Field Investigation and Finite Element Analysis of Smooth Bore Tank Gun Muzzle End Behavior with Sand Ingress During High Energy Fragmentation Shell Firing

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Abstract— **Large number of failures and defects at muzzle end region was observed in the case smooth bore tank gun barrel, while firing High Explosive Fragmentation projectile. The obstruction due to sand deposits lead to high velocity impact between the sand and barrel, which causes large barrel bore radial deformation and results in material failure. To understand this effect of sand deposit, trials were conducted and compared with finite element computer simulation and analysis using ANSYS - Autodyn software. The field investigation and finite element analysis clearly demonstrates that the presence of sand obstruction beyond threshold quantity leads to permanent deformation of barrel bore to rupture and breakage of barrel. One of the means to reduce to influence of sand is to reduce the velocity of the projectile. In the present paper, the influence of the lower velocity projectile is being analyzed.**

Keywords— Finite Element Model, Sintered sand particles, Barrel muzzle end, High Explosive Fragmentation, Sand ingress, Desert terrain.

I. INTRODUCTION

Indian firing ranges are generally desert terrain and regions of sandy soil. During real battle like scenario, enormous amount of loose sand and dust storm around these tanks develop, especially in front of barrel muzzle end. This gun barrel bore [1] which is open to the sandy environment collects sand particles and may get deposited / settled at the bottom of the bore over the time period. The sand deposit is dragged by copper obscuration band of HEF [2] projectile and creates an obstruction. Gun barrel failure occurs due to this over load applied on the inner radius of the barrel.

Apart from the cost expense for replacement or service, the vital war equipment remains out of service during critical times, which is unwarranted for armed forces, especially during war time. Further, firing is also carried out when the tank is on move, which makes it more complex and nonlinear dynamic reactions [3] in the gun system. Hence, a detailed study is required to understand the physical nature of barrel failure at its muzzle end region. To study the interaction between the HEF projectiles with sand ingress inside the barrel bore at muzzle end, a series of 3D numerical simulations is carried out.

II. METALLURGICAL CHARACTERISTICS INVESTIGATION OF EARLIER MUZZLE END FAILURES OF 125 MM BARREL

All the barrels have been manufactured according to the approved process documentation, tested by long experience, of its usage. They meet all the set requirements in mechanical properties and chemical composition viz.

- Strength as per the document specification
- Chemical composition in accordance with the requirements set by the standards
- Ultrasonic tests for revealing the internal defects
- Magnetic particle inspection to reveal micro flaws on the outer surface of the barrel

After satisfaction of the above parameters, the barrels are assembled and mounted in the tank.

Hence, a detailed [4] metallurgical characteristics investigation of all muzzle end defective barrels has been carried out by Indian Defence Quality Assurance Department (Metals).

During the investigation, two samples viz. one at defective location and the other at non defective / non affected location has been collected and the above stated parameters have been tested. Metallurgical investigation of all the muzzle end barrel failure cases found no metallurgical deficiencies or process lapses and flaws in the barrel material and mainly concluded as over load failure. Also, investigation shows that most of the affected barrels have presence of foreign material deposit in sintered state at the defective location. This foreign material has been tested with EDX. As shown in the above table, EDX examination revealed peak of Si, Al, Ca& O with respective weight %, which has good agreement with standard desert sand composition.

The following Fig 1 show the sintered state Si content at the defective location of muzzle end of the affected barrel. These pictures have been captured during in-situ investigation immediately after the barrel failures at fields.

Weight % on the sand sticking barrel bore revealed through EDX examination	**[5]** Percentage of elements found in normal dessert sand
SiK - 24.94%	Quartz SiO_2 - 21.26%
CaK - 15.05%	Dolomite $CaMg(CO_3)_2$ - 14.58%
NaK - 6.23%	Calcite $CaCO_3$ - 14.21%
OK - 44.32%	Smectite - 9.10%
	Halite NaCl - 7.99%
	Kaalinite $Al_2Si_2O_5(OH)_4$ - 7.89%

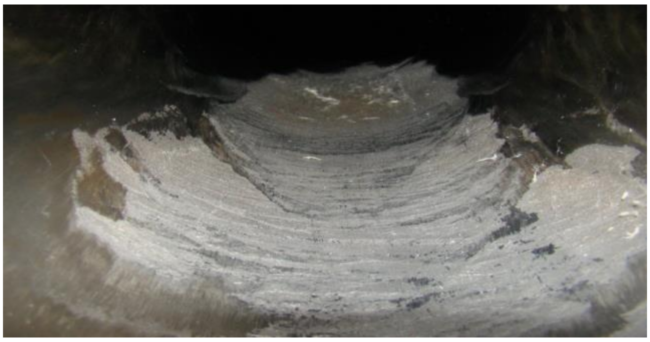

Fig 1. Defective barrel showing sintered sand particles

Fig 2. Failed gun barrel showing presence of sintered sand particles

Similarly, a detailed investigation and analysis on HEF lot ammunition showed that there no flaw / lapses, which can lead to premature functioning of ammunition. Hence, it is concluded that ammunition was not the primary cause for these barrel muzzle end failures / defects.

Apart from the above, these defects have been in-situ investigated and confirmed the presence of sand / foreign particles deposited at the defect location in majority of cases. The Fig.2 above clearly depicts presence of sand / foreign particles inside the barrel bore at burst / bulge location.

III. OUTCOME AND FINDINGS OF SAND INGRESS TRIALS CONDUCTED IN DESERT TERRAIN

Two trials were conducted to study the effects of sand ingress. In the trials, four tanks participated. During the first trial, these 4 tanks have moved 25 km distance each with its various ports viz. gunner hatch, commander hatch and driver hatch open & close condition. During the last phase of trials, i.e., during final 3 – 4 km distance, a heavy sand storm was also noticed. Sand ingress inside the barrels were meticulously collected and weighed and found to be 1 gm in one of the barrel and in remaining three barrels about 0.6 – 0.8 gm. The quantity of sand recovered i.e., 1 gm collected after moving the tanks for 25 km and running around two hours in desert terrain seems insignificant. This meager quantity sand dust can be swept away by high velocity shell / shot and hence would not obstruct the internal ballistics of the shell/shot.

On day 2 of second trials, the four tanks, which were separated by a distance of 250 m each, covered a distance of 6 km. During these tanks movement two numbers HEF projectiles from each tank have been dynamically fired [6,7,8]. After this exercise, sand ingress inside the barrel bore were collected and measured. In three barrel bores, less than 0.1 gm sand dust have been found and recovered. However, in forth barrel bore, approximately 3.0 gram sand dust was recovered. Since all four tanks operated in the same terrain, with the same firing drills, at the same time and with same tank operating conditions, recovery of significant quantity of sand ingress in only one barrel bore, has been seriously analyzed and viewed as cause of concern. Hence, the cause for sand ingress has to be studied in detail.

IV. NUMERICAL SIMULATION OF SAND INGRESS INFLUENCE IN GUN BARREL AT MUZZLE END

Finite element based explicit dynamics solver ANSYS Autodyne 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 [9, 10,11] with 125 mm HEF projectile.

A. 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 6000mm. Steel material with 0.2% proof strength 1000 MPa and 1250 MPa UTS is 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. The following Fig 3 figure 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 of 61524 elements and inner core consists of 35420 elements. The following Fig 4 shows the dimension and mesh of the projectile.

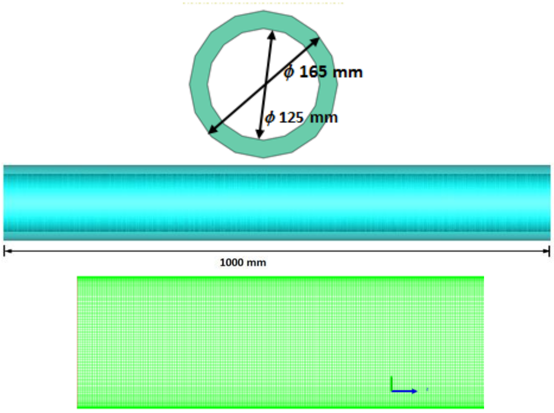

Fig. 3 Barrel dimension and meshing

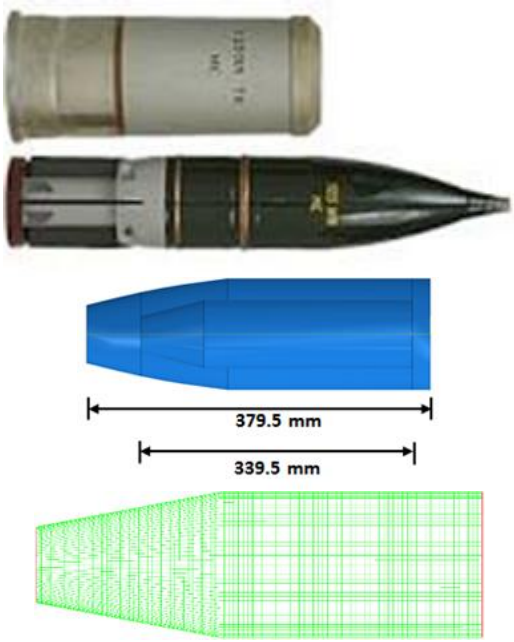

Fig 4. (a) actual HE projectile (b) Solid model of Projectile with dimension (c) meshed model

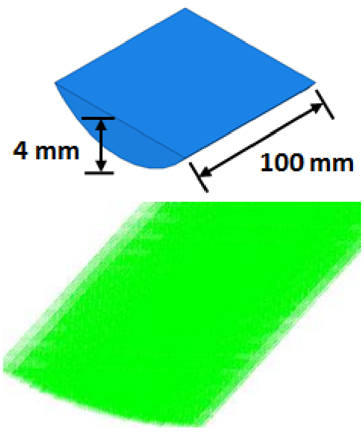

Fig 5. Sand dimension and meshing

The material property of sand is taken from the ANSYS Autodyne [12] library. The sand is modeled as section of cylinder with height of 4 mm. Length is considered as 100 mm. In the present study, the sand is modeled using SPH with particle of sizes 0.5 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 above Fig 5 shows the dimension and mesh of sand model.

The following Fig 6 shows the complete assembly of barrel, projectile and sand used for simulation.

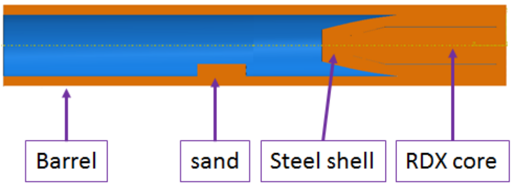

Fig 6. Assembly model consisting of barrel, projectile and sand

In the current work the purpose is to study the interaction of the obstruction with the barrel as a result of a projectile hit and hence functions such as recoil of the gun and barrel dynamic reactions are not relevant for the study. The results are discussed in the subsequent section. In the present investigation, the influence of projectile velocity in barrel failure is studied.

B. 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. Two different simulations for 4mm sand height with sand particle size of 0.5 mm was done and the results are discussed as follows.

(a) Influence of sand with projectile velocity 840 m/s:

With the sand particle size 0.5 mm, a significant change in barrel deformation is observed. This causes rupture and bulge in barrel. In the present case, the ruptured condition extends to two locations where sand particles tend to settle as can be seen in Fig 7. The stresses also extend beyond yield strength.

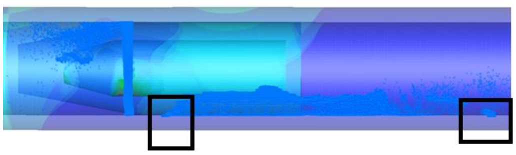

Fig 7. Contour showing barrel deflection and rupture filled with sand SPH particles

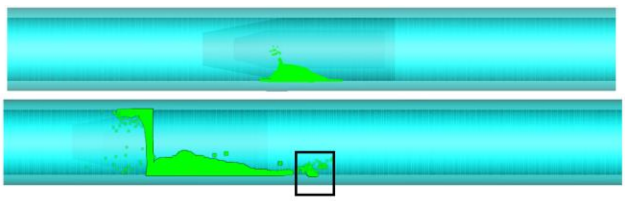

Fig 8.Barrel rupture due to sand particle of size 0.3mm at simulation time (a) 0.28 ms (b) 0.44 ms

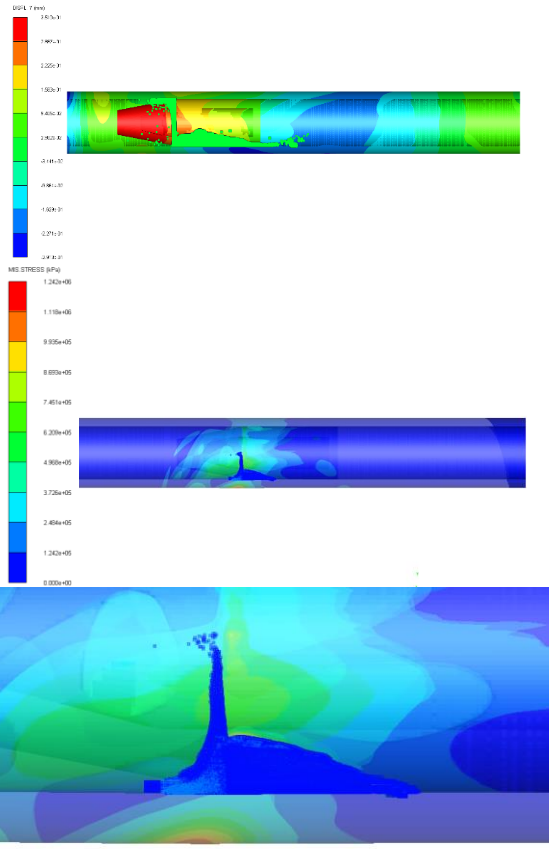

Fig 9. (a) Displacement in vertical direction (b) von Mises stress contour at the time of interaction (c) Peak deformation at the instant of interaction between sand and projectile

(b) Influence of sand ingress in barrel with reduced projectile velocity of 420 m/s:
The sand particle of size 0.5 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 can be seen in Fig 8. From the simulation results, it is observed that the rupture zone reduces to one location. Also, there is reduction in the rupture area.

Further, this interaction between the sand and projectile causes barrel bulge to an extent of 0.29 mm as can be seen from Fig 9.

Taking into account the designed clearance between the projectile drivers and the bore between 0.2 and 0.5 mm, as well as the projectile elastic deformation on firing, the critical sand blister / height value, when the barrel bulging can start, is evaluated as approximately 4 mm height of sand. Further, finite element based numerical simulation reveals that the failure rate increases with increase in projectile velocity. This is due to the fact that decrease in velocity causes decrease in energy and hence reduced damage.

V. CONCLUSION

Field investigation cum metallurgical investigation and analysis of 125 mm smooth bore tank gun barrel muzzle end explosion and bulge reveals that sand particles ingress is the highly probable cause for muzzle end barrel defects. Detailed metallurgical examination and investigation of the affected barrels reveal that there was no metallurgical and manufacturing deficiency in the barrel material, both at defective location and unaffected location which confirms and meets specification requirements. Further, detailed investigation on ammunition also reveals there were no flaw / deficiency in the involved ammunition lot. However majority of metallurgical investigation findings confirms presence of very high content of Si at the burst / bulged location, which in turn reveals presence sand particles at the affected portion.

The high velocity projectile is obstructed by sand ingress then subsequently impacted with barrel wall. Due to high energy impact, the barrel cross-section stress reaches to 1311 – 1323 MPa approx., which is very much higher than the barrel material yield strength of 1200 MPa. This over stresses cause barrel deforming as bulging at the area of sand obstruction, in the lower part because of contact force and in the upper portion because of reaction. The investigation was conducted with finite element based explicit dynamics numerical simulation using ANSYS Autodyne software which recreated the gun barrel behavior with sand ingress during HEF shell motion inside the barrel at muzzle end.

A finite element based numerical simulation was done with different HEF projectile velocities, namely, 840 m/s and 420 m/s. From the simulation, it is clear that the barrel ruptures and bulges at both the cases. However, the failure rate increases with increase in projectile velocity.

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