Simulation of shrink Fitting process of cannon Liners For Explosive Testing

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Abstract : A Cannon is a large tubular firearm designed to fire heavy projectile over a considerable distance using propellant. Basically cannons are made of three liners, the inner cannon liner, which holds the explosives have greater chances to get wear out. The dimensional tolerance of its physical design and type of fit plays an important role in enhancing the longevity of the liner. To improve the life of the liner, one should have prior information of the stress levels on the liner after the shrink fit. This is done by using finite element method the cannon shrink fitting process is simulated majorly focusing on optimization of heating (temperature range) before shrink fit, structural expansion after supplying of heat, the contact behaviour on the interface in shrink fit and structural deformation after shrink fit (i.e. stress maps). Some of the inferences from the simulation are (1) By increasing the temperature, the expansion is more i.e. diameter extension is obtained by supplying temperature to outer liner during heating process, (2) Once the heating time is completed required expansion is obtained and after fitting the inner liner, the outer layers is then squeezed in radius and extended in axial by the act of shrinking when the assembly is allowed cooled and relative amount of compression also observed after reaching temperature, (3) Stress analysis done for both perfect fit and misfit at different conditions. For perfect fit stress concentration is high at the innermost liner particularly where explosive charge is placed. But for the misfit stress concentration is maximum at the interface of the two liners, (4) Perfectly fitted cannon require more pull out load when compared to misfitted cannon and they are more reliable in avoiding the accidents during the explosive testing. The results are verified with both analytical and Experimental analysis (XRD).

***Index Terms* - Shrink fitting process simulation, Stress analysis, Interference, Perfect fit, Misfit, ANSYS, XRD.**

I. INTRODUCTION

A Cannon is a type of gun classified as artillery that launches a projectile using propellant dealing with kinetic damage and can inflict significant damage to targeted modules and the modules around it. Generally, cannons are assembly of three liners and this assembly is achieved by shrink fitting processes. Shrink fit is a type of interference fit in which a negative difference between diameter of the hole and the shaft is called interference. In such cases, the diameter of the shaft is always larger than the hole diameter, Interference fit has a negative allowance. In such a fit, the tolerance zone of the hole is always below that of the shaft [1]. Interference fits are widely used for connecting two cylindrical parts. Assembling two cylindrical parts by pressing or shrinking one member on to another creates a contact pressure and friction force at the interference of the two mating parts [2]. It is defined by the technique in which an interference fit is achieved by a relative size after assembly. This is usually achieved by heating or cooling one component before assembly and allowing it to return to the ambient temperature after assembly, employing the phenomenon of thermal expansion [3]

The dimensional tolerance, interference between the liners and the heating temperature plays an important role in shrink fitting processes. At the time of shrink fitting compressive stresses are generated at interface of the both the liners. To prevent slip, a certain magnitude of interference has to be ensured; meanwhile, the interference needs to be controlled to avoid failure of the mechanical components caused by high assembly stress. Because of the improper interference values and rate of cooling sometimes the shrink fit cannot done properly. Due to this reasons the cannon liners are failing very frequently and the life of cannon is reducing because of this. By shrinking outer liner onto an inner liner of the different thickness, an elastic state of biaxial, hydrostatic stress can be induced in the liners [4]. When such compound cylinders are subjected to internal pressure, the compressive stress in the relieved first, and then tensile stress is developed. The tensile stress in outer liner is further increased due to internal pressure. Generally the three principal stresses in cylindrical or tapered cylindrical pressure vessels are- circumferential stress, radial stress and longitudinal stress and these stresses should be within the elastic limit of the material.

II. DESIGN AND MODEL ANALYSIS

2.1 Material data

AISI4340 is used for all the liners i.e for outer liner, middle liner and inner liner. (But in this investigation outer liner and middle liner are considered as a single liner).

Density	=	ρ	=	7850 kg/m^3
Young's modulus	=	E	=	200GPa
Poisson's ratio	=	μ	=	0.30

Tensile strength	=	σ_t	=	1126MPa
Yield strength	=	Ys	=	1017MPa
Coefficiernt of thermal expansion	=	α	=	3E-05
Thermal conductivity	=	K	=	44.5W/mk

2.2 Cross section data

2.2.1 cross section data of original cannon

Length of the cylinder	= 1.52meters
Outer diameter of outer liner	= 0.457meters (both sides)
Inner diameter of outer liner	= 0.19meters (right side)
Inner diameter of outer liner	= 0.14meters (left side)
Inner diameter of inner liner	= 0.055meters (right side)

2.2.2 cross section data of proto type cannon

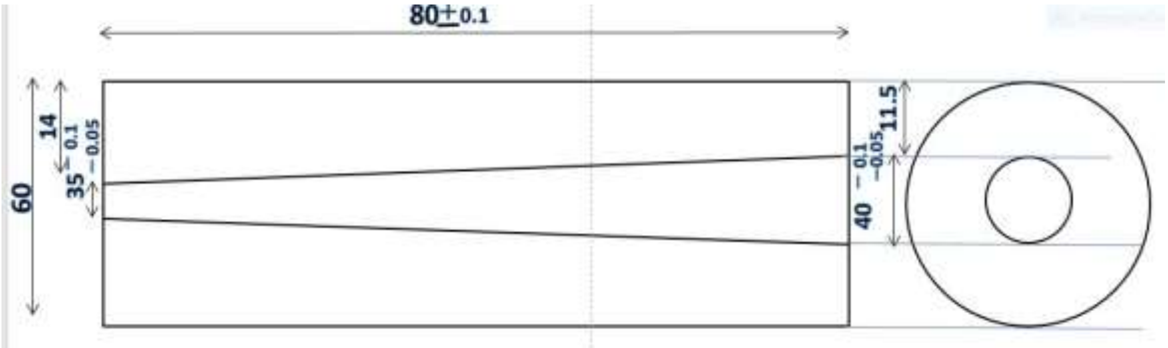

Figure 1 cross section of outer line

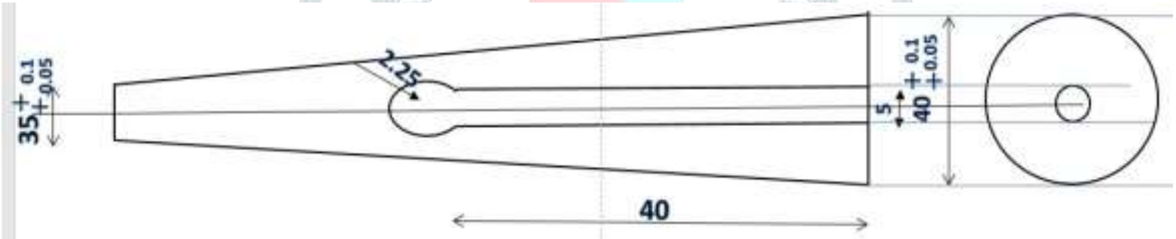

Figure 2 cross section of inner liner

2.1.3 Boundary conditions and constrains for the cylinder (liners)

The boundary conditions for the cylinders are

Supplying temperatures of 180℃, 200℃, 250℃ for 1hour to the outer liner for expansion.

Boundary condition after expansion is constraining outer surface of the inner liner in all three x,y,z directions. (At the time of cooling)

2.3 Modeling and Analysis procedure

Using the cross section data, the liners are designed in SOLID EDGE which resembles the structure of tapered compound cylinder with length 1.52m, outer diameter of the outer liner, inner diameter of the outer liner, and diameter of the inner liner are 0.457m, 0.19m, 0.055m respectively on right side of the cannon. These files are imported to ANSYS workbench to do the coupled analysis. Coupled thermal analysis is carried out for the investigation, firstly transient thermal analysis is done for the heating cycle and then the inner liner is inserted and transient structural analysis is carried out for the cooling cycle. Finite element analysis is carried out with orthogonal element with 0.1mm element size. Investigation is carried out for different fit positions like 0mm misfit (perfect fit), 1mm misfit, 3mm misfit, 5mm misfit and 10mm misfit at three different temperatures.

Due to the limitation of cross section of original cannon investigation is carried out on a prototype cannon with reduced dimensions. X-ray diffraction technique results and analysis results of prototype cannon are compared.

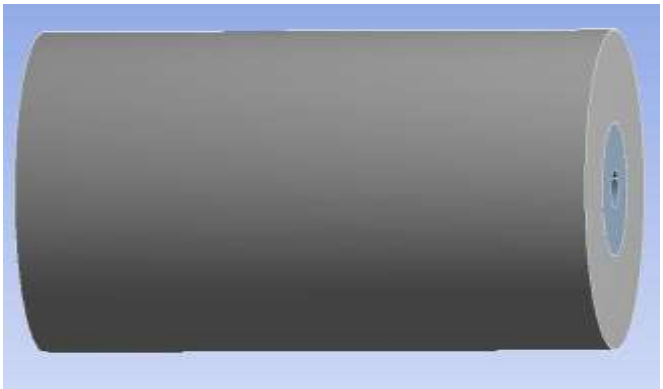

Figure 3 0mm misfit cannon model in ANSYS workbench

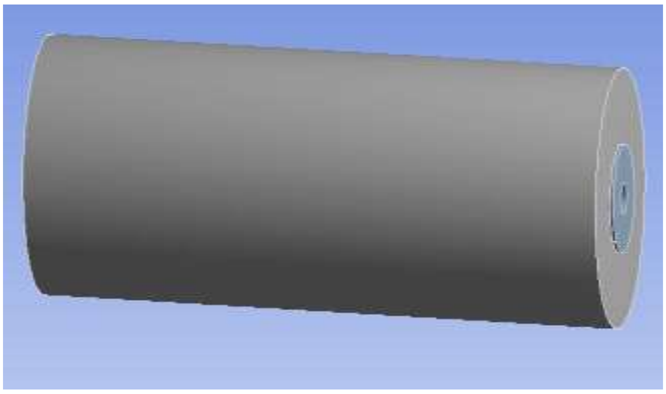

Figure 4 10mm misfit cannon model in ANSYS workbench

III RESULTS AND DISCUSSIONS

3.1 FEA results

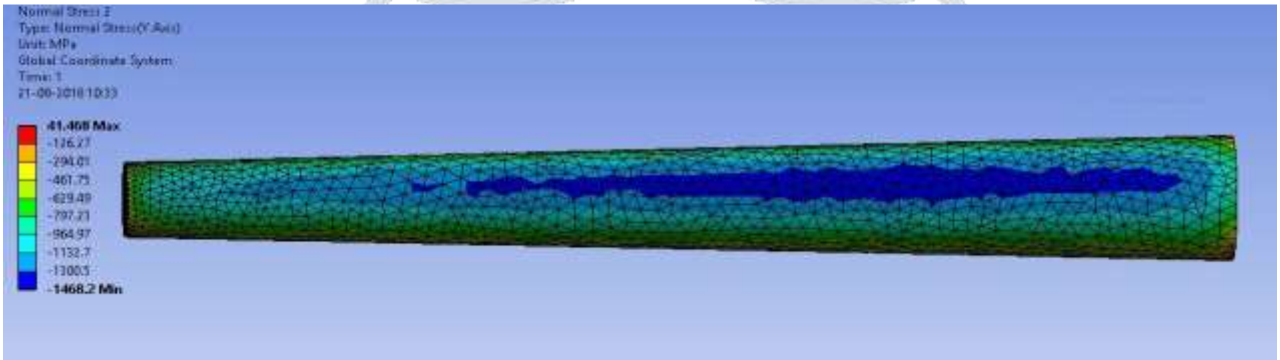

Figure 5 Normal stress distribution on the liners (200℃)

In original cannon also it is observed that at the interface more compressive stresses are generating as the blue colour indicates by going outwards, that means on the inner liner it is observed that combination of tensile and compressive stresses but on the inner liner it is purely compressive stresses.

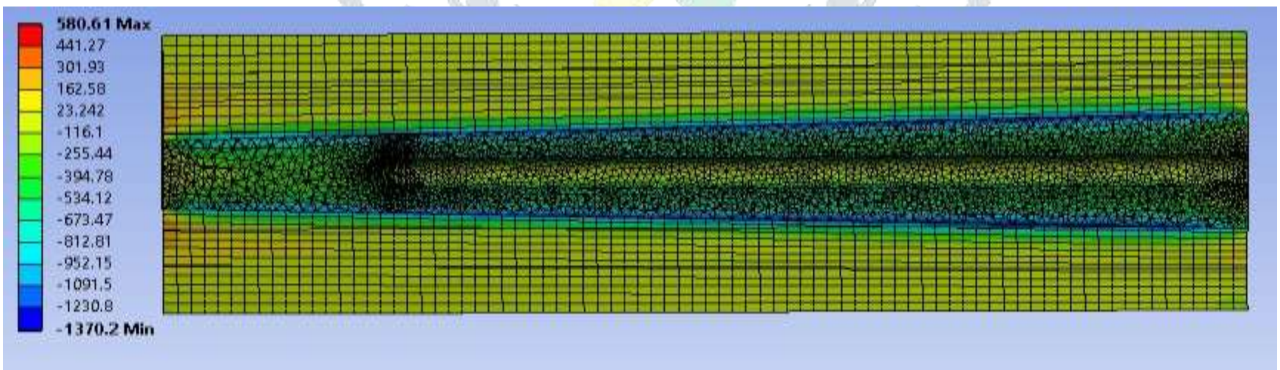

Figure 6 stress distribution at 200℃ for 1mm misfit

In 1mm misfit it shows clearly that the same kind of stress bands on the liners like perfectly fitted cannon (0mm misfit) but here it is observed that concentration of stresses is more compared to the 0mm misfit. Here also at the interface more compressive, on the outer liner it is combination of both type of stresses and the inner liner it is purely compressive stresses.

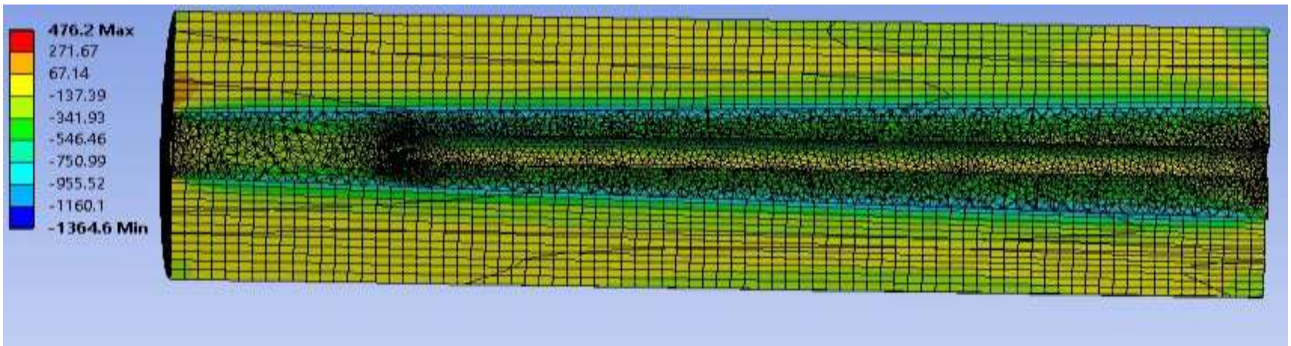

Figure 7 stress distribution at 200°C for 3mm misfit

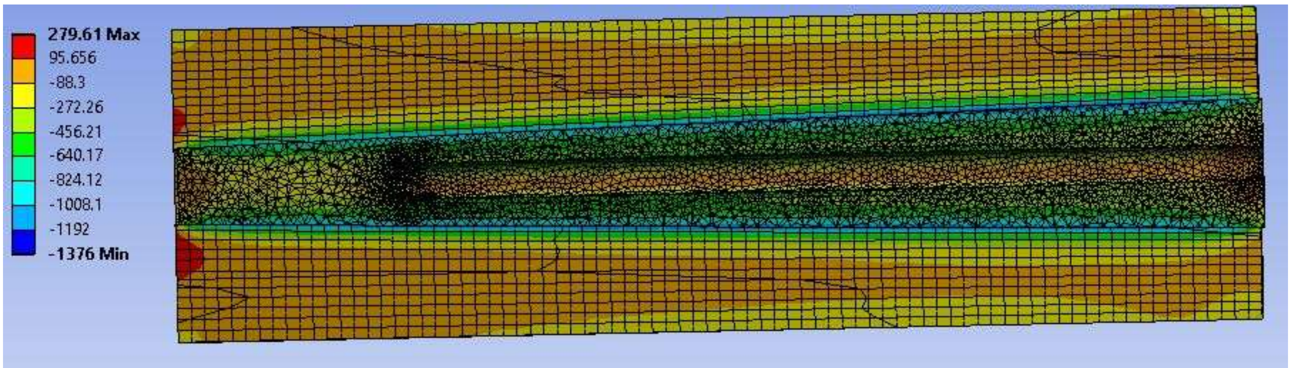

Figure 8 Stress distribution at 200°C for 5mm misfit

In the 5mm misfit it is observed that most of the outer liner is with tensile stresses and the maximum tensile stresses are at the edges of the interface. And it is also observed that the stresses are more in 5mm misfit than the 3mm misfit.

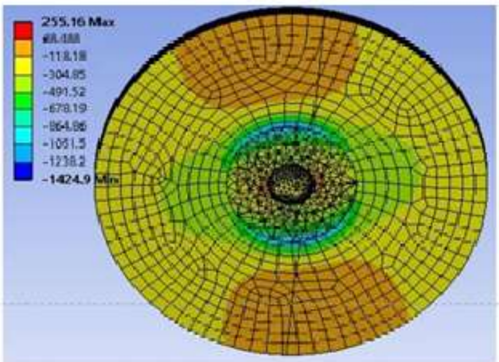

Figure 9 Stress distribution at 200°C for 10mm misfit

Normal stresses (on total cannon)	180°C	200°C	250°C
Perfect fit	-1257.5 to 420.26 MPa	-1393 to 471.4 MPa	-1825.6 to 452 MPa
1mm misfit	-1234.1 to 542 MPa	-1370 to 581 MPa	-1813.3 to 544 MPa
3mm misfit	-1205.9 to 447 MPa	-1365 to 476 MPa	-1844.2 to 605 MPa
5mm misfit	-1217.5 to 246 MPa	-1376 to 280 MPa	-1820 to 654 MPa
10mm misfit	-1263.4 to 224 MPa	-1390 to 255.1 MPa	-1825 to 333 MPa

Table 1 comparison of normal stresses in perfect fit and misfits at different temperatures

Generally, more compressive stresses do favour for the component to fit tightly and it will increase the value of load needed to pull it out. From the above table it can say that more compressive stresses are present in the perfectly fitted cannon than the remaining misfits. From this also it is showing that more pull-out load required for the perfectly fitted cannon than the misfitted once.

3.2 X-Ray Diffraction technique results

Residual stresses(at interface)	180℃
FEA	689.66-205.21 MPa(compressive)
XRD	355.2-250.8 MPa(compressive)

Table 2 comparison of residual stresses for prototype cannon

3.3 Results for explosive testing

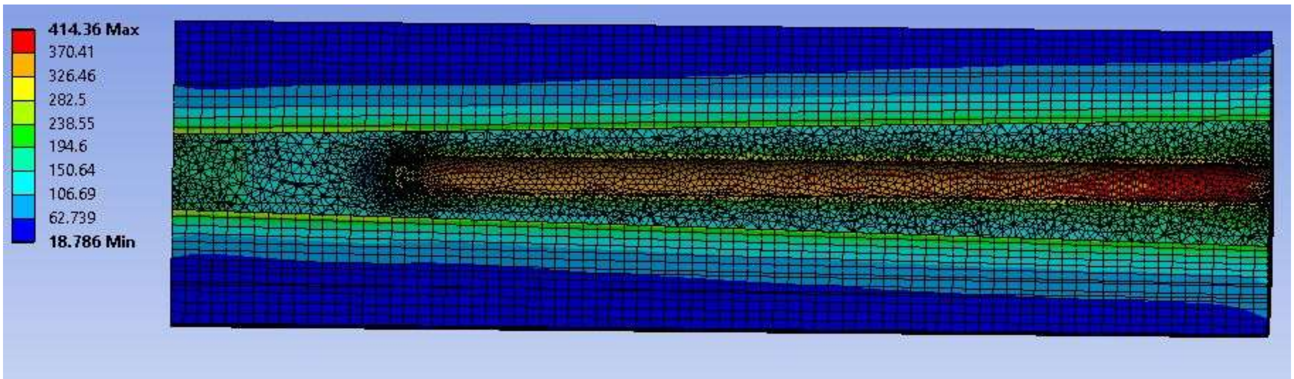

Figure 10 stress distribution in perfectly fitted cannon after explosive testing

In 0mm misfit (perfect fit) it shows that stress concentration is between 20- 430MPa and that stresses are more on the inner liner. But these stresses are less than the yield strength of the material of the liners so this design is safer while the explosive testing. After explosive testing simulations also it is proven that perfectly fitted cannon is more reliable than the any misfited cannon.

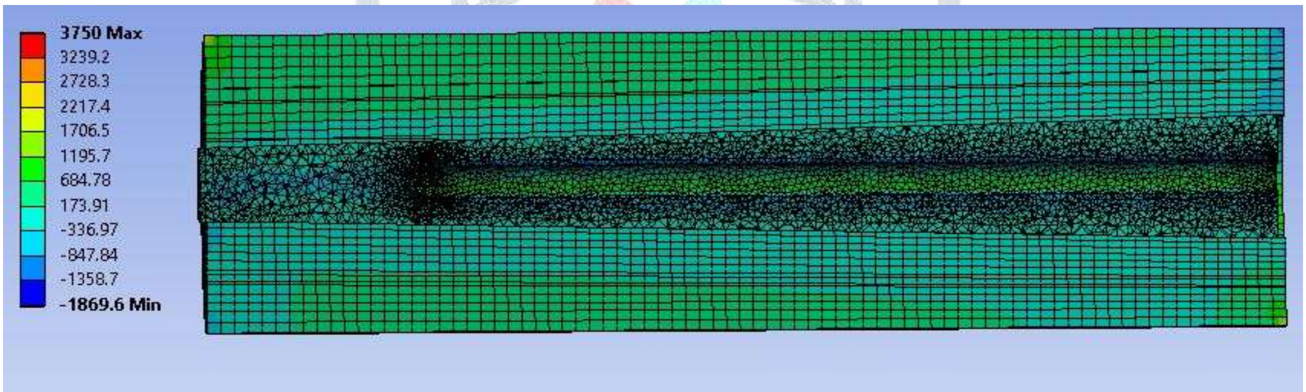

Figure 11 stress distribution in 10mm misfit cannon after explosive testing

In 10mm misfit explosive testing it is observed that, for the maximum part of the cannon stress lies in between 680 -1700MPa and this is more than the yield strength of the material of the liners. So there are more chances for plastic deformation or failure of the liners.

IV. CONCLUSION

By means of coupling of thermal and structural analysis, deformation, contact stresses at the interface, the stresses generated while the liners are cooling, and the stresses generated at the time of explosive testing of cannon are simulated by FEA analysis at the different thermal load conditions. For experimentation a cannon fabricated with reduced dimensions (prototype) and X-Ray diffraction technique is done on that model and the modelling of cannon in done solid edge software and for analysis we used ANSYS 19.0. Results (residual stresses) of FEA are validated with X-Ray diffraction technique.

- The both results are matched satisfactorily and same path of analysis is chosen for the cannon with original dimensions.
- This analysis carried for perfectly fitted cannon and misfitted cannon at different positions (1mm, 3mm, 5mm & 10mm misfits). It is concluded that the results of equivalent stresses which required for design consideration are less in perfectly fitted cannon comparative to the misfitted. And the compressive stresses which increase the strength of fit at the interface is also more in perfectly fitted cannon so pull-out load required for the perfectly fitted cannon is more for the misfitted once.
- It is observed that compressive stresses in the inner liner and at the interface and tensile stresses at the outer liner. In this investigation mapping of the stress results that obtained from the structural analysis after cooling are supplied to the explosive testing simulation.

- And it is observed that misfit cannon gives more stresses and it is some extent going into plastic region. By this it is clear that there are more chances of failure of misfitted cannon before its expected lifetime.

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