

Stress Analysis and Safety Factor Determination of Cannonballs Colliding into Sand

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Abstract—There are several firing tests of cannonballs. In sand firing tests, cannonballs without gunpowder charged are fired against sand pile. When a cannonball collides into sand, stress occurs on the cannonball due to the impact. In this study, stress analysis was done to find whether the cannonball is fractured, and safety factors were obtained. It was found that under the initial condition, the cannonball did not experience high stress enough to cause fracture.

Keywords—stress, sand, collision, behavior, safety factor, fracture

I. Introduction

There are several firing tests of cannonballs. In sand firing tests, cannonballs without gunpowder charged are fired against sand pile. When a cannonball collides into sand, stress occurs on the cannonball due to the impact during collision. If the stress is higher than the strength of the material of cannonball, the cannonball gets fractured[1]. To find cannonball fracture is important because the fractured pieces will be scattered, and a sand maintenance equipment should be operated according to the analysis results of scattering. Thus, stress analysis of cannonball is important for efficient operation of the firing test.

In this study, stress analysis on cannonballs is done to find whether the cannonball is fractured, and the safety factors which mean a margin to fracture are determined.

II. Theoretical Background

The finite element analysis program used for this study is ANSYS Explicit Dynamics. The Explicit Dynamics solver uses a central difference time integration scheme. After forces have been computed at the nodes of the mesh, the nodal accelerations are derived by equating acceleration to force divided by mass. Therefore the accelerations are

$$\ddot{x}_i = \frac{F_i}{m} + b_i. \quad (1)$$

where \ddot{x}_i are the components of nodal acceleration, F_i are the forces acting on the nodal points, b_i are the components of body acceleration, m is the mass attributed to the node[2].

With the accelerations at time n determined, the velocities at time $n+1/2$ are found from

$$\dot{x}_i^{n+1/2} = \dot{x}_i^{n-1/2} + \ddot{x}_i^n \Delta t^n. \quad (2)$$

And finally the positions are updated to time $n+1$ by integrating the velocities

$$x_i^{n+1} = x_i^n + \dot{x}_i^{n+1/2} \Delta t^{n+1/2}. \quad (3)$$

III. Analysis and Result

For stress analysis of a cannonball colliding into sand, a 3D model of the cannonball and sea surface are prepared and a dynamic analysis was done. Fig. 1 shows the 3D model of cannonball and sand.

In this study, K307 and KM107 cannonballs for high angle guns were studied. K307 and KM107 cannonballs are shown in Fig. 2. The material of both cannonballs are copper alloy. The initial launch velocity of K307 is 950 m/s and the angular velocity is 125 rad/s. The initial launch velocity of KM107 is 450 m/s and the angular velocity is 80 rad/s[3]. The shear modulus of sand is 7.69×10^7 Pa[4].

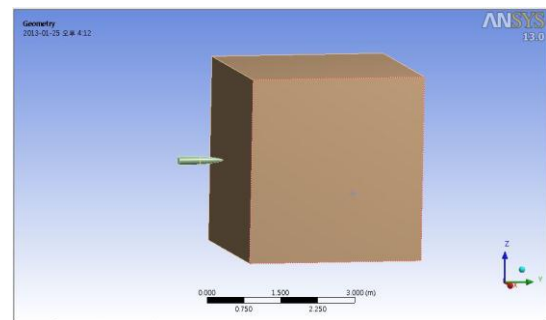


Figure 1. Models of cannonball and sand



Figure 2. K307 and KM107 cannonballs

The behavior of K307 during collision is shown Fig. 3. The color on the cannonball represents the elastic strain intensity.

Fig. 4 shows the maximum shear stresses on the cannonball, Fig. 5 shows the maximum equivalent stresses, and Fig. 6 shows the maximum principal stresses. With these stresses applied to stress theories, the safety factors to cannonball fracture can be predicted. Since the collision occurs at an extremely short time, it is not clear which stress should be considered to check whether the cannonball gets fractured. This will be studied in the future. In this study, all the stress theories were considered.

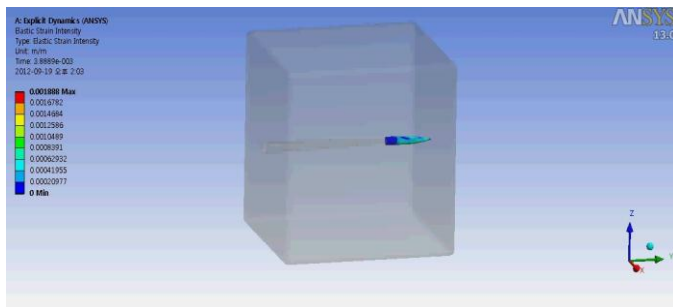
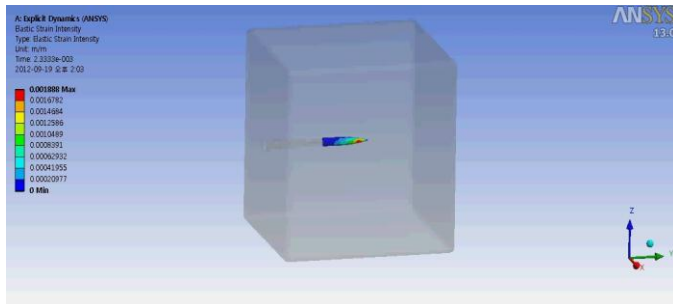
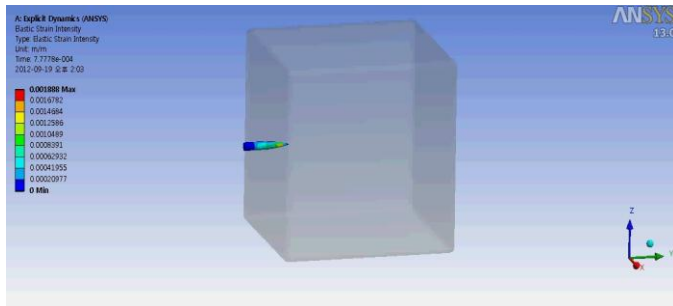


Figure 3. Behavior of K307 Colliding into Sand

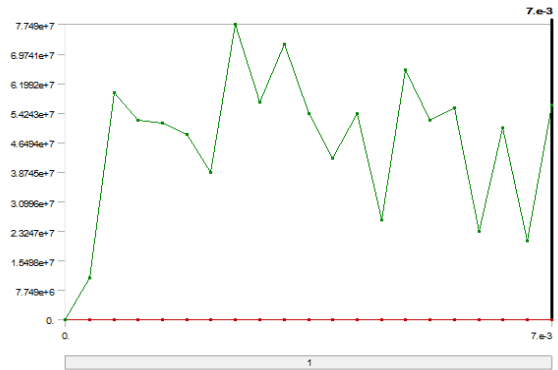


Figure 4. Maximum shear stress of K307 cannonball

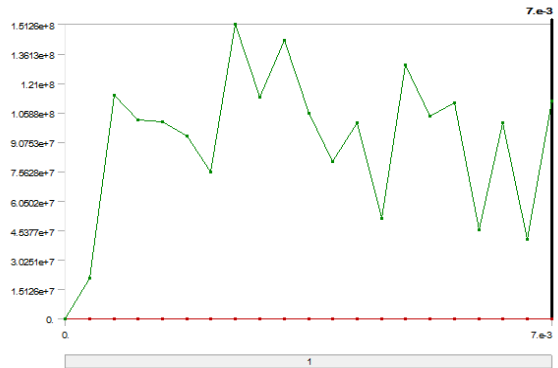


Figure 5. Maximum equivalent stress of K307 cannonball

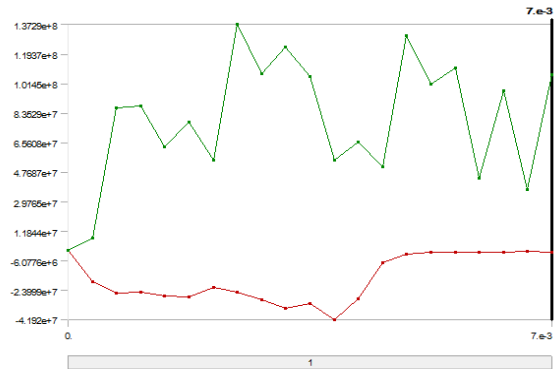


Figure 6. Maximum principal stress of K307 cannonball

Safety factors based on the stress theories were determined, and shown in Fig. 7 - 10. Since the minimum safety factor was found to be 5.68 according to the Mohr-Coulomb stress theory, the cannonball will not be fractured.

The KM107 cannonball was analyzed in the same way as the K307. The behavior of KM107 is shown Fig. 11.

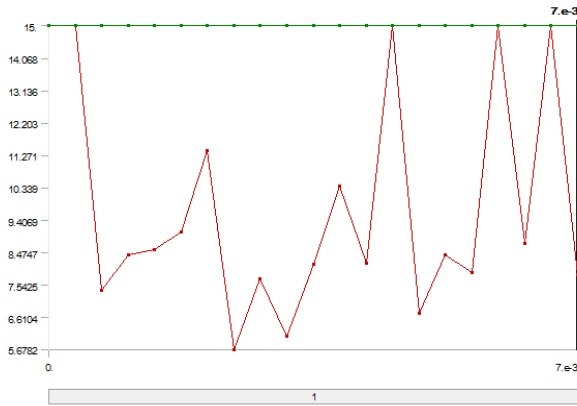


Figure 7. Safety factor of K307 for maximum shear stress theory

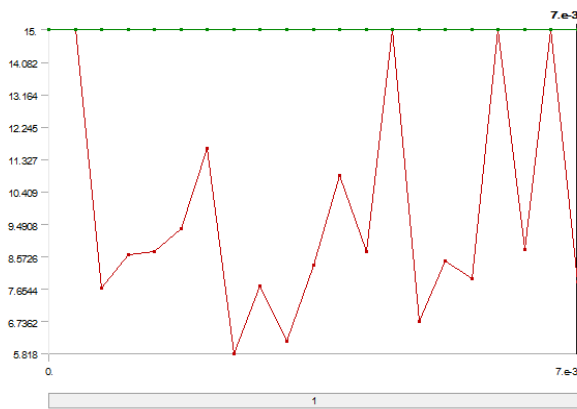


Figure 8. Safety factor of K307 for maximum equivalent stress theory

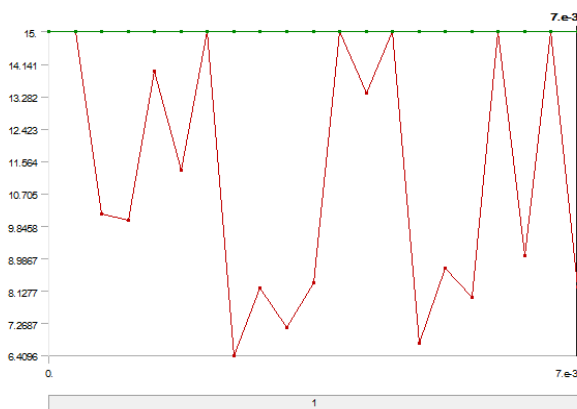


Figure 9. Safety factor of K307 for maximum principal stress theory

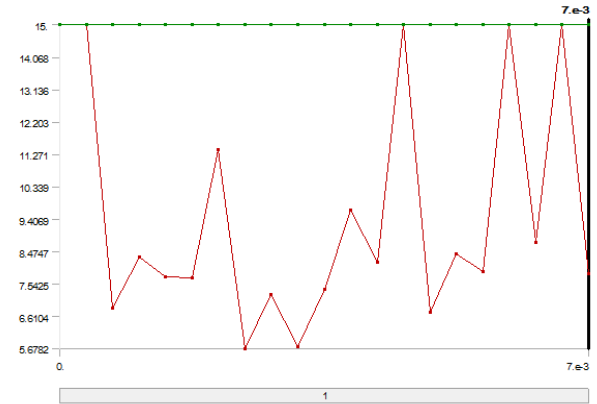


Figure 10. Safety factor of K307 for Mohr-Coulomb stress theory

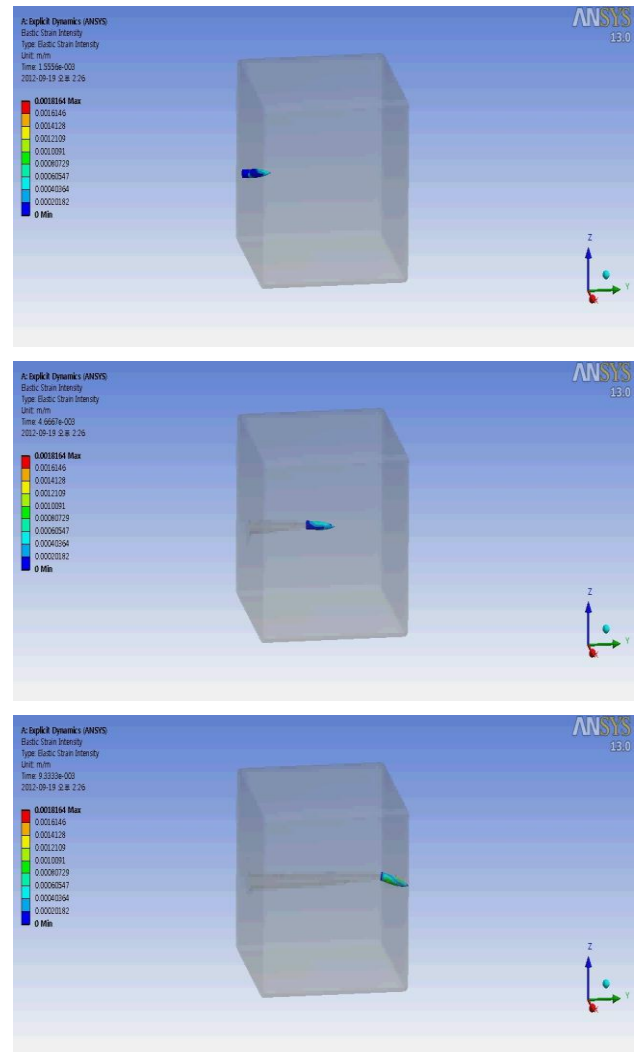


Figure 11. Behavior of KM107 Colliding into Sand

Fig. 12 shows the maximum shear stresses on the cannonball, Fig. 13 shows the maximum equivalent stresses, and Fig. 14 shows the maximum principal stresses.

Safety factors based on the stress theories were determined, and shown in Fig. 15 - 18. Since the minimum safety factor was found to be 5.90 according to the Mohr-Coulomb stress theory, the cannonball will not be fractured.

For given condition, the K307 and KM107 cannonballs do not get fractured, because the safety factors predicted by the four stress theories are greater than 1.

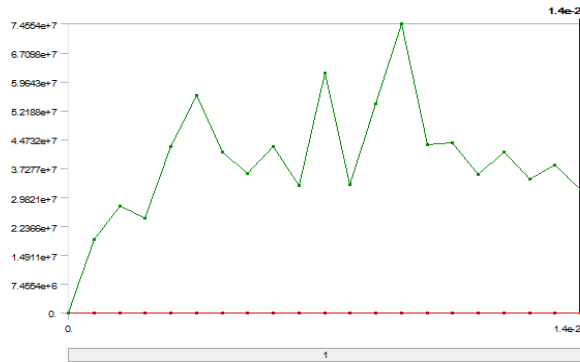


Figure 12. Maximum shear stress of KM107 cannonball

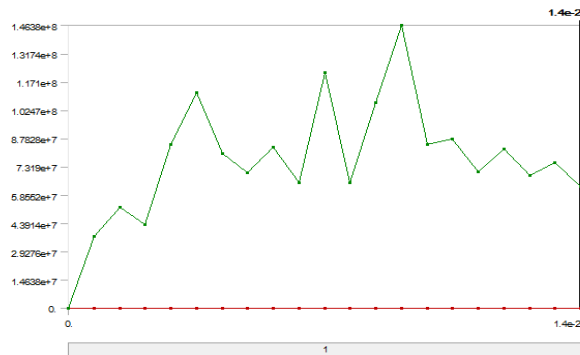


Figure 13. Maximum equivalent stress of KM107 cannonball

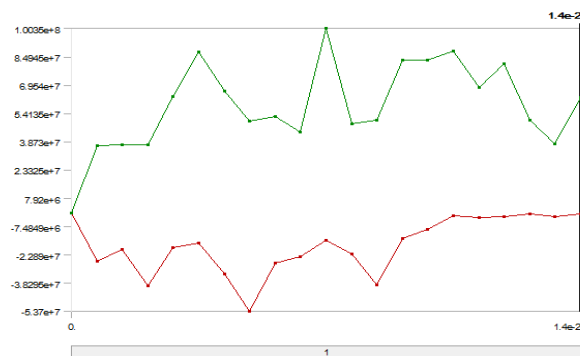


Figure 14. Maximum principal stress of KM107 cannonball

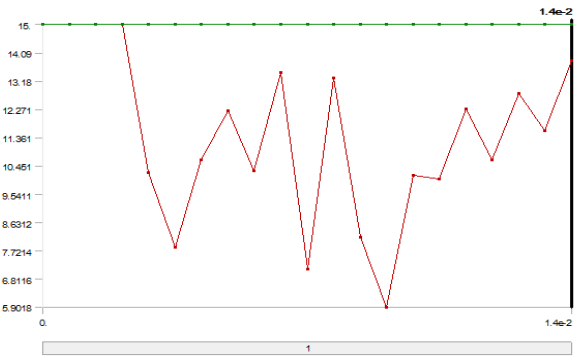


Figure 15. Safety factor of KM107 for maximum shear stress theory

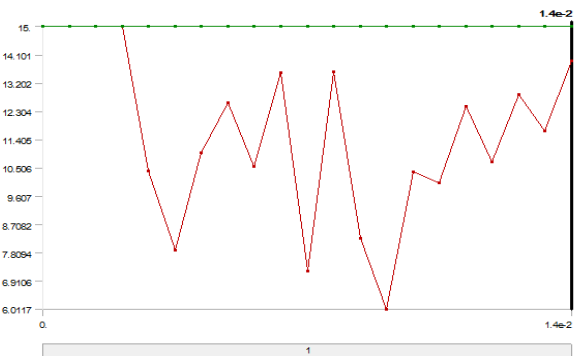


Figure 16. Safety factor of KM107 for maximum equivalent stress theory

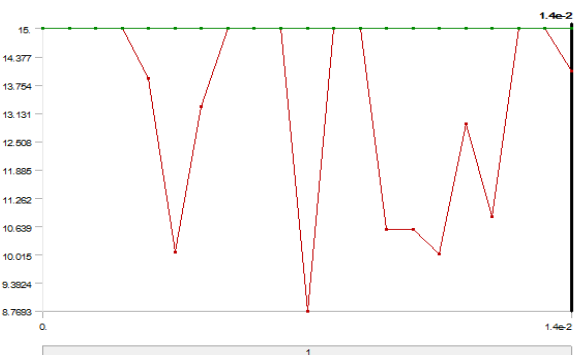


Figure 17. Safety factor of KM107 for maximum principal stress theory

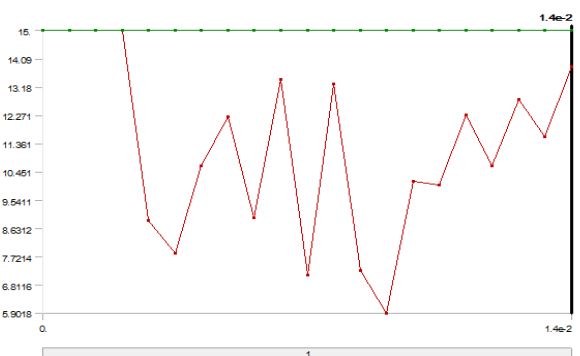


Figure 18. Safety factor of KM107 for Mohr-Coulomb stress theory

IV. Conclusions

In this study, analysis was done on the stress of cannonballs and the safety factors were obtained, when a cannonball collides into sand. The followings are drawn as conclusions

- With the initial launch velocity 950m/s and 450 m/s for K307 and KM107 cannonballs, the safety factors are greater than 1.
- According to many stress theories, K307 and KM107 cannonballs would not get fractured.

Acknowledgment

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