Diameter and Pattern Effects of Al_2O_3 Balls on Ballistic Strength of Metal–Ceramic Composites

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Abstract

In composite materials made from metals and ceramics, a metallic substrate material is reinforced with ceramic hardened particles. This combination makes it possible to combine the low weightiness of the metal with the resistance of ceramics. Used metals in those types of composites have greater density than the ceramics, so relatively, metals are heavier than ceramics, but in metal-ceramic composite applications, the metal parts are used in small quantities as in thin slices. These types of composites can combine attractive properties of both a ceramic, such as high temperature resistance and hardness, and those of a metal, such as the ability to undergo plastic deformation.

Metal-ceramic armors are used in the fields where the weight factor is not crucial yet important for mobilization. Metal-ceramic composites show their unique values in armor technologies especially in vehicle protection applications.

Ceramic balls offer advantages such as being lightweight, lower friction resistance, high temperature resistance, higher rigidity, higher hardness, and higher corrosion resistance than metallic composite core, but these properties belong to the material nature. In ballistic applications like high velocity impact situations, spherical shape, theoretically must influence bullet trajectory. Because of the curved surface of a sphere, chances are a projectile hits any spherical surface obliquely. That means the projectile loses some of its kinetic energy by transferring it into the sphere and changing course into another trajectory axis. Shao et al. showed this trajectory deflection effect vividly [1].

Keywords: metal-ceramic composites, ballistic impact, finite element method

Introduction

In the chosen base study, alumina ceramic balls are used as the main component for the armor plate [2]. Backing material is high hardness steel layer of 5.13 mm. Ceramic balls are adhered to backing layer using high tensile strength polymer and the whole plate has the outer dimensions of 300 × 300 mm. The projectile is 13,4 g. of cold rolled annealed steel with the standard dimensions taken from Standardization Agreement of North Atlantic Treaty Organization [3].

Table 1. Exit velocity test results of base study [2]

Armor	Impact velocity (m/s)	Exit velocity (m/s)	% Reduction of initial velocity
12,7mm 90% Al_2O_3 Balls / 5,13mm HHS	2300	1051	54,2
15,9mm 90% Al_2O_3 Balls / 5,13mm HHS	2305	764	67

It is intended to investigate and show the ballistic strength effects of ceramic ball diameter and ceramic ball pattern on a backing plate in the present study. 12,7 mm and 20 mm of diameters for ball diameter parameter and hexagonal and checkerboard layouts for ball pattern parameters are investigated and the results are compared.

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In the present study, depending on the exit bullet-velocity results of the base study, a verification process is conducted as the first step. The hexagonal pattern of Al_2O_3 balls and the High Hard Steel backing plate of the base study is modeled in ANSYS FEM software. All the dimensions and material properties are kept same with the base study parameters. The results are in a good agreement with a convergence ratio of 97,65%. After getting verified our FE model, ballistic impact simulations are executed with different diameter and pattern (checkerboard) of Al_2O_3 balls.

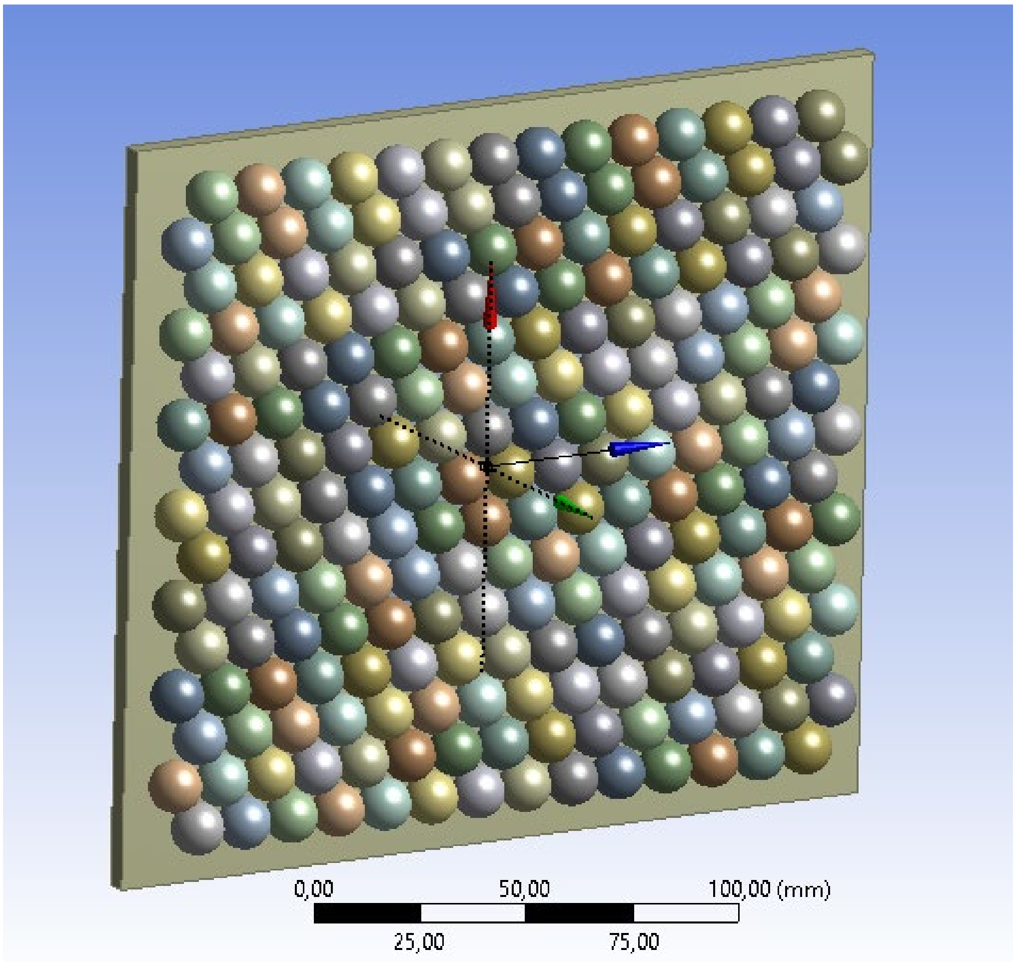

Figure 1. FE model of armor with 12,7 mm spheres, in hexagonal formation

Table 2. Exit velocity results of verification model

	Exit velocity (m/s)	% Convergence
Base study	1050,95	97,65
Verification model	1026,3	

Results

After the verification of present model, without changing any other parameters, the ceramic ball formation is changed from hexagonal to checkerboard. Applying the same ballistic impact velocity with same bullet model, it is concluded that the exit velocity of the bullet becomes 1050,1 m/s.

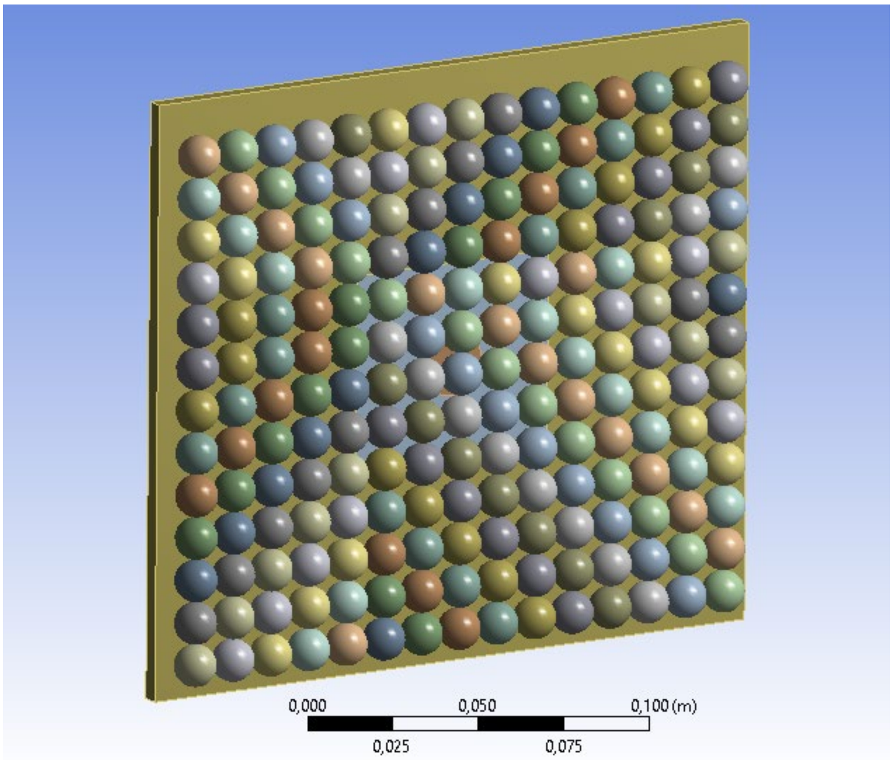

Figure 2. FE model of armor with 12,7 mm spheres, in checkerboard formation

Table 3. Different diameter and pattern results of exit bullet-velocities

Pattern/Diameter	12,7 mm	20 mm
Hexagonal	1026,3 m/s	752,61 m/s
Checkerboard	1051,1 m/s	277,71 m/s

The results showed that, 20 mm diameter of Al_2O_3 balls dramatically improve the ballistic strength of the armor with respect to the ones with 12,7 mm of diameter. For the armor with ceramic balls of 20 mm diameter, checkerboard formation slows down the exit velocity of the bullet by 63,1% more than hexagonal formation. Increasing the ball diameter from 12,7 mm to 20 mm, decreases the exit velocity value by 26,67%, in hexagonal formation. The same diameter upsizing for checkerboard formation, develops ballistic strength of the armor by 73,58%.

Conclusions

Ballistic impact experiment on an armor plate with Al_2O_3 ceramic balls and high hardness steel backing plate from literature, is simulated with a verified model. Ceramic ball diameter and formation parameters are investigated with exit velocity simulations.

- Employing checkerboard formation of ceramic balls in a composite armor provides better ballistic resistance than the one with hexagonal formation.
- Upsizing ceramic ball diameter improves ballistic strength of metal-ceramic armor.
- Ceramic ball diameter upsizing affects the ballistic strength of the armor with checkerboard formation more than the one with hexagonal formation.

References

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