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Finite Element Analysis of 125 mm Tank Gun Smooth Bore Barrel Behaviour During Sand Ingress

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Abstract: This work presents a detailed study of 125 mm tank gun smooth bore barrel behavior during sand ingress while firing with High Explosive Fragmentation (HEF) projectile. The field and metallurgical investigation of failed muzzle end barrels confirms that the presence of sintered sand deposit at the defective location. Hence, finite element analysis using ANSYS–Autodyn software is done to understand the barrel failure during sand ingress. In this analysis, the barrel and projectile are modeled using 3D brick elements and the sand particles are modeled using SPH approach. The present work involves a series of simulation for studying the effect of different sand heights and SPH particle sizes on the barrel. The 3D numerical simulation clearly demonstrates that the sand obstruction beyond threshold quantity leads to high-velocity impact between the sand and barrel which causes barrel bore radial deformation and results in material failure. Further, finite element analysis shows that the size of the sand particle and velocity of the projectile also plays a significant role in the barrel damage.

Keywords: Smooth bore gun barrel, muzzle end, High Explosive Fragmentation (HEF), sand particles, finite element modeling, ANSYS-Autodyn.

1 Introduction

Indian field firing ranges are generally desert terrain and regions of sandy soil. During field firing cum training, number of tanks move simultaneously so as to demonstrate and simulate a real battle like scenario. Movement of tanks creates vibration of its gun barrel resulting in enormous amount of loose sand and dust storm generation around these tanks, especially in front of barrel muzzle end. The vibration of gun barrel during tanks movement is discussed in [1]. This results in deposit of sand particles-cum-dust into gun-barrel-bore over a period of time.

The sand deposit is dragged by High Explosive Fragmentation (HEF) projectile's copper driving band, which finally put an obstruction against HEF projectile moving at high-velocity nearer to muzzle end. In fact, it is to be noted that the factor of safety is 5 to 6 times higher in muzzle end when compared to breech end. Hence, a detailed study is required to understand the physical nature of 125 mm smooth bore tank gun barrel failure at its muzzle end region. The technical diagnostics of 125 mm smooth bore gun barrel is studied in [2] and numerical simulation of HEF projectile is studied in [3]. To study the complex interaction between the HEF projectiles with sand ingress inside the barrel bore at muzzle end, a series of 3D numerical simulations is carried out using hydrodynamic codes and Smoothed Particle Hydrodynamic (SPH) codes.

A detailed metallurgical characteristics investigation of all muzzle end defective barrels has been carried out by controllerate of quality assurance (Metals). Metallurgical investigation shows that overload was the primary cause for the defects and failures at the muzzle end barrel. The investigation also shows that most of the affected barrels had the presence of foreign material deposit in sintered state at the defective location. This foreign material has been tested with EDX examination which revealed peak of Si, Al, Ca and O with respective weight %, which has good agreement with standard desert sand composition discussed in [4].

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Fig. 1: Defective barrel showing sintered sand particles

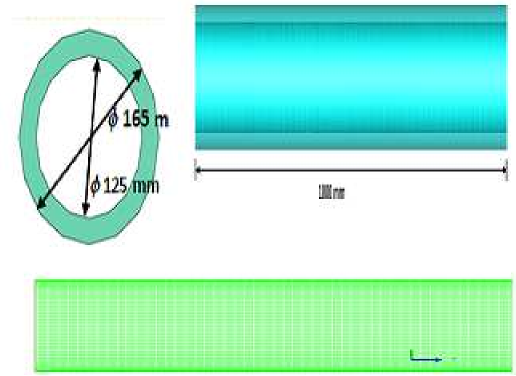


Fig. 2: Barrel dimension and meshing

The sintered state Si content at the defective location of muzzle end of the affected barrel is shown in Fig. 1. Similarly, controllerate of quality assurance (Ammunition) has carried out a detailed investigation and analysis on involved HE lot ammunition. In the ammunition investigation, no major flaw / lapses leading to premature and erratic functioning of ammunition have been found.

Hence, controllerate of quality assurance (Ammunition) concluded that ammunition was not the primary cause for these barrel muzzle end failures / defects.

The primary purpose of the current work is to study and determine maximum stress and barrel behavior during the interaction between projectile and sand ingress of different grain size. Hence the other gun dynamic reactions such as recoiling and barrel vibrations etc. are not relevant and considered for the study.

2 Proposed Method of Sand Ingress Influence in Gun Barrel at Muzzle End

2.1 Finite Element Analysis

Finite Element Analysis (FEA) is a numerical method for finding approximate solutions of partial differential equations as well as of integral equation. The finite element analysis is a good choice for solving partial differential equation over complicated domains, viz, gun internal ballistics, oil pipe line and vehicle motion etc. This method can be able to solve physical problem involving complicated geometrics, loadings and material properties which cannot be solved by analytical method. In this method the domain in which the analysis to be carried out is divided into smaller bodies or unit called as finite elements. The properties of each type of finite element is obtained and assembled together and solved as whole to get solution. Suitable assembly process is used to link the individual elements to the given system.

The global system of equation then obtained is always in the form

$$[K]\{U\} = \{F\} \tag{1}$$

This is similar to the equation for a spring loaded with force F.

$$KX = F \tag{2}$$

where X is the spring elongation or shrinkage and K is spring stiffness.

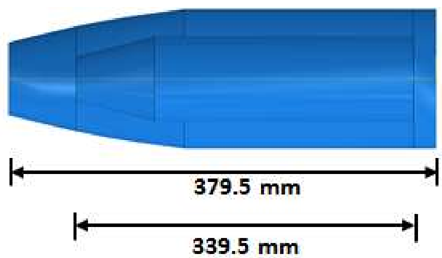
The analogy with this, matrix $[K]$ is called elemental stiffness, $\{U\}$ elemental displacement or primary variable vector and $\{F\}$ is elemental load vector. Here Finite element based explicit dynamics solver ANSYS Autodyn is used to simulate and study the influence sand ingress in gun barrel during HE shell motion at muzzle end. The study is carried out to understand the physical phenomenon of 125 mm smooth bore gun barrel bore behavior similar to model presented by [5–8] with 125 mm HEF projectile.

2.2 Finite element model

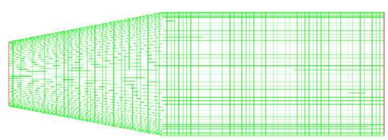
As the aim of the present study is to analyze the failure at muzzle end, the barrel length is considered as 1000 mm from the muzzle end, though the full length of the barrel is 6000 mm. Steel material with 0.2% proof strength 1000 MPa and 1250 MPa UTS are considered in the present study. The barrel is modeled using hex mesh of size 2 mm. Total number of elements used to model barrel is 1648200. Fig. 2 shows the dimension and mesh of the barrel.

The HEF projectile model which is used in the simulation has the geometrical, material and mass properties as the actual projectile. Total mass of RDX filled is 1.4 kg and total projectile mass is 22 kg. The projectile is HE shell which consists of outer shell made of steel material with 800 MPa 0.2% proof strength and 1050 MPa UTS and the inner core is made up of RDX. The material property of RDX is taken from the Autodyn library. Both the outer shell and inner core are modeled using hex elements of size 2 mm. The outer shell consists

(a) Actual HE projectile



(b) Solid model



(c) Meshed model

Fig. 3: Dimension of various modeling

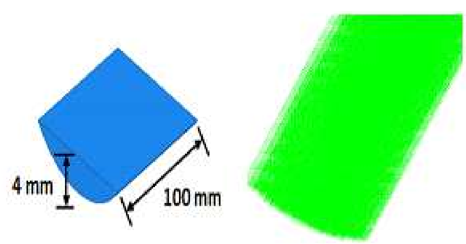


Fig. 4: Sand dimension and meshing

of 61524 elements and inner core consists of 35420 elements. Fig. 3 shows the dimension and mesh of the projectile. Initial velocity of the projectile is taken as 840 m/s.

The material property of sand is taken from the ANSYS Autodyn library [9]. The sand is modeled as section of cylinder with height of 4 mm is considered. Length is considered as 100 mm. In the present study, the sand is modeled using SPH with particle of sizes 0.3 mm, 0.5 mm, 0.7 mm and 1 mm. SPH has proven to be useful in certain classes of problems where large mesh distortions occur such as in high-velocity impact, which characterizes our problem. The dimension and mesh of sand model is shown in Fig. 4.

Fig. 5 represents the complete assembly of barrel, projectile and sand used for simulation.

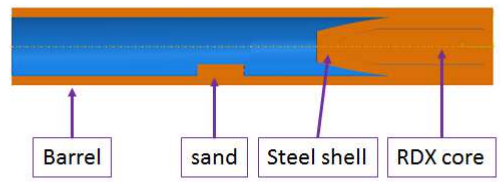


Fig. 5: Assembly model consisting of barrel, projectile and sand

2.3 Maximum safe pressure calculations for 125 mm Smooth bore tank gun barrel muzzle end

125 mm smooth bore tank gun barrel is made from high quality alloy heat treated steel forging assembled with casing through shrink fit. Hence ASME standard Article KD-8 special design requirement for layered vessels has been used for calculating maximum safe pressure.

$$\text{max safe pressure} = P = \frac{Y}{2}\left[1 - \frac{1}{K^2}\right] \quad (3)$$

where Y = limit of proportionality = 1177 MPa
and K = thickness ratio.

Hence maximum safe pressure at muzzle end = 441 MPa.

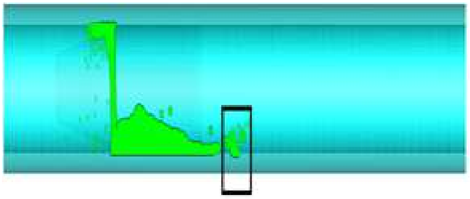
3 Results and discussion

With the sand height of 4 mm, total sand mass is 19 gm. With this amount of sand, a significant change in barrel deformation is observed. Four different simulations for 4 mm sand height with sand particle sizes of 0.3 mm, 0.5 mm, 0.7 mm and 1 mm, respectively are done and the results are discussed as follows.

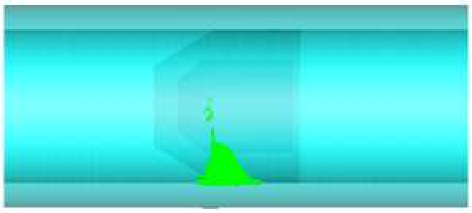
(a) Influence of sand with particle size 0.3 mm: the sand particle of size 0.3 mm is considered. When the projectile strikes the sand particles, they get stuck between the projectile and the barrel. This causes rupture and bulge in barrel. In the ruptured locations sand particles tend to settle as it can be seen in Fig. 6. Further, this interaction between the sand and projectile causes barrel bulge to an extent of 0.29 mm as it can be seen from Fig. 7.

(b) Influence of sand with particle size 0.5 mm: with the sand particle size 0.5 mm, a significant change in barrel deformation is observed when compared with 0.3 mm size. This causes rupture and bulge in barrel. In the present case, the ruptured condition extends to more than one location where sand particles tend to settle as can be seen in Fig. 8. The stresses also extend beyond yield as in the previous case.

(c) Influence of sand with particle size 0.7 mm: with the sand particle size is 0.7 mm, a significant change in barrel deflection is observed when compared to earlier

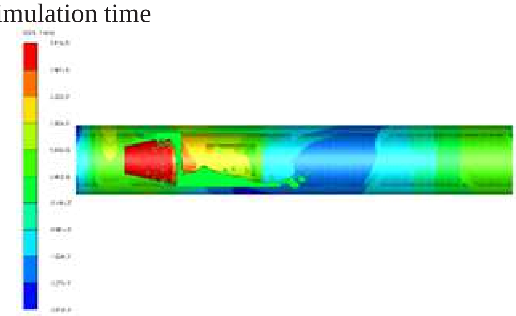


(a) 0.28 ms

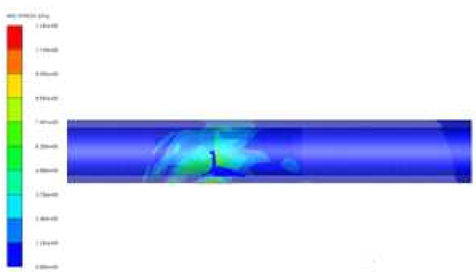


(b) 0.44 ms

Fig. 6: Barrel rupture due to sand particle of size 0.3 mm at simulation time



(a) Displacement in vertical direction



(b) Von Mises stress contour at the time of interaction

(c) Peak deformation at the instant of interaction between sand and projectile

Fig. 7: Causes of barrel bulge

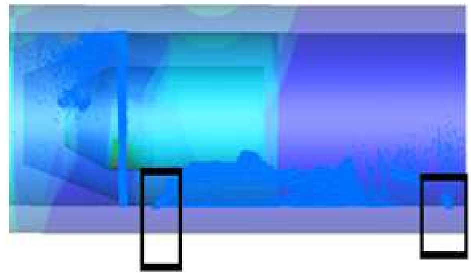
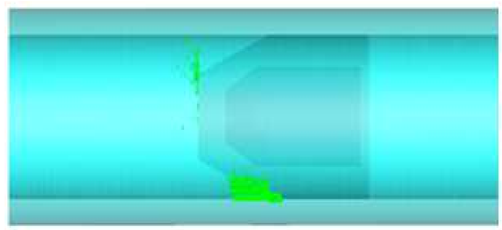
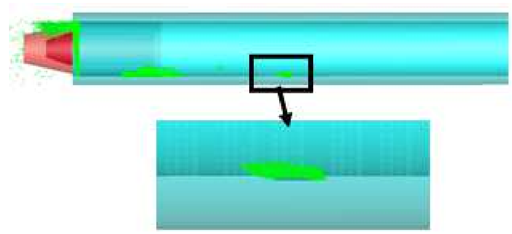


Fig. 8: Contour showing barrel deflection and rupture filled with sand SPH particles

cases. This causes rupture and bulge in barrel. In the present case, the ruptured condition extends to larger area as it can be seen in Fig. 9.



(a) 0.24 ms



(b) 0.9 ms

Fig. 9: Barrel failure at simulation time at 0.7 mm

The stresses also extend beyond yield as in the previous cases in Fig. 10.

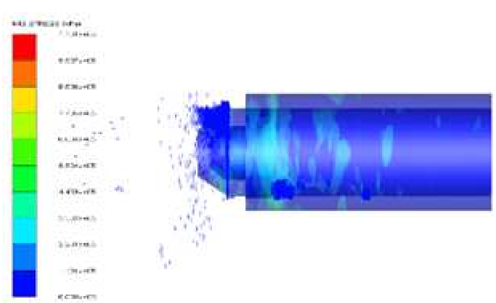
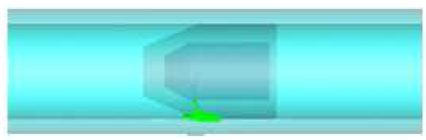
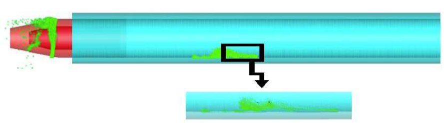


Fig. 10: VonMises stress contour at 0.98

(d) Influence of sand with 1 mm particle size: as the particle size of sand increases considerably, rupture extended further. In fact, complete barrel rupture is observed with a huge opening of size about 50 mm. The failed condition of the barrel is shown in Fig. 11. The crack propagation is in good agreement with the actual barrel failure as shown in Fig. 11.



(a) 0.28 ms



(b) 0.98 ms

Fig. 11: Barrel failure at simulation time at 1 mm particle size

The stress in this case is also extends beyond yield stress as seen in the following figure. The von Mises are exceed yield limit as seen in Fig. 12.

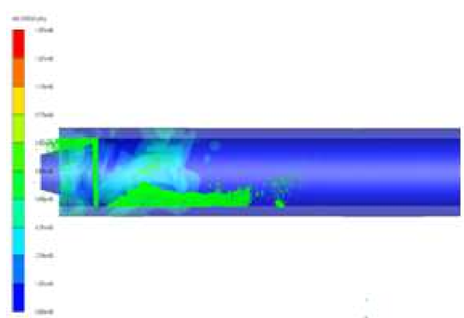


Fig. 12: VonMises stress contour at 0.98 ms

From the above simulations, it is observed that as the grain sizes increases, the rupture area increases as it can be observed from Fig. 13. As seen, the rupture area in case of 0.3 mm SPH particle size of sand is insignificant compared to that of SPH particle size of 1 mm.

4 Conclusion

This present investigation and analysis of tank gun barrel muzzle-end explosion and bulge reveals that sand particles ingress (10) is the highly probable cause for muzzle end barrel defects viz, burst & bulge. The

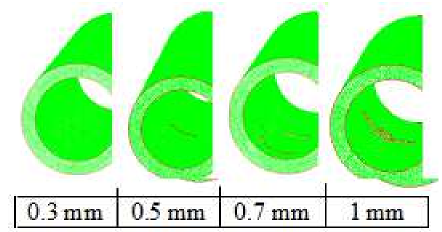


Fig. 13: Mesh model showing rupture area in case of different SPH particle size of sand

investigation is conducted with finite element-based explicit dynamics numerical simulation using ANSYS Autodyn software which recreates the gun barrel behaviour with sand ingress during HE shell motion inside the barrel at muzzle end. Simulation of different sand particle size models so as to find its effect on various scenarios.

All affected barrels detailing metallurgical examination and investigation reveal that there is no metallurgical and manufacturing deficiency in the barrel material both at defective location and unaffected location which confirms and meets specification requirements and similarly-detailed ammunition aspect investigation also reveals that there are no flaw or deficiency in the affected ammunition lot which can lead to muzzle end barrel deformation or burst. However majority of metallurgical investigation findings confirm presence of very high content of Si at the burst / bulged location, which in turn reveals presence of sand particles at the affected portion barrel bore.

A finite element-based numerical simulation was done with different sand particle sizes, namely, 0.3 mm, 0.5 mm, 0.7 mm and 1 mm. From the simulation, it is clear that sand obstruction leads to excess of maximum safe pressure by which the barrel ruptures and bulges at all the four cases of sand particle sizes. However, the failure rate increases with increase in particle size.

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