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Fatigue study on the cracks of a cannon

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Analysis and modelling

ABSTRACT

Purpose: Cannon is one of the most usage parts in military industries and analysis of its pipe is very important. Therefore, the prediction of its longevity to say, the number of cannon ball that can be fired till it is break down should be under consideration.

Design/methodology/approach: Since the life of cannon,s barrel directly depends on the inner micro-cracks under numerous firing, the study of these cracks are very important. From this point of view, the stress analysis on crack tip is carried out via ANSYS software in this research.

Findings: This analysis shows that the stress intensity on the tip of the crack is a function of its length and increases with the number of these cracks.

Research limitations/implications: In this research the fatigue with several cracks is analyzed in the barrel according to the explosion pressure in order to find the critical conditions.

Originality/value: Since the cannon barrel life is a convert function of the stress intensity of the cracks, multi-cracks condition passes the most fatigue cycling. The shape function of the cracks is also decreased with the number of the cracks.

Keywords: Numerical techniques; Fatigue; Monte Carlo; Crack; Life; Cannon; Thick-walled

1. Introduction

The history of cannon pipes refers to the thick-walled pipes. The first cannon pipe is built in 14 century. According to the improvement in material properties adopting a policy to prevent the inner surface of these pipes against erosion is under consideration. Cracking phenomena often lead to a few-times decrease in its strength and are peculiarly dangerous in especially brittle materials[1]. Even though much achievement has been made in crack modelling techniques, both simple and practical crack modelling technique is still needed, in particular for complex multiple crack growth problems[2]. The prediction and estimation of failure behaviour of elastic-perfectly plastic material containing a crack loaded by two pairs of point tensile forces are of great interest to researchers and engineers in many science and engineering disciplines[3]. The stochastic nature of fatigue-related parameters was correlated to die life and Monte Carlo simulation was used to predict the life distribution of a die under given manufacturing conditions and mechanical properties[4]. For an impermeable interface crack in general anisotropic piezoelectric biomaterials, Suo et al. Obtained the crack-tip generalized stress field by solving an eigenvalue problem with four non-ero eigenvalues and four associated linearly independent eigenvectors. The crack geometries provide the original interest in predicting the mixed-mode solutions to the multiple perpendicular crack problems[5]. In order to attain the best possible results in engineering problems numerical methods are widely employed[6]. Among several elastic two-dimensional modelling strategies by the boundary element method, there exist the multi-domain formulation the stress formulation with regularization and the dual boundary element method[7]. Particularly flows or cracks lying along the interface reduce the strength of the structure significantly[8]. Presence of non-linear fault like a crack brings non-linearity in the originally linear system equations[9]. During the low-cycle tests, the material may be damaged in the conditions of elastic-plastic strain[10]. Even very small differences in internal stresses between the layers close to the strip surface can result in its folding, twisting or similar defects[11]. Monte Carlo method is a suitable and precise fatigue analysis method in cannon barrel. In this research 155 mm cannon pipe with one, two, three, four and twenty five cracks on inner surface is fatigue analyzed. The cross section of this cannon pipe is shown in Figure 1.

Analysis in carried out with ANSYS software and it is compared with the other work which is done via ADINA software [12].

2. General conditions

2.1. Characteristics of the cannon barrel cross section

The break down phenomenon usually takes place in the cannon pipes where the explosion pressure is maximum. The characteristics of the critical section is as follows:

- Inner diameter: r_i =85 mm
- Outer diameter: r_o =160 mm
- Thickness : $w = r_o - r_i$ =75 mm

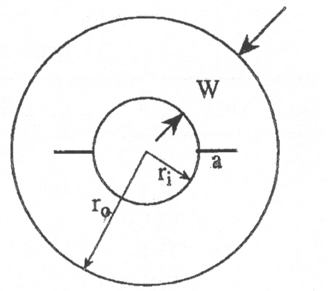

Fig. 1. Cross section of a cannon pipe

2.2. Mechanical properties of cannon barrel's material

The material of cannon pipe is 4340 Steel. Its properties is shown in Table 1.

Table 1.
Some useful properties of cannon pipe

Material	E (GPa)	S_y (GPa)	S_{uts} (GPa)	K_{IC} (MPa.m½)
4340 Steel	206.2	1.131	1.232	125.8

2.3. Boundary conditions

The form of the model for any number of the cracks should be symmetric so that, its boundaries could move just in the radial direction and in any other situation; the ramp on boundaries should be zero.

2.4. Stress intensity factor calculation

Stress intensity factor is a function of the length of the crack and it is increased with this length[13]. This parameter is also a function of geometrical shape of the crack and model. For this thick-walled pressure vessel not Autofrettaged, the variation of stress density is as follows:

$$\Delta K = K_{max} - K_{min} = \bar{K}(P_{max} - P_{min})\sqrt{\pi \times a}$$
$$\Delta K = \bar{K} P_{max}\sqrt{\pi \times a} \qquad (1)$$

Where P_{max} is maximum explosion pressure and P_{min} which is usually zero is its minimum value and a is the length of the crack. K is a coefficient related to the geometrical shape of the crack and sample. This coefficient can be considered as constant value since its variations is very small. To calculate the stress density variations as a function of the crack length, various finite element methods are used. Modelling and its analysis is carried out via ADINA and ANSYS software (See Table 2).

Table 2.
Comparison between stress density factors

a(mm)	0.1	0.3	0.5	0.7	1.1	1.5	1.9
ADINA K_I ($MPa\sqrt{m}$)	20.9	36.21	46.52	54.92	68.56	79.82	89.56
ANSYS K_I ($MPa\sqrt{m}$)	21.32	38.12	47.12	55.18	70.12	81.52	91.56

So that, the cross section is modelled due to one, two, three, four and twenty five cracks and according to the length of various cracks, stress intensity is calculated.

2.5. Fatigue life calculation

The fracture toughness is obtained experimentally; then, the critical length of the crack can be calculated from the following equation:

$$K_{IC} = \bar{K} P_{max}\sqrt{\pi \times a_{cr}} \qquad (2)$$

Where K_{IC}, $\bar{K}$ and a_{cr} are fracture toughness, average coefficient in un-cracked manner and the length of critical crack respectively. The amount of fracture toughness for 4340 Steel is shown in Table 1. By integration of Paris Formula [14]:

$$N_f = \int_{a_0}^{a_{cr}} C^{-1}[\Delta K = f(a)]^{-n}\, da \qquad (3)$$

Where N_f is cycle life and a_0 is the length of initial crack. In this case the main problem is the length of initial crack which should experimentally be obtained. Figure 2 shows a standard sample which is used to calculate the fracture toughness experimentally [15].

Modelling section depends on the number of cracks. Fore instance, in one crack case the modelled section is the half of pipe's cross section and in 25 cracks case, it is a portion of pipe's cross section with center angle of 7.2 degree. The cross sections modelled in 2 and 25 crack cases is shown in Figure 3.

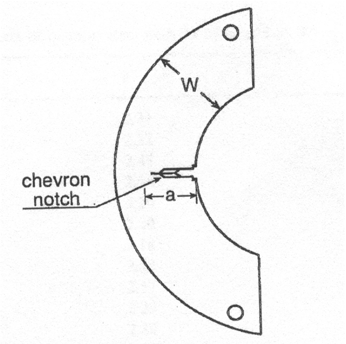

Fig. 2. A standard sample for fracture toughness determination

a)

b)

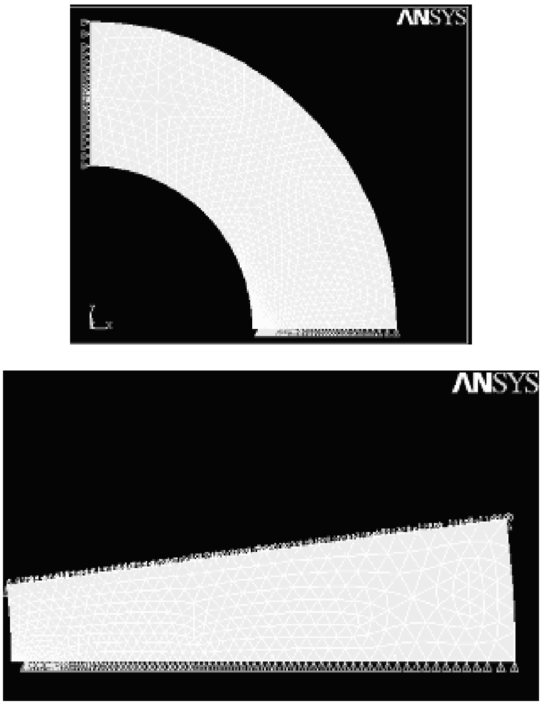

Fig. 3. Schematic cross-section modelled with (a)-two cracks and (b)- Twenty five cracks

It is noticeable that in general case when the number of cracks are n, then the modeled section is a portion of circle with b=180/n central angle.

3. Fatigue analysis

Paris Formula is used in fatigue analysis so that, the relation between stress density and the length of the crack is determined via EXEL and then this is replaced in Paris Formula and afterwards, fatigue equation is obtained via integration. This analysis is carried out according to the following conditions:

- Maximum explosion pressure(P_{max}): 380 MPa
- Minimum explosion pressure(P_{min}): 0
- Initial length of crack(a_0): 0.2 mm
- Fracture toughness(K_{IC}): 125.8 MPa.m^{½}

4. Conclusions

Before fire, the ball passes a distance inside the cannon's barrel as thick-walled cylindrical vessel so that, the explosion pressure behind it reaches to its maximum amount. In this passing distance, there is a critical section which is fatigue analyzed here. Stress intensity increases with the length of cracks (See Figure 4).

a)

b)

c)

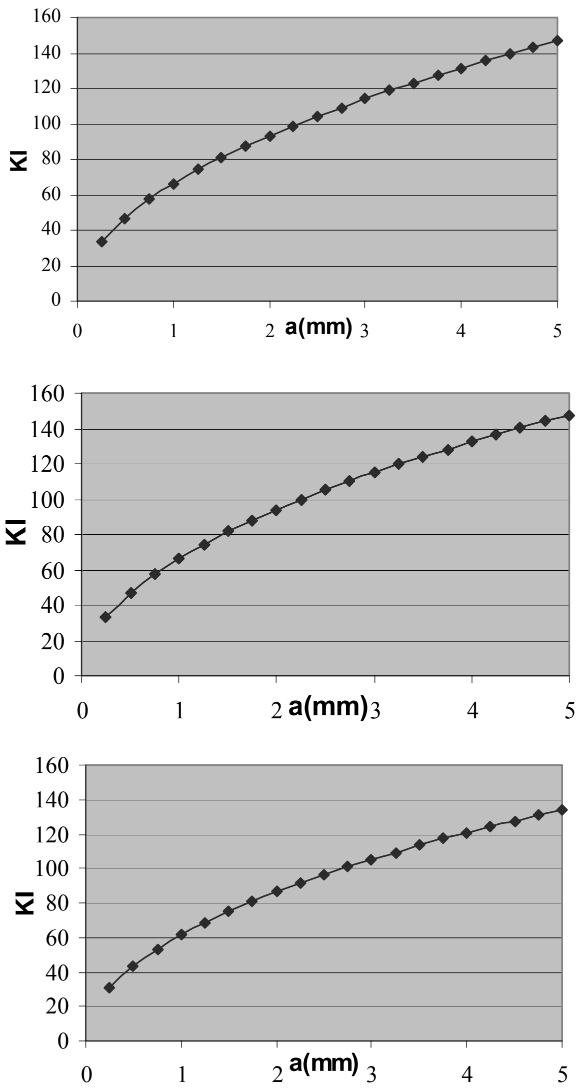

Fig. 4. Stress density variations with the length of the cracks: a)-one crack, b)-2 cracks, c)-3 cracks

Figure 5 shows the comparison between the length of the cracks and dimensionless coefficient K in various conditions.

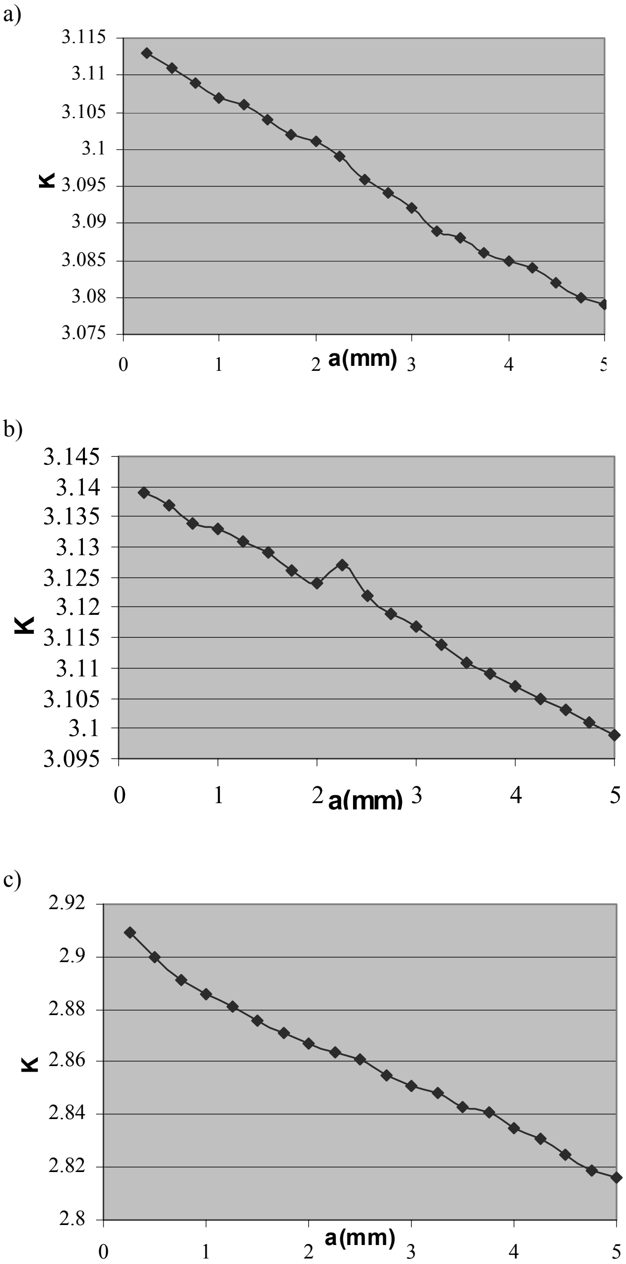

Fig. 5. Variations of K coefficient with the length of cracks at critical section: a)-one crack, b)-2cracks, c)- 3 cracks

According to the fatigue values, these parameters are variable and their amounts decrease with the length of the cracks. But these variations are very small, so that, they can be assumed to be constant. The average of these amounts is used in calculations.

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