,11]. When hard projectile impacts with concrete target, critical impact energy of the projectile is a main reason that makes the concrete target deform. Therefore, critical impact energy, which can cause penetration and perforation in concrete structures, is also noteworthy in determining the dynamic response of concrete structures against the penetration and perforation of hard projectile [1,2,9]. In this paper, a numerical simulation study is conducted to show the effect of using ceramic (Al_2O_3-99.7%) plates as a reinforcement to concrete target.

There are two groups of models. First group the target is concrete to validate the numerical simulation according to experimental investigation that was performed by Mohamed et al. [3]. In which steel blunt-nose projectile with a diameter of 23 mm and a mass of 175 g is fired with striking velocity about 960 m/s to hit the target, and the penetration depth was 400 mm. The second group is concrete shielded by (Al_2O_3-99.7%) ceramic plate as a sandwich panel.

Ceramic can be used as an alternative to steel reinforcement in specific structures such as medical, nuclear, power generating and electronic applications, because of its functions (electric, magnetic, and thermal insulation) and to overcome steel lacks.

Ceramic is used because of its technical and cost advantages. Technical advantages [4]; high strength, high hardness, corrosion resistance, electromagnetic neutrality, thermal insulator and light weight. Therefore ceramics (Al_2O_3-99.7%) can be used not only for protective structures but also for medical, nuclear, power generating and electronic applications. Cost advantages [4]; net-shape ceramic manufacturing, however, can lower the cost by almost 80% for many applications by eliminating or reducing the cost of hard machining using diamond tooling. Also ceramics can be injection molded. This lowers the cost to the level of stainless steel.

Background

Local and overall impact phenomena; for hard missile impact are schematically shown in Fig. 1 with very low velocities, the missile will strike the target wall and bounce off without creating any local damage. As the velocity increases, pieces of concrete are spalled (ejected) off the front of impacted face of the target. This spalling forms a spall crater that extends over a substantially bigger area than the cross-sectional area of the striking projectile. As the velocity continues to increase, the projectile will penetrate the target to depths beyond the depth of the spall crater, forming a cylindrical penetration hole with a diameter only slightly bigger than the missile diameter. As the penetration depth increases, the projectile will stick to the concrete target rather than rebounding. At this stage, the impact meets the criteria of a plastic impact. However, even at lesser penetration depths, we can treat the impact approximately as a plastic impact when determining the energy absorbed by the impacted target. Further increase in velocity produces cracking of the concrete on the back surface followed by scabbing (ejection) of concrete from this rear surface. The zone of scabbing will generally be much wider but not as deep as the front-face crater. Once scabbing begins, the depth of penetration will increase rapidly. For low barrier thickness-to-projectile, diameter ratio (< 5) the pieces of scabbed concrete can be large and have substantial velocities. As the projectile velocity increases further, perforation of the target will occur as the penetration hole extends through to the scabbing crater. Still higher velocities will cause the projectile to exit from the rear face of the target. Upon plastic impact, portions of the total kinetic energy of the impacting projectile converted to strain energy associated with deformability of the projectile and energy losses associated with target penetration. The reminder of the energy is absorbed or given as input to the target. This absorbed energy results in overall target response that includes flexural deformation of the target barrier and deformation of its supporting structure.

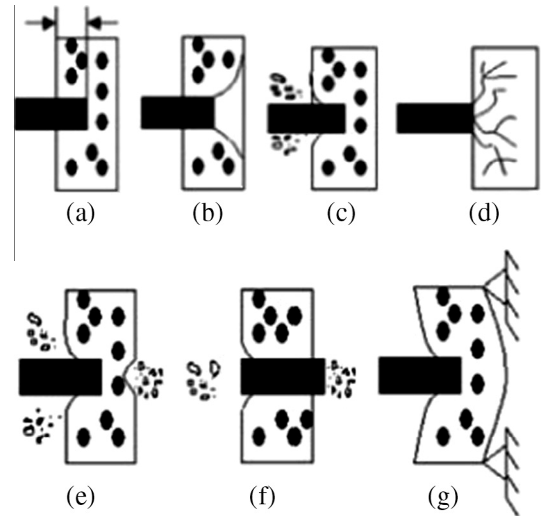

Figure 1 Missile impact effects on concrete target: (a) penetration, (b) cone cracking, (c) spalling, (d) cracking, (e) scabbing, (f) perforation, and (g) overall target response.

Numerical analysis

The efficient and accurate numerical prediction of kinetic energy penetrator impacts on the concrete structure requires three basic components; appropriate numerical techniques, a set of constitutive laws and material data input to the constitutive laws. Here a description of a combined mesh and meshfree approach developed in the AUTODYN software [5] and used for the simulation of projectile impacts onto plain and shielded concrete.

The concrete target represented numerically by a mesh based Lagrangian technique except in the regions where high deformations are expected. Here, a meshfree Lagrangian technique (SPH) used to overcome problems of mesh tangling and remove the requirement for the use of erosion algorithms. Technique for representing continuous joins between mesh and meshfree Lagrangian techniques is presented [6]. Ceramic represented explicitly through a meshfree Lagrangian technique (SPH) element formulation. The concrete region local to the penetrator, which experiences large deformation, represented using the SPH solver. The modeled penetrator and the concrete further away from the impact observed to undergo little or no deformation by using the Lagrange solver.