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Finite element analysis of artillery self-tightening body tube stresses

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Abstract: The self-tightening technology of body tube is to apply a certain pressure in the inner bore of the body tube so that the corresponding residual stress is generated in the body tube, and the self-tightening residual stress can improve the stress situation of the body tube when it is in use and extend its service life. Most of the existing self-tightening body tube research for large-caliber artillery and are simplified to a thick-walled cylinder model, ignoring the internal rifling of the body tube and chrome-plated processing factors, and for the impact load on the body tube and cracks on the self-tightening body tube internal stresses of the impact of the same did not take into account the rifling and chrome layer. In order to address the above problems, this paper takes a small-caliber artillery body tube as the research object, compares the theoretical calculations with the finite element simulation, and carries out the simulation research on the ideal elastic-plastic artillery steel body tube.

1. Introduction

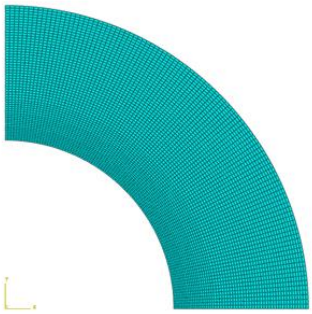
In this paper, taking into account the simplification of both the Tresca yield criterion and the modified Mises yield criterion, ABAQUS finite element simulation software is used to numerically simulate and analyze the body tube model, and analyze the self-tightening pressure required by the body tube in this paper as well as the stresses in the body tube during self-tightening loading and the residual stresses after unloading, with respect to different self-tightening degrees [1-3].

2. Irrelevance verification

In order to reduce the calculation time, in some finite element simulation, a plane model is usually used instead of a 3D model for simulation and analysis. For the self-tightening body tube model, a planar model can be considered instead of a 3D model for simulation and analysis, and before that, it is necessary to verify the irrelevance of the 3D model and the planar model to make sure that the models have no effect or a small effect on the simulation results [4-6].

As shown in Figure 1, respectively, the establishment of the body tube three-dimensional and planar quarter model, the model mesh, three-dimensional model end face mesh and planar model is identical, and the model is given the same material model and boundary conditions, and then the same self-tightening pressure loading and unloading simulation of the model.

a) 3D mesh model



b) Plane Grid Model

Figure 1: Three-dimensional and planar mesh model

3. Establishment of finite element model

According to the results of the irrelevance verification, the quarter-plane model of the body tube is established for the centrosymmetric cross-section of the body tube, and the quadrilateral mesh is divided into 5600 cells for the body tube model, and the grid model of the body tube divided into good cells is shown in Figure 2.

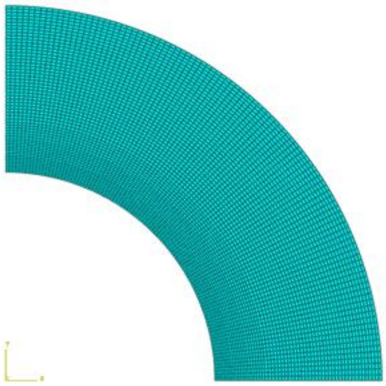


Figure 2: Body tube finite element model

Since a symmetric model is used for simulation, a symmetric fixed constraint is applied to the model boundary, a self-tightening pressure load is applied to the inner wall of the body tube, and the outer wall of the body tube is a free boundary, and the body tube model with the applied load and boundary conditions is shown in Figure 3.

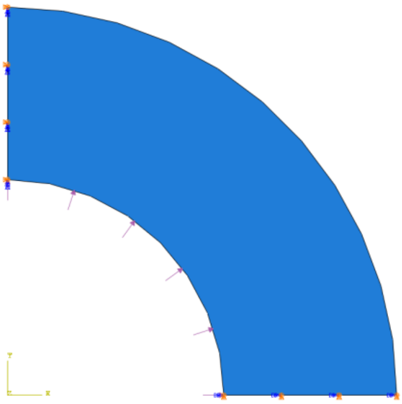


Figure 3: Loads and Boundary Conditions

A certain artillery steel material is used for the body tube in the simulation, and its relevant physical property parameters are shown in Table 1.

Table 1: Physical parameters of a gun steel material

Density /(Kg/m3)	Modulus of elasticity /GPa	Poisson's ratio	Yield limit/MPa	Loading linear reinforcement factor	Unloading linear reinforcement factor	The Bowsinger Effect Impact Factor
7833	206	0.3	1250	0.01	0.32	0.43

After the simulation, the equivalent stresses in the body tube along the radius direction are extracted and analyzed, and the results are obtained as shown in Figure 4. From the figure, it can be seen that the stress distribution of the body tube obtained from the 3D model and the plane model under the same boundary and load conditions is almost identical, so the plane model can be used instead of the 3D model for the analysis in the simulation.

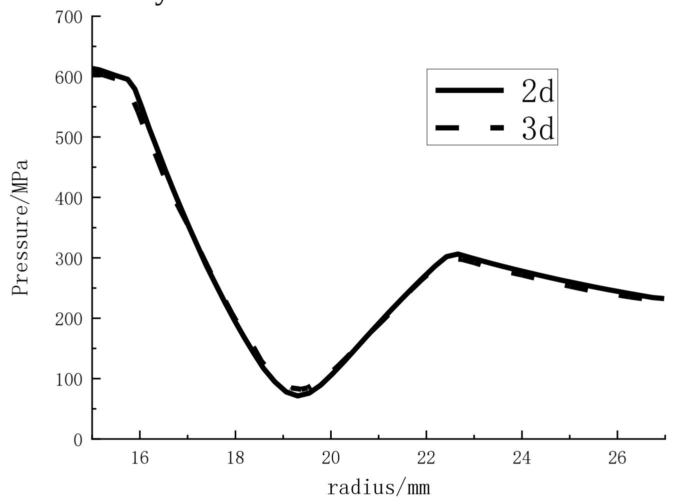


Figure 4: Equivalent residual stresses of different model body tubes

From the finite element simulation theory, it can be known that the larger the mesh density in finite element simulation, the higher the simulation accuracy, but correspondingly, the time required for simulation increases exponentially, and the computational cost will increase dramatically. In order to balance the relationship between computational accuracy and cost, it is necessary to verify the irrelevance of the model mesh size, and select a suitable mesh size that does not affect the computational results.

The models with mesh sizes of 1.2 mm, 0.6 mm, 0.3 mm, 0.15 mm and 0.075 mm are selected for the numerical simulation of the body tube self-tensioning, and the residual stresses are extracted along the radius of the body tube for comparison at the end of the simulation, as shown in Figure 5.

From the figure, it can be seen that when the mesh is smaller than 0.6mm, the effect of its size on the simulation results is almost negligible. Considering that the perimeter of the inner wall of the body tube is smaller than the perimeter of the outer wall, in order to divide the quadrilateral mesh, this paper chooses the scheme with the inner wall size of the body tube of 0.15mm, the outer wall of 0.4mm, and the middle mesh size of linear transition.

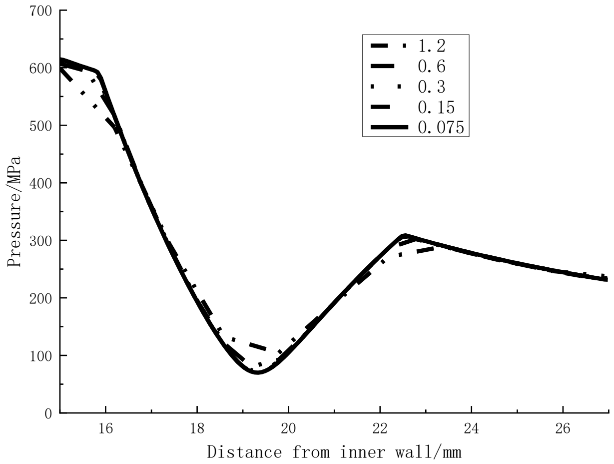


Figure 5: Equivalent residual stresses of body tubes with different mesh sizes

4. Self-tightening simulation of ideal elastic-plastic gun steel body tube

Ideal elastic-plastic gun steel constitutive model is used to simulate the self-tightening process of the body tube, ignoring the strengthening effect of the plastic phase of the gun steel, and ignoring the Bauschinger effect of the gun steel. In the simulation process, the loading and unloading process of the self-tightening pressure is considered as a steady state process. (1) Self-tightening pressure simulation

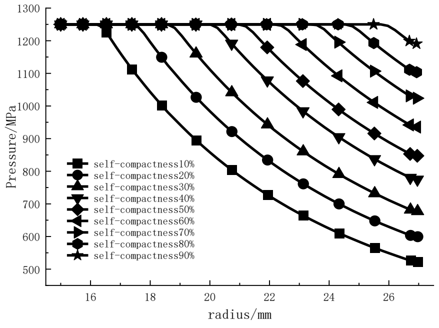
Finite element numerical simulation of the respective tightness of the body tube is performed separately to obtain the required pressure at the respective tightness as shown in Table 2.

Table 2: Pressure required for different self-tensioning degrees of the body tube of the ideal elasto-plastic gun steel constitutive model

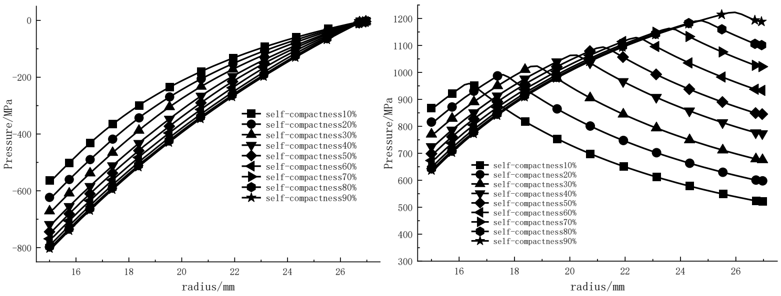
Self-tightness/%	10	20	30	40	50	60	70	80	90
Radius of elastic-plastic interface/mm	16.2	17.4	18.6	19.8	21	22.2	23.4	24.6	25.8
Self-tightening pressure/MPa (Mises yield criterion)	570.6	629.4	678.7	719.1	751.6	776.2	793.7	804.1	810.3

(1) Stress of the body tube during self-tightening loading

The stresses of the body tube during self-tightening under different self-tightening degrees are shown in Figure 6, and the stress trends are basically the same as those of the theoretical calculations. The simulation takes into account the product of principal stresses in each direction of the body tube, so that there is no stress difference in the elastic-plastic interfaces and the transition is relatively smooth.



a) Mises equivalent force

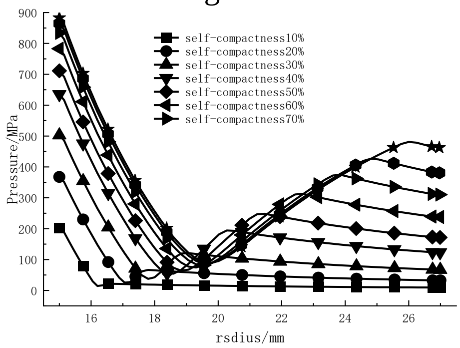


b) Radial stresses c) Tangential stress

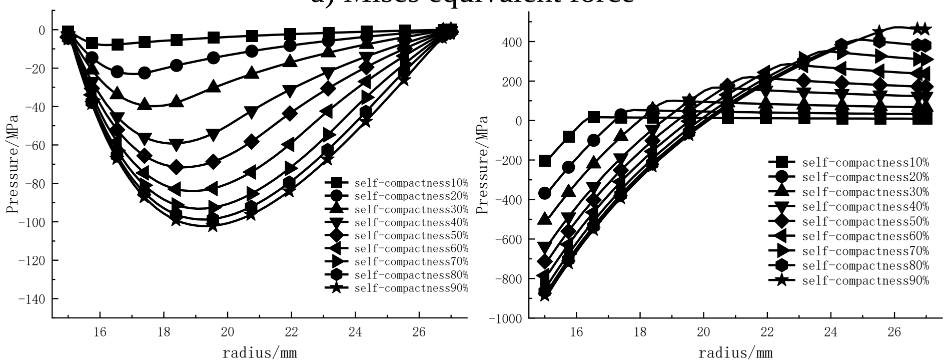
Figure 6: Ideal elastic-plastic gun steel intrinsic model body tube self-tensioning loading stresses

(2) Residual stresses after unloading of self-tightening pressure

The residual stresses inside the body tube after unloading of the self-tightening pressure with different self-tightening degrees are shown in Figure 7.



a) Mises equivalent force



b) Radial stresses c) Tangential stress

Figure 7: Ideal elastic-plastic gun steel intrinsic model body tube residual stresses

The trend of residual stresses in the diameter and tangential directions of the pipe is the same as that of the theoretical calculation, and there is no stress difference at the elastic-plastic interface and the transition is relatively smooth.

5. Conclusion

There is a certain difference between the self-tightening pressure needed for the body tube under the same self-tightening degree from theoretical calculation and finite element simulation, in which the self-tightening pressure calculated by using Tresca yielding condition has a big difference with that simulated by using Mises yielding condition; the self-tightening pressure obtained by using Modified Mises yielding condition has a smaller difference with the simulation result; the reason is that the Tresca yielding condition does not consider the principal stress product, while the Modified

Mises yielding condition equates the principal stress product to a fixed correction factor. The reason is that the Tresca yield condition does not consider the product of principal stresses, and the modified Mises yield condition equates the product of principal stresses to a fixed correction factor.

The theoretically calculated residual stresses in the diameter direction of the body tube using the ideal elastic-plastic gun steel model are somewhat different from the simulation results due to the principal stress product.

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