Optimization of the Thickness of Aluminum Ceramic Targets using Numerical Simulation

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Abstract**—** One of the most important issues in the design of armored plates is to achieve the highest efficiency coefficient in a given weight or thickness. Therefore, in this study, a target of Alumina ceramic and Aluminum 6061 support layer is sought to achieve the highest resistance using simulation. For simulations in this study we use explicit Solver software, the result of comparison with the experimental work of other researchers in the field of ceramic armor shows that simulation The work done has an acceptable accuracy. The results show that with increasing speed of bullet collision, the role of ceramic paints becomes more intense and its optimum thickness increases. As the collision angle increases, the role of aluminum support plate plays a more important role.

Index Terms**— Aluminum ceramic armor, optimization, explicit solving, simulation.**

I. INTRODUCTION

THIS This paper aims to optimize the dimensions of aluminum ceramic armor. The issue of penetration in the military industry has a special position and so far there have been many studies in this field. One of the applications of penetration topics is the creation of armor, anti-bullet vests, shelter design, hangar and more. Long rod projectiles are one of the most important projectiles in the discussion of heavy armor. In this study, their influence on ceramic armor has been investigated. From the researchers who examined the surface failure problem are Rozenberg et al [1], they studied the relationship between ballistic returns and compressive strength of ceramic tiles. Hauver et al [2] examined the change in target resistance during the penetration of Long rod projectiles. During the collision due to the high pressure on the surface of the Long rod projectile, the aiming beam flows at the point of contact of the projectile material radially to the outside of the collision surface. At this time and during the surface failure phase, there is no penetration in the ceramic. Anderson and. Royal [3] examined the ballistics performance of Al2O3 ceramic. Landberg et al [4] studied the effect of metal projectiles on ceramic targets vertically. Orphal and Anderson [5] examined the dependence of the bullet penetration rate on the speed of the bullet collision.

One of the most important issues in the design of armored plates is to achieve the highest efficiency coefficient in a given weight or thickness. Therefore, in this paper, we will examine the target of the alumina ceramic and the aluminum-6061 support layer to achieve the highest resistance.

The goal is to achieve the optimum thickness ratio of this target at different speeds and angles.

For many years, armored engineers followed a general law that assigned two-thirds of the weight of the armor to the ceramic and one-third to the support layer. The ceramic-aluminum armor with this ratio exhibited good thickness performance at low collisional speeds and vertical angles. In the area of optimizing the thickness ratio for a ceramic-metal armor, little information is available; further investigation of this can result in achievable results.

Hetherington and Ali [6,7] examined a metal bullet at 850 m / s with a ceramic-aluminum armor. According to the orders, they concluded that at this speed and angle of the vertical collision the best thickness ratio is 1/5, but at the same speed and angle of 30 degrees, the best thickness ratio is reduced to 1.

In another study, Hohler et al. [8] examined the thickness ratio of these types of armor. In their experiments, a Tungsten Treadmill with a diameter of 8.2 mm and a speed of 1500 m / s was tested in a ceramic armor / RHA. According to these experiments, the ratio of optimum thickness to the normal collision angle was equal to 2; at this same speed and angle of collision of 45 degrees this ratio decreased to 1.25; and at a collision angle of 60 degrees this ratio was as high as 82.

II. OPTIMIZATION OF THE THICKNESS OF METAL CERAMIC TARGETS WITH NUMERICAL SIMULATION

Based on experiments performed by Hetherington [6], and Hohler [8 and 9], it can be concluded that the optimal thickness ratio depends on various factors such as the speed and angle of impact, as well as the ratio of ceramic strength to the support layer. The following experimental relationship is suggested for predicting optimal thickness.

$$\frac{T_{cer}}{T_{met}} = \frac{V}{60000}\left(90-\beta\right)\left(\frac{A_{cer}}{2A_{met}}\right) \tag{1}$$

In the given relationship (1), v is the collision velocity and in m/s, β the angle of impact, A_{cer} the initial normal ceramic resistance and the ultimate metal resistance. A_{met} In Table I, a

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comparison was made between the laboratory values and the values obtained from equation (1).

TABLE I
COMPARING THE OPTIMUM THICKNESS OBTAINED FROM RELATIONSHIP 1 AND LABORATORY VALUES

velocity (m/s)	Angle of impact	Experimental optimum ratio	The optimal ratio of the equation(1)	References
850	0	1.5	1.31	[6]
850	30	1	0.87	[6]
1450	60	0.71	0.73	[9]
1500	0	2	2.32	[8]
1500	45	1.25	1.16	[8]
1500	60	0.82	0.77	[8]

In the following section, we will discuss the modeling and geometry of the problem, material gender and boundary conditions, in this research, a steel bullet with a conical nose hits a target sheet of AL2O3 ceramic with an aluminum support plate that See the geometry and meshing of the target and the bullet in Fig.1, Our goal is to obtain the optimal thickness for ceramic and aluminum support, in which the target is best.

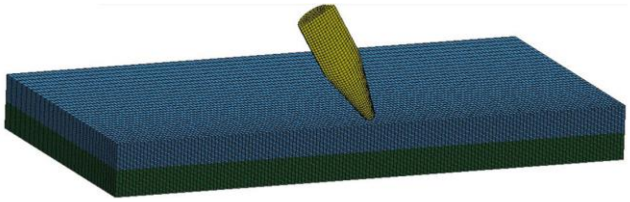

Fig. 1. Problem Geometry and meshing

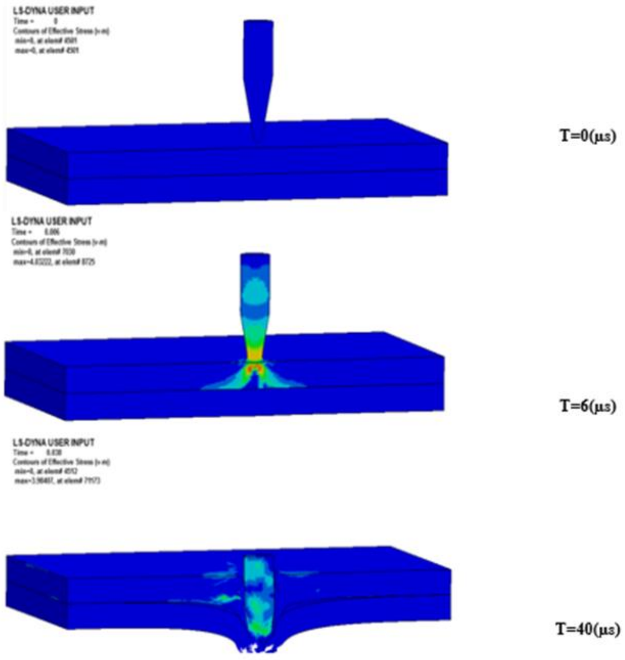

Fig. 2. Bullet Infiltration in target at 1000 m/s

Table II
SPECIFICATIONS OF MESH AND TARGET AND PROJECTILES MODELS

material	Element type	Material model	Equation of state	boundary conditions
ceramic	Cubic	Johnson *holmquist*	-	clamp
Steel	Cubic	Johnson Cook	Mie-Gruneisen	free
Aluminium	Cubic	Johnson Cook	Mie-Gruneisen	clamp

Table III
PROPORTIONAL STEEL MATERIAL MODEL

amount	Symbol (unit)	Parameter
7800	Ro $(\frac{kg}{m^3})$	Density
80	G (Gpa)	Shear modulus
210	E (Gpa)	Modulus of elasticity
0.31	PR	Poisson's ratio
507	A (Mpa)	Initial yield strength
320	B (Mpa)	Hardness constant
0.28	C	Strain rate constant
0.15	D_1	First failure parameter
0.72	D_2	Second failure parameter
1.66	D_3	Third failure parameter
0.005	D_4	Fourth failure parameter
-0.84	D_5	Fifth failure parameter
1.70	Γ	Gruneisen parameter

In Figure 2, a sample of simulation performed for thicknesses equal to the ceramic and aluminum armor and bullet penetration at a collision velocity of 1000 m /s.

In Table II, the specification of the material model, the objective and projection state equations, and the boundary conditions of those used in the simulation are shown.

The alumina ceramic material and the aluminum support layer are 6061 and is the type of steel projectile whose specifications are given in Table III.

III. RESULTS AND DISCUSSION

In this part of the paper, which consists of two section, we first verify the results of numerical simulations. then examine the optimum thicknesses for the ceramic-aluminum target at different speeds of the bullet.

A. validation

One of the main parts of any research work is validating the results with other researchers' research.

Table IV
Comparison of numerical and laboratory values [10] for the amount of displacement of the backup layer at an angle of 0 ° from the normal line on the surface

test number	collision speed(m/s)	Numerical results (mm)	experimental results (mm)	percentage error
1	775	14.67	14.91	1.61
2	844	16.35	17.77	7.99
3	378	8.58	7.62	12.60
4	266	6.41	7.33	12.55
5	287	6.57	6.11	7.53

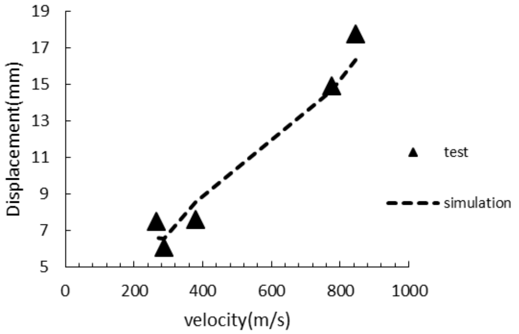

Fig.3. Comparison between simulation results and laboratory results [10]

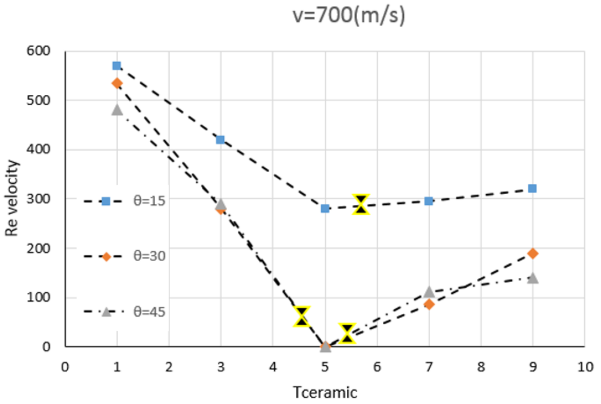

Fig. 4. Residual velocity in different thicknesses of ceramic at different angles and comparing the optimum thickness of the numerical solution and the experimental relation at the collision velocity (700 m / s)

In this section, in order to validate the numerical solution, we use the comparison of the displacement value of the backup layer with the experimental values [10]. The comparison of results is shown in the table IV.

Fig.3 shows a comparison between the results of the simulation and the experimental results [10] in graphical form.

In the following, the thickness optimization problem has been investigated.

B. *Optimization of optimal thickness ratio of ceramic / metal targets*

In this section, we will examine numerically the optimal thickness ratio of ceramic to supporting metal to achieve the highest performance of the armor. In this study, the projectile is thrown at three different speeds of 700, 1000, and 1400 m / s towards a ceramic / metal target with a total thickness of 10 mm.

In the diagrams below, the mark ⧗ in each graph represents the optimum ceramic thickness at that angle and the collision velocity, which is calculated from equation 1. The angles are measured relative to the line perpendicular to the surface; The optimum ceramic thickness (in millimeters) at various speeds and angles is shown in Fig.4 to Fig.6.

According to Figures 4 to 6, it is clear that with increasing collision rate, the role of the ceramic has been enhanced to improve the armor performance and The optimal size of the ceramic has been increased, on the other hand, with the increase in the angle of the collision, the increasing role of the supporting aluminum sheet and the thickness of the ceramic plate decreased.

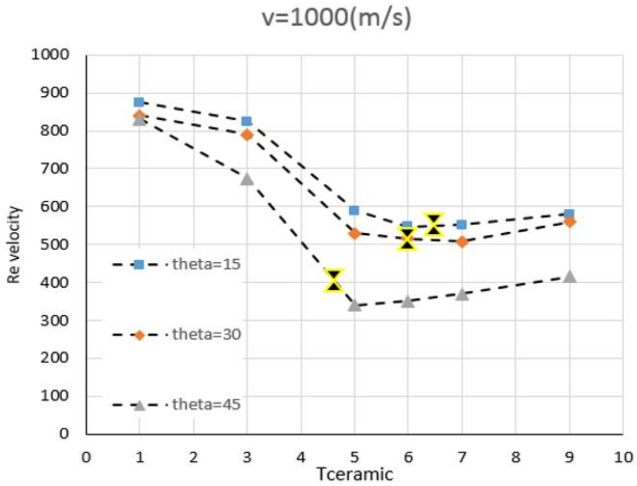

Fig. 5. Residual velocity in different thicknesses of ceramic at different angles and comparing the optimum thickness of the numerical solution and the experimental relation at the collision velocity (1000 m / s)

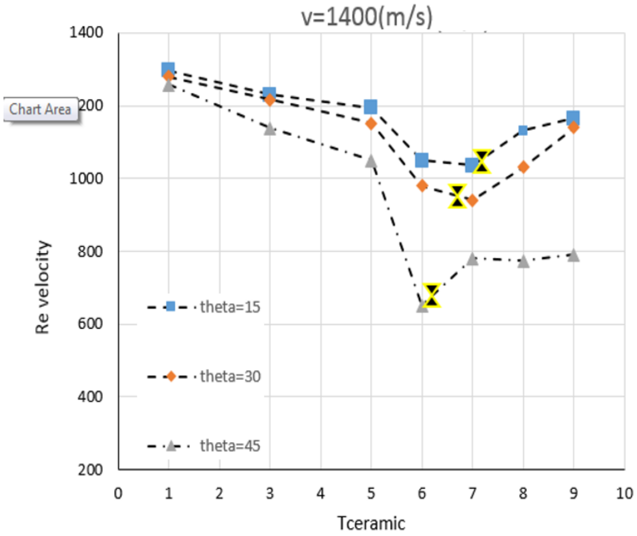

Fig. 6. Residual velocity in different thicknesses of ceramic at different angles and comparing the optimum thickness of the numerical solution and the experimental relation at the collision velocity (1400 m / s)

IV. CONCLUSION

In this paper, using numerical simulation, we investigated the optimum thicknesses for ceramic-aluminum target, it is observed that the role of the ceramic has become more important with increasing speed of bullet collision, and the optimum thickness of the ceramic has been increased. On the other hand, with the increase in the angle of collision, the importance of the supporting aluminum plate has increased, and the optimal thickness of the ceramic section has been reduced.

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