ANALYSIS OF CANNONBALLS PENETRATION DEPTH AND SAND TEMPERATURE COLLIDING INTO SAND MEDIUM

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Abstract- There are several types of firing tests of cannonballs. In ground firing tests, cannonballs without gunpowder charged are fired against sand heap. When a cannonball collides into sand, the cannonball's penetration depth, stress and sand temperature depend on the sand properties. Sand tends to become harder than before after plenty of cannonball firing. This is because kinetic energy of a cannonball is dissipated due to friction. Thus, analysis of temperature in sand is important. In this study, a method of sand temperature analysis is suggested.It is found that temperature rises by about 150℃, and the temperature risein sand depends highly on sand density. The results obtained in this study can be used in management of impact test sites.

IndexTerms- Penetration, Sand, Cannonball, Temperature.

I. INTRODUCTION

Since the 1950s, tests of cannonball firing onto sand have been done to study protecting an object from a cannonball and exploding a target. Experiments with stable flat-nosed, conical-nosed cannonballs were done and behavior of cannonball penetration into sand was predicted using formulas of Robins-Euler, Poncelet, and Résal.[1-2] In the 1970s, formulas and theories were established when cannonballs penetrated into various materials.

As numerical analysis and finite element analysis were developed, stress and fracture of cannonballs were predicted. Much research have been done on destruction of targets being penetrated by cannonballs. Moreover, penetration trajectories in sand were analyzed for various types of cannonballs.[3] Similar cannonball behavior was predicted by different theories and analyses.[4] Recently, penetration depth for shapes and materials of cannonballs have been studied, because the aspect ratio and shape affect the penetration depth significantly and the behavior of targets being destroyed depends on the shape of cannonballs. Penetration analysis has also been done for sand void ratio and particle size, since a target can be composed of sand, clay, mud, etc.[5-10]

However, temperature analysis of cannonball and sand during penetration was seldom done. This is because ofthe small heat dissipation in much of dynamic elasticity and flow, by the insensitivity ofmany of the material propertiesto temperature and by the rapidity of the mechanical events.Penetration processes are highly dissipative and dissipation occurs in small regions.[3]

In a ground firing test of cannonballs, inactive cannonballs are fired onto the particle medium like sand. When a cannonball penetrates into sand, the kinetic energy of the cannonball turns into frictional energy. If many cannonballs are fired into sand, the sand particles tend to get hardened due to large frictional heat. Because of the hardening phenomenon, the number of cannonballs that can be fired is limited, and much cost is needed to change the hardened sand. For an efficient management of an impact test site, the temperature distribution in the sand should be known causing hardening phenomenon.

In this study, temperature distribution in sand is analyzed in cannonball penetration into sand, based on the penetration depth of a cannonball.

In order to analyze the penetration depth and stress, ANSYS Explicit Dynamics, a dynamic analysis program, is used. In order to investigate the temperature distribution in the sand during cannonball penetration, the temperature of the cannonball is obtained from exiting the gun barrel to reaching the sand just before the impact. When the cannonball penetrates into sand, the temperature in the sand is obtained using CFX, a fluid mechanics computer program.

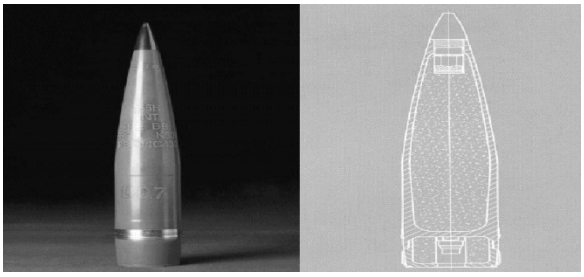


Fig. 1 K307 Cannonball

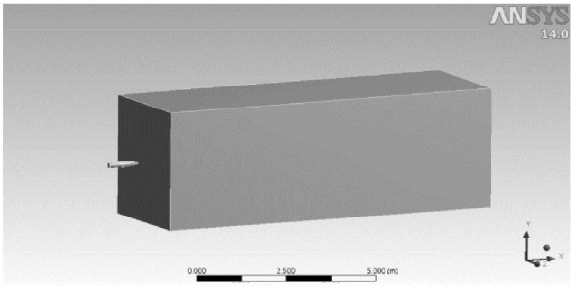


Fig. 2 Cannonball and sand 3D modeling

Table 1Technical data of K307 cannonball

Property	K307
Weight	46.4 kg
Length	945 mm
Filler	TNT
Maximum range	41 km
Muzzle velocity	950 m/s

II. PENETRATION DEPTH OF CANNONBALLS

The cannonball used in this study is K307 spin-stabilized cannonball. Fig. 1 shows the picture of K307. Table 1 shows the data of K307[11].

For analysis, a 3D model was used as shown in Fig. 2. The material of K307 is copper alloy. The properties of the sand were selected from ANSYS Explicit Material Data. The properties were presented by Norwegian Geotechnical Institute. The initial speed of the cannonball was 950m/s, with a spin rate of 125rad/s[11].

The sand heap was 3.6m×10m×3.3m and its bottom was fixed. The gravitational acceleration was applied to both the sand and cannonball.

Fig. 3 shows the cannonball penetrated and stopped in the sand for sand density of 1500 kg/m3. The penetration depth was found to be 9.3m.

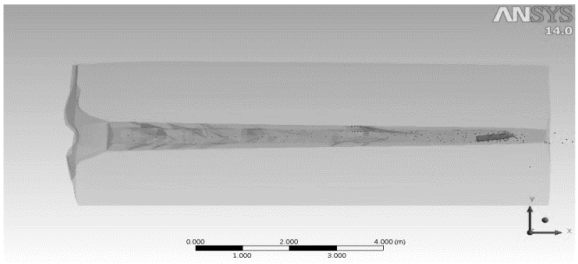


Fig. 3 Collision behavior of K307 cannonball when sand density is 1500 kg/m3

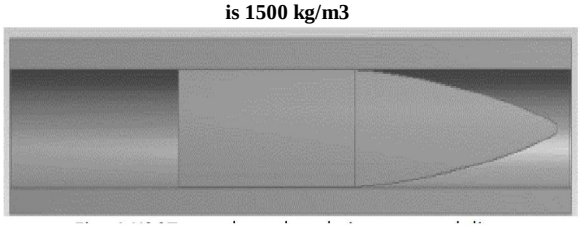


Fig. 4 K307, gun barrel and air area modeling

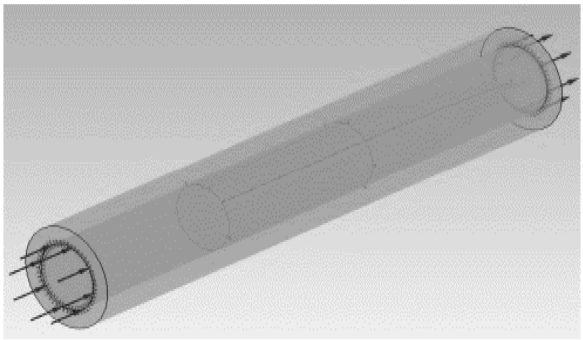


Fig. 5 Boundary condition of gun barrel

III. SAND TEMPERATURE ANALYSIS

When a cannonball impacts sand and penetrates into the sand, the stress analysis can be done using ANSYS Autodyn. However, temperature analysis cannot be done because meshes are removed if they deform above a certain value.

The temperature analysis of K307 penetration was done using ANSYS CFX.

In order to analyze the temperature in the sand, the temperature of the cannonball should be obtained from the time of exiting from a gun barrel to the time of impacting the sand. The cannonball is propelled by high temperature propellant combustion. Because of the heat transfer from flame, the gun barrel and the cannonball are heated. Fig. 4 shows the 3D models of the gun barrel and the K307. The thickness of the gun barrel was 4cm, and its material was steel. The gap between the gun barrel and the cannonball was 2mm. the length of the gun barrel was 381mm[12].

A total energy model was used for CFX heat transfer model. The model includes enthalpy transport and kinetic energy effect and is good for high speed flow greater than Mach 0.2[13].

In order to obtain the temperatures in the cannonball and the gun barrel, GGI interface was used. GGI interface is good for obtaining the surface temperature since discontinuity does not exist at the interface. Fig. 5 shows the cross-section with boundary conditions applied. For the entrance boundary condition, the propellant flame flows at 300m/s and at temperature of 3289K.

Fig. 6 shows the temperature of the gun barrel when the cannonball leaves the barrel. The maximum temperature, which was about 643C°, occurred at the region where flame enters the gun barrel. The temperature in the middle was about 330 ~ 490C°. The results are very similar to those reported in other studies. Fig. 7 shows the temperature at the K307 surface. The maximum temperature was about 197C° near the tail of the cannonball. The average temperature was about 160C°. After the cannonball is fired, it travels 250m and reaches the impact region. During this time, the temperature changes due to heat transfer with air. This temperature was obtained using CFX. Fig. 8 shows the model of the cannonball and the air. The air flow was set at 950m/s, and the calculation time was 0.05sec.

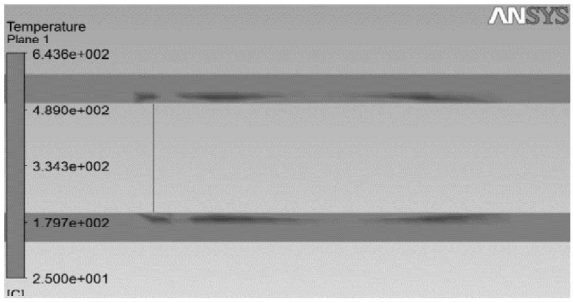


Fig. 6 Surface temperature of gun barrel

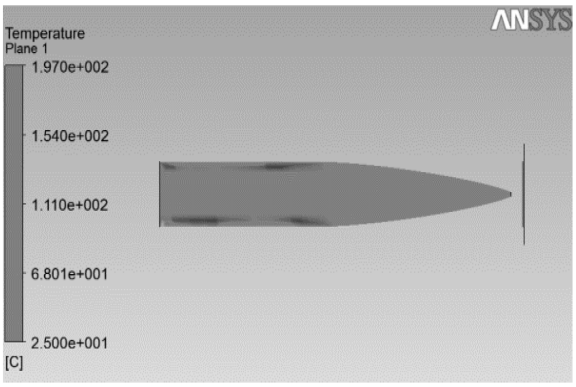


Fig. 7 Surface temperature of K307 cannonball

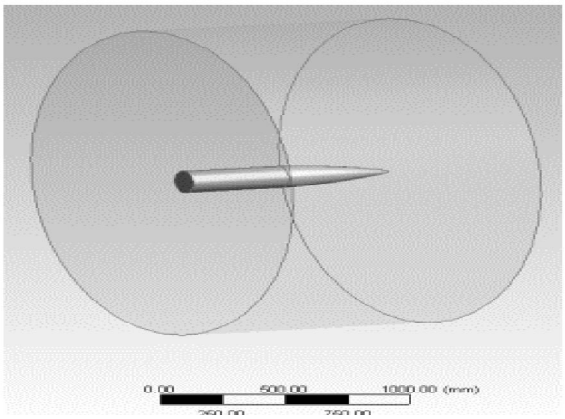


Fig. 8 K307 and air modeling

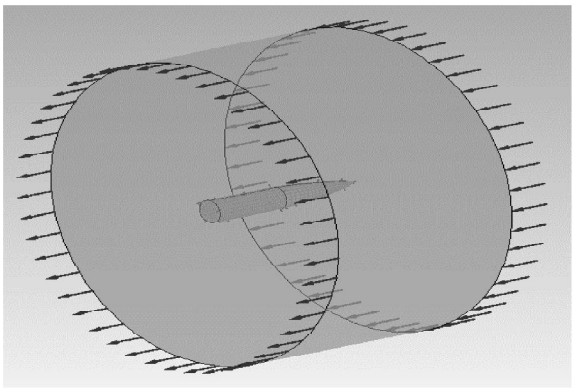


Fig. 9 K307 and air modeling

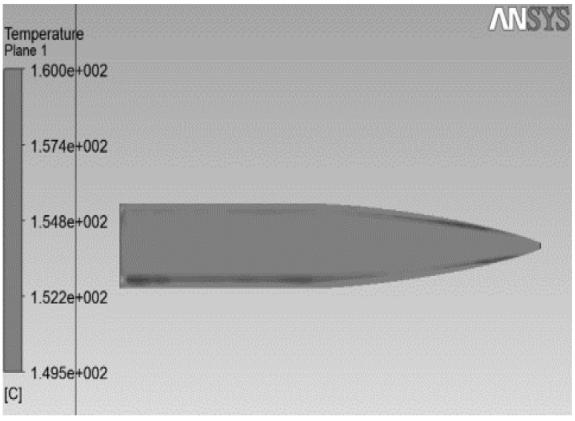


Fig. 10 Temperature of the cannonball after flying 0.05s

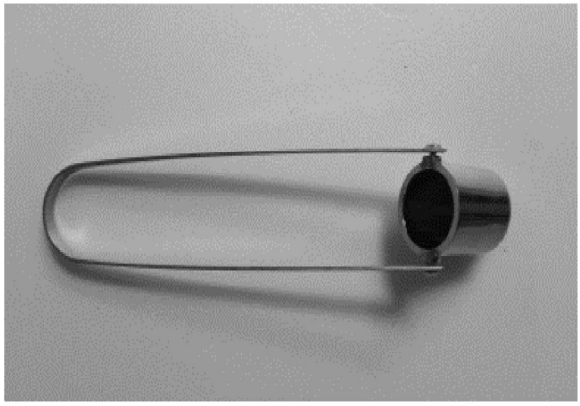


Fig. 11 IWATA viscosity meter NK-2

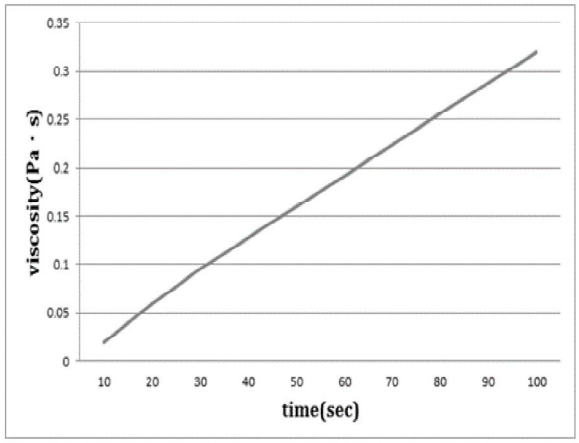
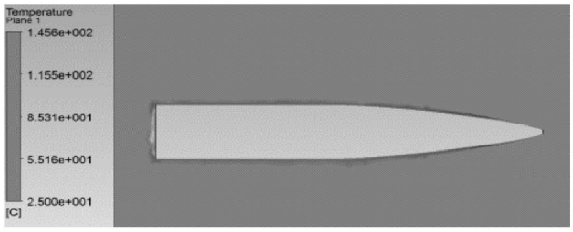


Fig. 12 Graph according to the time and viscosity using NK-2[14]

Fig. 9 shows the boundary conditions. Fig. 10 shows the temperature of the cannonball after flying 0.05 sec. The average temperature was found to be 150C°, just before the impact.The temperature analysis during penetration was done with the sand treated as fluid. In order to do this, the viscosity should be known. Although sand is solid, it is a collection of small particles, and its viscosity was measured by using a viscosity meter. Fig. 11 shows the IWATA viscosity meter NK-2. Viscosity is obtained from the viscosity-time relation curve, after measuring the time that all the fluid from the cup of 45cc flows out of the container. The time measured was 86sec, and the viscosity was found to be 0.27Pa・s.

The analysis was done with the velocity result obtained from the Autodyn analysis. Fig. 13 shows the temperature of the sand for density of 1500 kg/m3. The cannonball whose



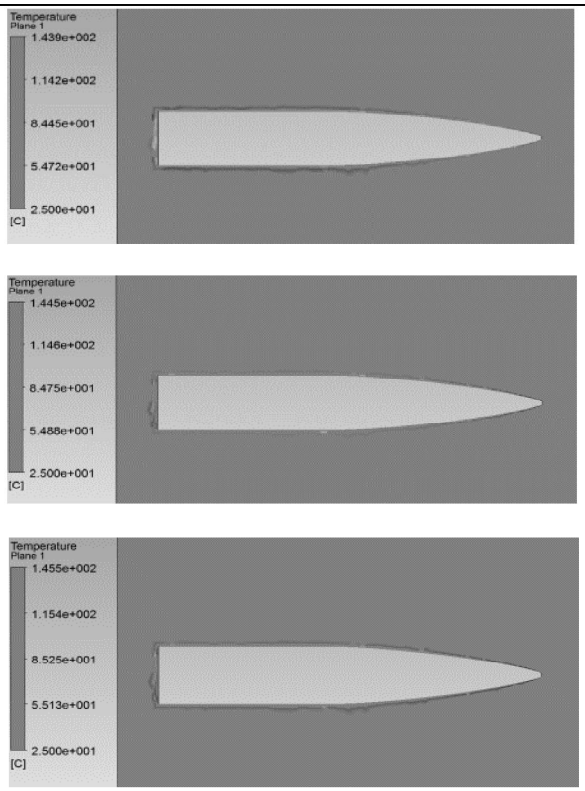


Fig. 13 temperature of the sand for density of 1500 kg/m3

initial temperature was 150C° was heated by frictional heat. The temperature of the sand was 145C° at the cannonball front and 135C° at the end. In a ground firing test, 200-300 cannonballs are normally fired, and the sand is heated to above 1000C°. Low melting point material is melted in the sand, which tends to bond sand particles.

CONCLUSION

This study analyzed the behavior of a cannonball when it penetrates into particle medium like sand. It also obtained the temperature resulting from the friction between sand and cannonball.From the study, the following conclusions are drawn;

The penetration depth was analyzed using Autodyn

- The temperature of a cannonball was obtained from exiting the gun barrel to reaching the impact target.
- The method of analyzing the temperature of sand medium was proposed using a fluid mechanics program, CFX.
- Due to friction heat, the temperature of the sand near cannonball penetration reaches up to 145C°.

The result can give good information for managing sand impact sites.

ACKNOWLEDGMENT

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