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STRAIN INTENSITY OF THE STEEL PIPE UNDER THE ACTION OF EXTERNAL TENSILE, COMPRESSIVE AND COMBINED LOADS

Abstract*: Comparison of stress state of the steel pipe under the action of constant pressure applied to the outer and inner cylindrical surfaces (separately and simultaneously) was performed in the article. The values of the steel strain intensity coefficient were calculated at the ratio of D/d=0.7 (the inner diameter of the pipe to the outer diameter).*

Key words*: the pipe, pressure, stress, strain, material.*
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Introduction

The pipes are used in various industries (moving liquid and gaseous substances over the certain distance, torque transmission and material saving in mechanics, etc.). The pipe material under the action of various loads (including combined loads) is subjected to compression, tensile, bending, torsion [1-10], etc. Since the pipe in the cross section has the ring shape, it is necessary to enter the ratio of the inner diameter to the outer diameter for the calculations.

Let us consider the process of fluid flow under pressure in the cylindrical pipe. Pressure resulting in material tensile acts on the inner walls of the pipe. Excessive pressure acting on the outer diameter of the pipe (the pipe that is subjected to plastic deformation or the pipeline that is under water) leads to compression of material. Strain intensity of the pipe material at the action of these loads will be different. The models of stressed and deformed states of the pipe material at the action of one or two loads at the same time can be obtained after solving the dynamic problem in the explicit statement. Comparison of stress-strain state of material will allow us to draw the conclusion about the most rational scheme of the pipe loading.

Materials and methods

The research of stress-strain state of the pipe at the action of various loads was performed in the modules of the Ansys program (Explicit Dynamics and Autodyn). The pipe fragment model had the outer diameter (*d*) of 40 mm and the inner diameter (*D*) of 28 mm. Constant pressure *P* of 1 MPa was applied to the various surfaces of the pipe fragment model. The duration of the load action was 3 seconds. The pipe loading schemes are presented in the Fig. 1.

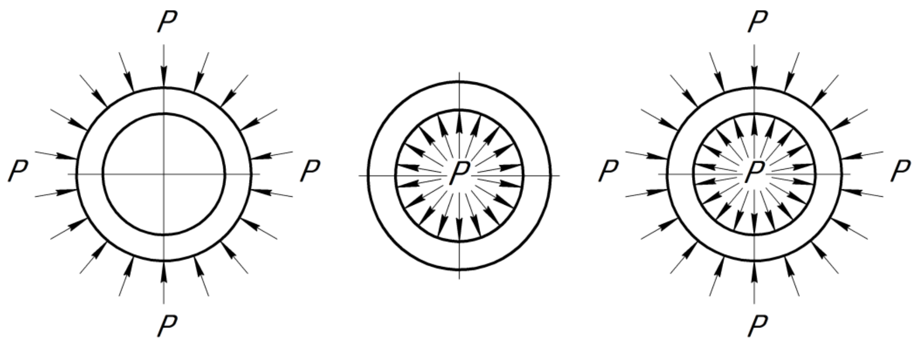

Figure 1 – The steel pipe loading schemes: *A* – the first scheme (pressure acting on the outer surface), *B* – the second scheme (pressure acting on the inner surface), *C* – the third scheme (pressures acting on the outer and inner surfaces).

The model of the pipe fragment was made of structural steel with the following properties: density – 7850 kg/m^3, coefficient of thermal expansion – 1.2×10^{-5}, specific heat – 434 J/(kg×K), thermal conductivity – 60.5 W/(m×K), resistivity – 1.7×10^{-7} Ohm×m, compressive yield strength – 250 MPa, tensile yield strength – 250 MPa, tensile ultimate strength – 460 MPa, Young's modulus – 2×10^5 MPa, Poisson's ratio – 0.3, bulk modulus – 1.6667×10^5 MPa, shear modulus – 76923 MPa, relative permeability – 10000, strength coefficient – 920 MPa, strength exponent – -0.106, ductility coefficient – 0.213, ductility exponent – -0.47, cyclic strength coefficient – 1000 MPa, cyclic strain hardening exponent – 0.2.

The simulation was performed when the following conditions: maximum energy error – 0.1, time step safety factor – 0.9, linear artificial viscosity – 0.2, quadratic artificial viscosity – 1, viscous coefficient – 0.1, static damping – 0, geometric strain limit – 1.5. The deformation process was simulated at the temperature of 22 °C.

Results and discussion

The color contours that characterize intensity of stress-strain state of the pipe material were distributed after the calculation on the volume of the fragments models. Stress state of the pipe material under the action of considered loads is presented in the Figs. 2 – 4.

Pressure acting on the outer diameter of the pipe leads to maximum von Mises stress, which is distributed in the volume of the surface layer of the hole. The volume stress of the surface layers of the hole is 1.3 times more than the volume stress of the surface layers of the outer diameter at the first loading scheme. Minimum stress of the pipe material is observed when two loads are applied simultaneously. The uniform distribution of almost the same value of material stress indicates the rational scheme of the pipe loading.

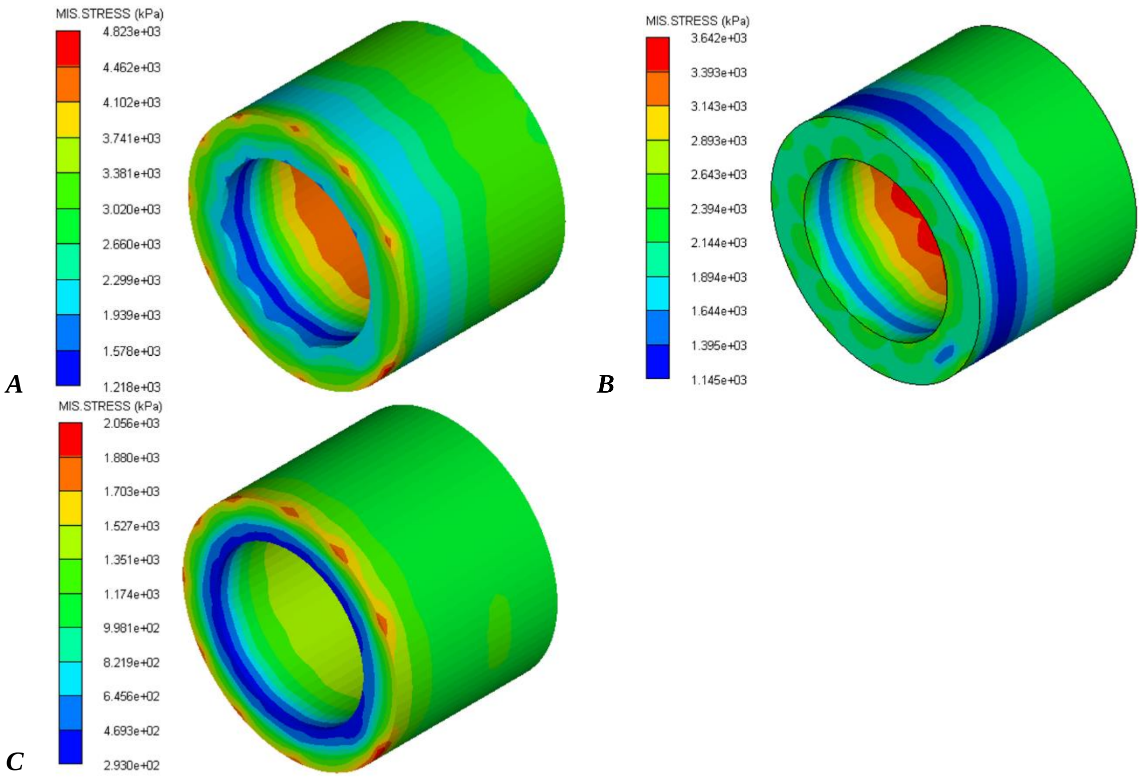

Figure 2 – Von Mises stress of the pipe material at pressure: the first scheme (*A*), the second scheme (*B*) and the third scheme (*C*).

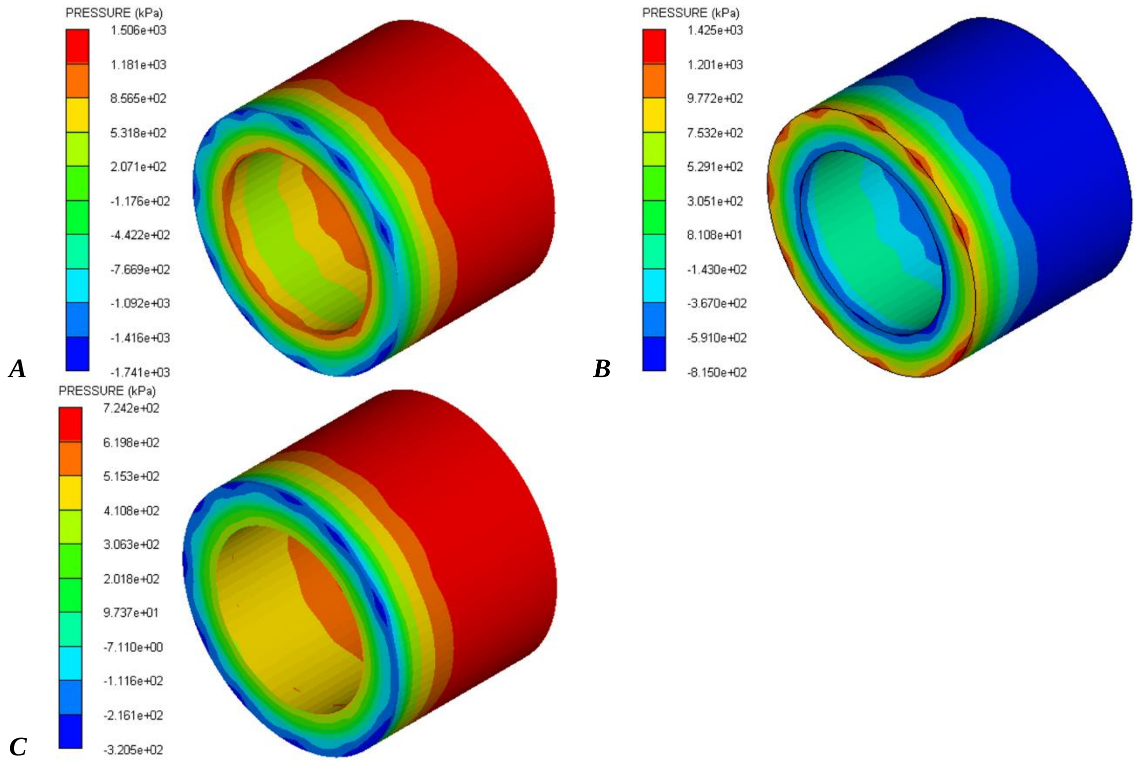

Figure 3 – Tensile and compressive stress of the pipe material at pressure: the first scheme (*A*), the second scheme (*B*) and the third scheme (*C*).

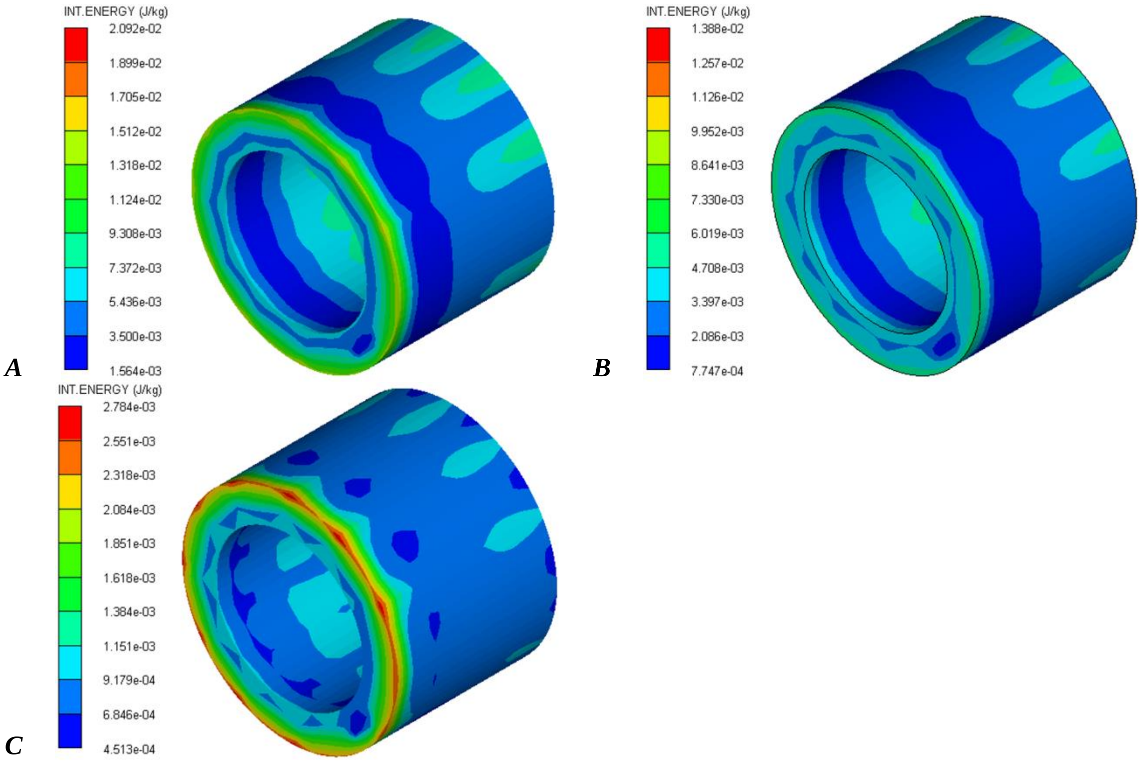

Figure 4 – Internal energy of the pipe material at pressure: the first scheme (*A*), the second scheme (*B*) and the third scheme (*C*).

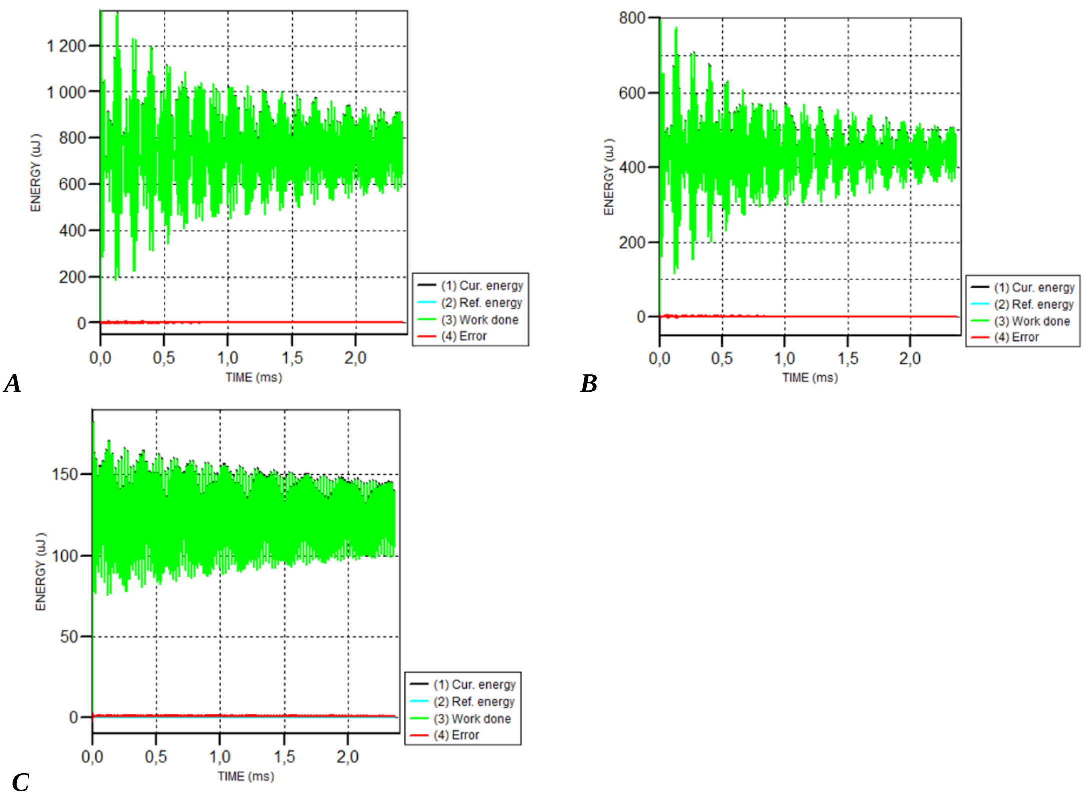

Figure 5 – Energy of work done during plastic deformation of the steel pipe: *A* – the first scheme, *B* – the second scheme, *C* – the third scheme.

The pipe material is subjected to compression and tensile, respectively, at the first and second loading schemes. The strain distribution of the pipe material is the same in both cases. The action of two loads simultaneously only leads to compression strain of the pipe material.

Work of external forces causes plastic strains without destruction of material. Acting radial loads lead to internal energy bursts in the axial direction of the loose section of the steel pipe.

Changing energy of work done during plastic deformation of the steel pipe is presented in the Fig. 5.

Energy of work done decreases (occurrence of plastic strains of material) with increasing application time of constant load for all the considered schemes. The simultaneously action of loads leads to decreasing the energy range of work done, since these pressures balance each other.

The calculated values of the material strain intensity coefficient at the action of pressure on the outer or inner surfaces and the simultaneously action of pressure on the outer and inner surfaces of the pipe are presented in the table 1. Steel destruction occurs at the strain intensity coefficient of 0.68. Elastic strains occur during deformation of steel by no more than 0.2%.

Table 1. The values of the strain intensity coefficient of the pipe material at D/d=0.7.

The number of the loading scheme	1	2	3
The value of the strain intensity coefficient	0.253	0.312	0.142

Conclusion

1. The action of pressure on the outer cylindrical surface of the pipe leads to maximum stress of material. Simultaneously application of loads on the outer and inner surfaces of the pipe is accompanied by the uniform distribution and stress decreasing of 2.4 times, compared to the first loading scheme.

2. The strain intensity coefficients of the steel pipe at *D/d=0.7* are defined: in the conditions of pressure application on the outer surface – 0.253, in the conditions of pressure application on the inner surface – 0.312, in the conditions of pressure application simultaneously on the outer and inner surfaces – 0.142. The estimation of the calculated values of the coefficient indicates significant plastic strain of the pipe, which was loaded according to the second scheme.

3. The outer and inner layers of the pipe material are subjected to 85% compression strain when application of two loads simultaneously.

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