

IMPACT OF CREEP ON FLANGE CLAMPING FORCE

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ABSTRACT

The study presents a numerical analysis of the impact of creep in thermoplastic stub ends on the flange clamping force of a thermoplastic pipe flange connection. The analysis uses available creep modulus values that depend on the stress level, temperature and time. A method that takes the creep modulus into account is proposed and applied to four different detailed variants with the aid of the finite element method. The calculations were performed for selected times at a constant temperature and with static load. The obtained results show that the influence of creep in thermoplastic stub ends causes a substantial reduction in flange clamping force in less than one year.

KEYWORDS

Creep modulus, Clamping force, Flange connection, FEM, ANSYS

INTRODUCTION

The study deals with a decrease in the initial clamping force of a thermoplastic pipe flange connection (Figure 1) due to creep [1, 2] in thermoplastic stub ends made from high density polyethylene (PE-HD). The creep in the PE-HD can be described by the creep modulus [3]. The method uses available long term creep modulus values from the EN 1778 standard [4]. The numerical analysis uses the finite element method (FEM) [5, 6]. The study presents a proposed method that takes into account the creep modulus, and applies the method to four different detailed variants. The proposed method considers the exposure time, the stationary temperature and the static load. Another technique that takes into account a creep modulus that is dependent on one temperature, stress field and time was published in [7].

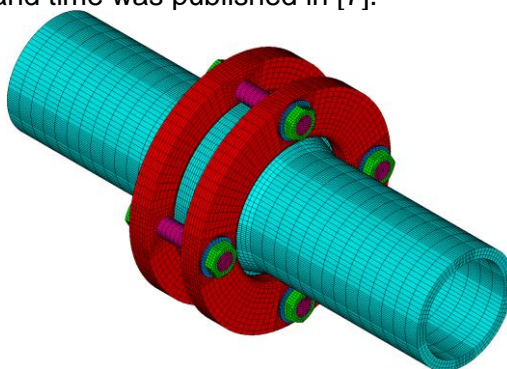


Fig. 1 - Model of a flange connection

FLANGE CONNECTION

As can be seen from the depiction of the parts of the flange connection [8] in Figure 2, the connection is an assembly in which stub ends are welded to pipes which are connected through

lap joint flanges by four bolts and an inner bolt circle gasket. The dimensions and materials of the flange connection parts are listed in Table 1. The fluid in the pipe system is water at an operating temperature of 20 °C with an internal pressure of 1 MPa.

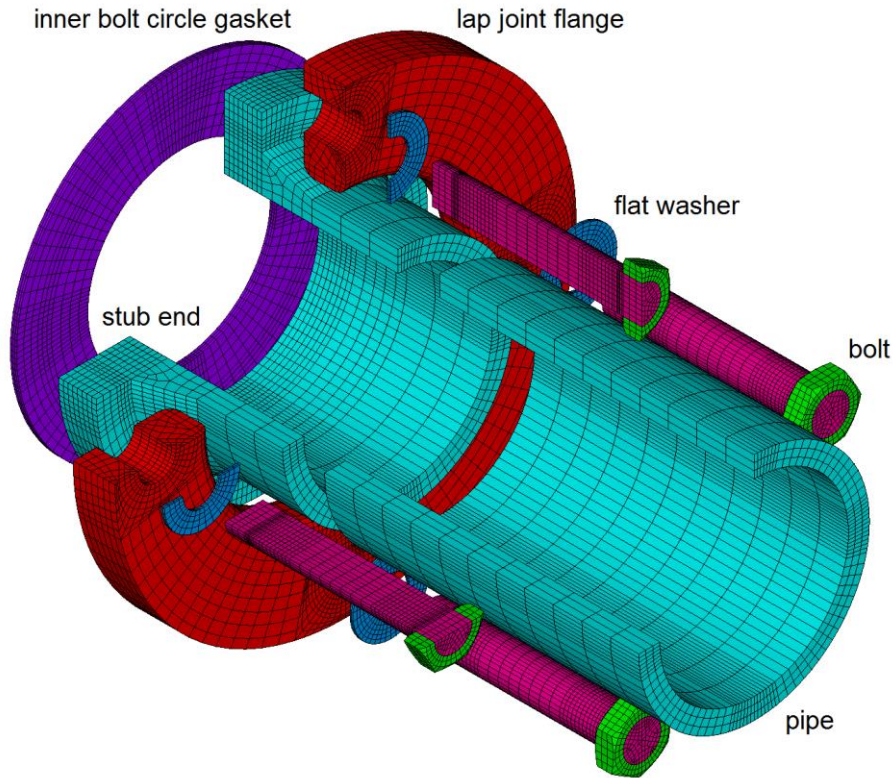


Fig. 2 - Flange connection parts and their mesh

Tab. 1 - Properties of flange connection parts

Flange connection part	Material	Dimension name	Value [mm]
pipe	PE-HD	outer diameter	110
		wall thickness	10
stub end	PE-HD	max outer diameter (length of this part)	158 (18)
		max outer diameter of middle part (length of middle part)	125 (24)
		min outer diameter (length of this part)	110 (41)
inner bolt circle gasket	EPDM	mean diameter d_G	124
		width b_G	34
		thickness	3
lap joint flange	steel	outer diameter	220
		inner diameter	128
		thickness	20
bolt	steel	bolt body diameter	18
flat washer	steel	outer diameter	34
		thickness	3

Creep modulus

Creep modulus values (Table 2) for some thermoplastic materials at the exposure time of 1, 10 and 25 years are given in the standard [4]. The creep modulus stated in [4] is defined as the secant creep modulus determined for a given exposure time for a specific stress level and temperature. The creep modulus values of the PE-HD at the temperature of 20 °C for different stress levels and exposure times obtained from the graphs in [4] are given in Table 2.

Tab. 2 - Creep modulus values of PE-HD for 20 °C for the times stated in [4]

Stress level [MPa]	Creep modulus values at selected times [MPa]		
	1 year	10 years	25 years
0.5	307	255	236
1.0	282	229	206
2.0	235	191	170
3.0	204	161	148
4.0	181	140	130
5.0	159	121	113

Clamping force

The flanged clamping force is considered according to the EN 12573-4 standard [9]. The standard defines the flanged clamping force under assembly and operating conditions.

The flanged clamping force F_A [N] under assembly conditions is defined as:

$$F_A = p_G \pi d_G b_G = 1 \cdot \pi \cdot 124 \cdot 34 = 13245 \text{ N} \quad (1)$$

where p_G [MPa] is the pressure exerted on the gasket under assembly conditions, d_G [mm] is the mean gasket diameter, b_G [mm] is the gasket width and π is a mathematical constant. The flange clamping force under assembly conditions (1) approximately corresponds to the product of the gasket area with a default pressure of 1 MPa applied to the gasket. The gasket area is determined approximately as the product of the circle length determined by the mean gasket diameter with the gasket width.

The flanged clamping force F_O [N] under operating conditions is defined as:

$$F_O = p_o \left(\pi \frac{d_G^2}{4} + \frac{3.8 d_G b_G}{2} \right) = 1 \left(\pi \frac{124^2}{4} + \frac{3.8 \cdot 124 \cdot 34}{2} \right) = 20087 \text{ N} \quad (2)$$

where p_o [MPa] is the operating pressure. The flange clamping force under operating conditions (2) corresponds to the product of the operating pressure with the sum of the two areas. The first area is defined by the mean gasket diameter. The other area is half of the gasket area determined in a similar manner as in formula (1) but with the value 3.8 instead of the mathematical constant π . The sum of the areas approximately corresponds to the area of the circle defined by the outer gasket diameter.

SIMULATIONS

Flange clamping force relaxation at the selected time points is calculated with the finite element method in the ANSYS software package [6]. The finite element mesh is shown in Figure 1 and Figure 2. The SOLID185 linear brick element is used. Surface to surface contacts are defined between the flange connection parts by a pair of contact elements: CONTA174 and TARGE170. Pretension is applied by a PRETS179 element in the middle of the length of each bolt. At this point a cut perpendicular to the bolt axis is defined. The surfaces created by the cut can be shifted towards each other. The result of this shift is a shortening of the bolt, and therefore pretension loading.

Material

The thermoplastic parts of the flange connection are made from high density polyethylene (PE-HD) [8]. The initial creep modulus value $E_0 = 800$ MPa (0 years) at a temperature of 20 °C is considered to be a constant value for all stress levels. The creep modulus curves in relation to stress level at a temperature of 20 °C for exposure times of 1, 10 and 25 years are shown in Figure 3. The curves pass through the creep moduli from Table 2. The curves are in the form of the polynomial functions used in the material model. The creep modulus values for stresses of less than 0.5 MPa are extrapolated, while for stresses greater than 5.0 MPa they are considered to be constant values.

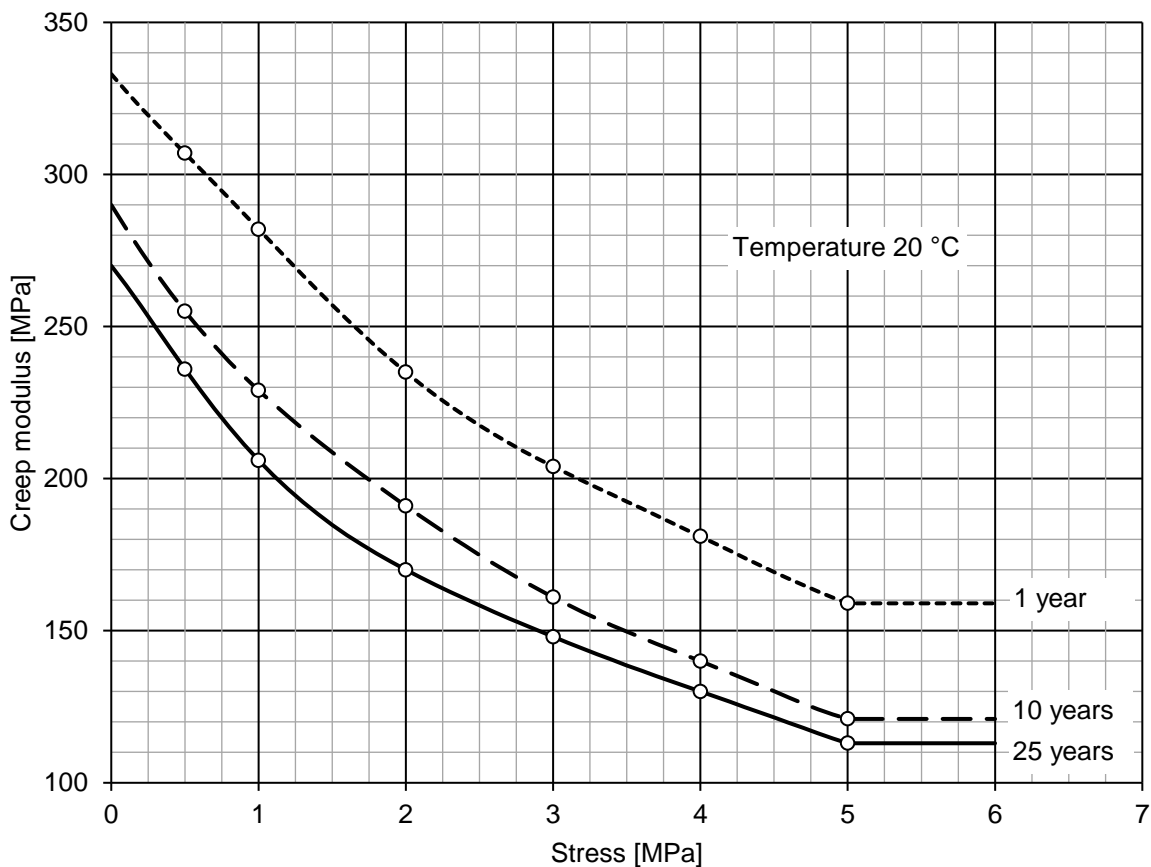


Fig. 3 - The creep modulus values for the three times for 20 °C in relation to stress

The linear elastic model is used for all the thermoplastic parts of the flange connection. The elastic modulus value is considered to be the creep modulus value from the curve (Figure 3) for the mean von Mises stress of a part of geometry. The von Mises stress [1, 2] is often used to predict the yielding of ductile materials. Creep modulus is determined based on knowledge of the stress level. However, that is generally not known in advance, so an iterative procedure is used.

The weighted mean of the von Mises stress value for the selected part is determined from the mean von Mises stress values on elements with a weight corresponding to the volume of the deformed elements. Therefore, the weighted mean von Mises stress value depends on the selection of the part of geometry, during which the aim is to divide the structure into a small number of parts of geometry with an approximately constant stress for each of them.

Model variants

The selected four variants of the finite element model of the flange connection, each with a different selection of monitored parts of geometry, are:

- Variant A – one part: the stub end and the pipe are together.
- Variant B – two parts: the stub end and the pipe are separate.
- Variant C – three parts: the pipe is separate from the stub end, which is divided into two parts.
- Variant D – each element is a separate part.

The four variants of the finite element model of the flange connection are solved in the same way in several load steps. First, pretension load equal to the assembly force F_A is applied to the bolts in several load steps, with the criss-cross tightening sequence being used. Subsequently, pressure is applied to the internal surface of the pipe, and in the same load step the pretension load of the bolts is increased to the operating force F_O . The ends of the model are defined by two cuts perpendicular to the pipe axis. In the first cut all displacements are set to zero. The other cut is closed with the pipe cap. The pipe cap is loaded by internal pressure as an axial load. The axial load corresponds to the assumption in the formula (2).

First, the shortening of the bolts corresponding to the operating force F_O is found for the initial creep modulus value E_0 . Then the obtained shortening of the bolts is set, and the flange clamping force is monitored while creep moduli (Figure 3) depending on exposure times and stress levels are decreased.

The dependence of the creep moduli on the stress field is solved iteratively. The first iteration uses the initial estimated stress values and this is repeated until the input and output stress field are sufficiently similar. Geometric nonlinear static analyses are used.

Results

The von Mises stress field at the initial time (0 years) is the same for all variants, see Figure 4. The von Mises stress fields after the exposure time of 1 year for each variant are shown in Figures 5 to 8. All figures only show the monitored thermoplastic stub ends and the pipes. In the case of variants B (Figure 6) and C (Figure 7) the monitored parts are additionally shifted towards each other and enlarged to show more detail. The same colour scale is used with each image to allow better comparison of the results.

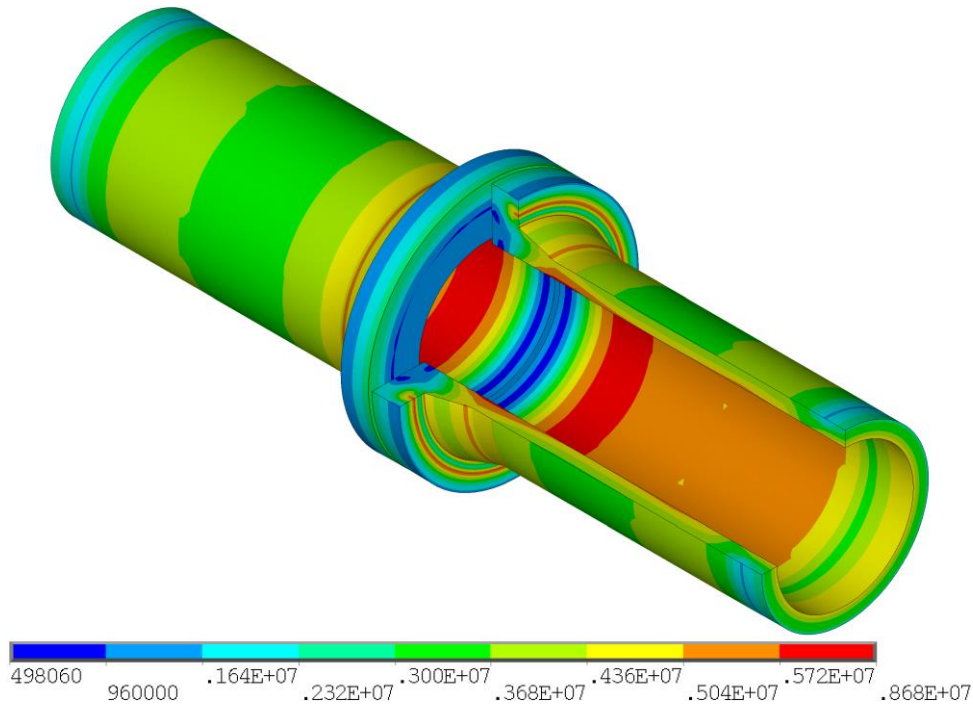


Fig. 4 - Von Mises stress in thermoplastic parts for variants A, B, C, D (0 years)

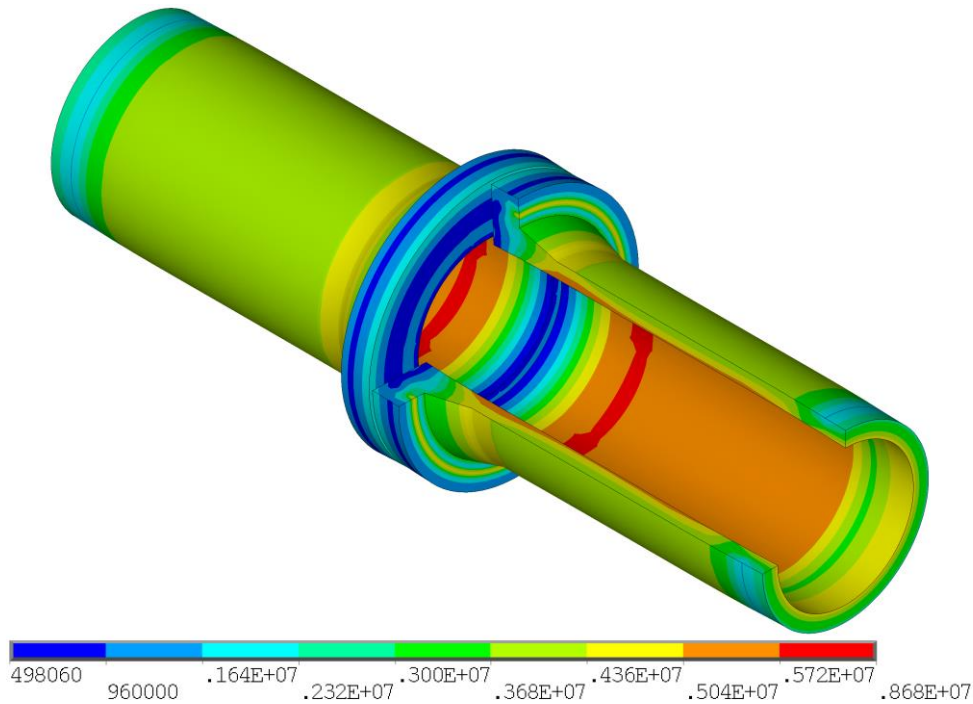


Fig. 5 - Von Mises stress in thermoplastic parts for variant A (1 year)

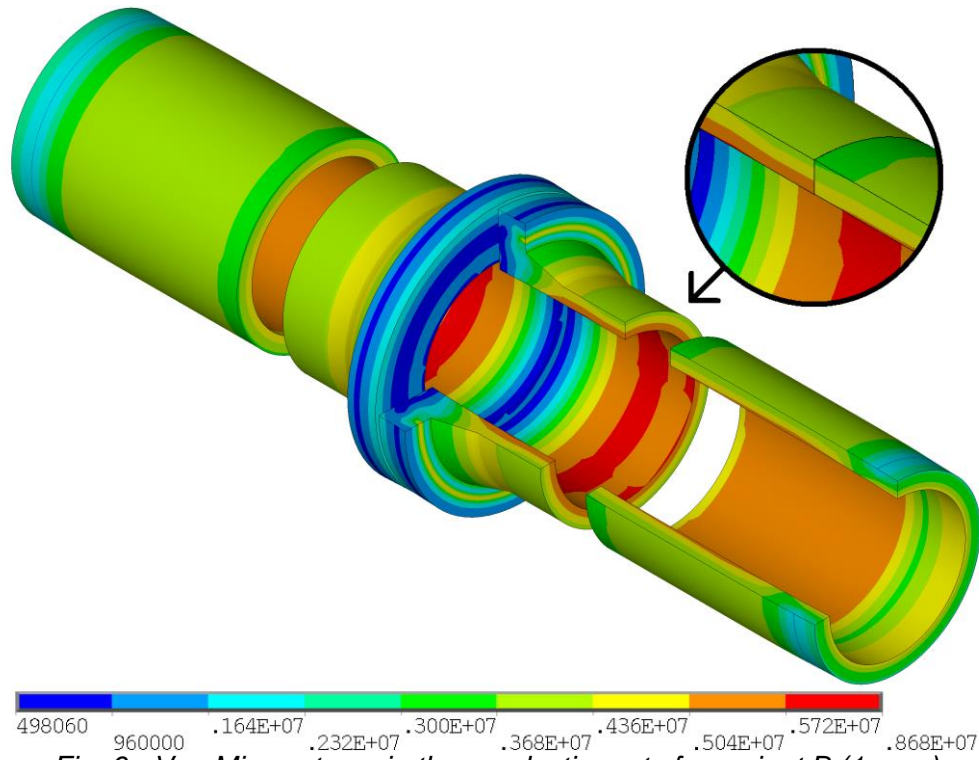


Fig. 6 - Von Mises stress in thermoplastic parts for variant B (1 year)

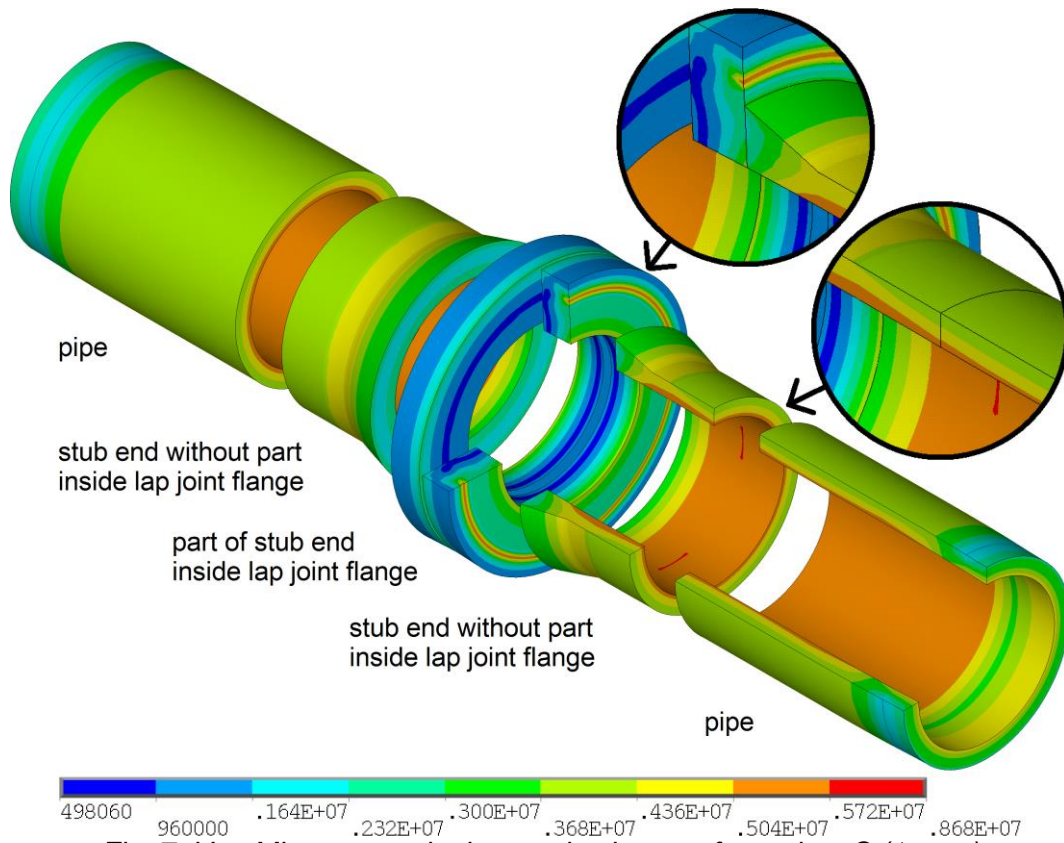


Fig. 7- Von Mises stress in thermoplastic parts for variant C (1 year)

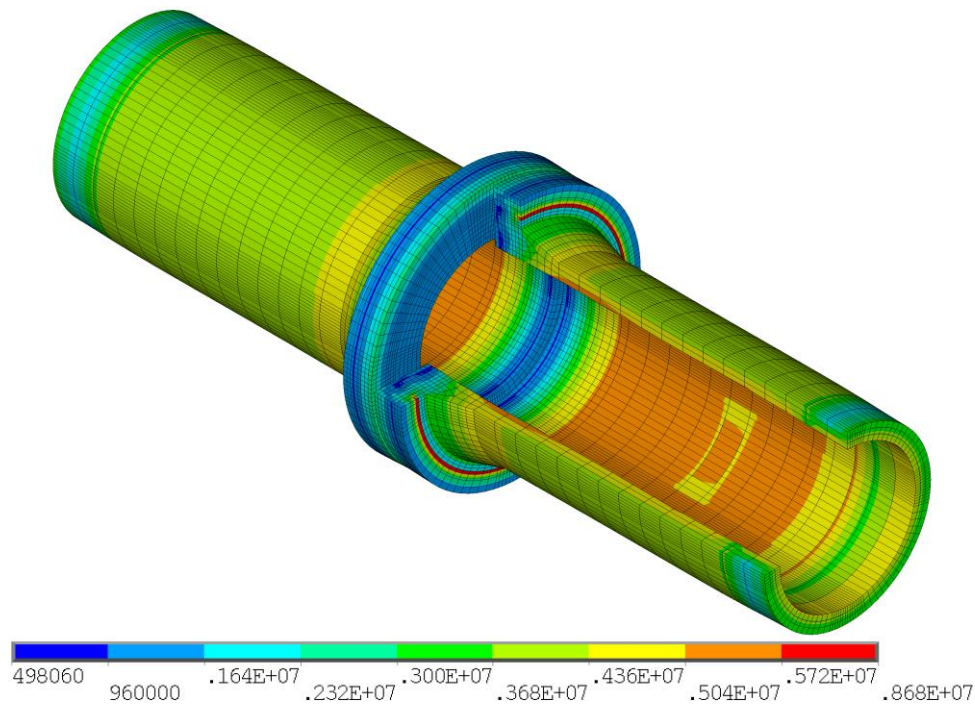


Fig. 8 - Von Mises stress in thermoplastic parts for variant D (1 year)

The results after the first year of exposure show that due to the creep in the thermoplastic material, the stresses are redistributed, extreme stresses are reduced and the variants are different from one another. According to expectations the greatest difference between extreme values is found for variants A (Figure 5) and D (Figure 8). The results also show that in variants B and C the stress field is discontinuous due to the discontinuity of the creep modulus between the individual parts. The stress fields at both ends of the model are affected by boundary conditions.

The von Mises stress values and the clamping force values for the exposure times are listed in Table 3. The mean von Mises stresses from all of the solved variants and times are compared in three monitored parts corresponding to variant C (Figure 7).

According to expectations the same results were obtained for all variants for the calculation at 0 years (Table 3) with the initial creep modulus value. The highest mean von Mises stress found for the monitored parts is in the stub ends without the part inside the lap joint flanges. The smallest mean von Mises stress is in the part of the stub ends inside the lap joint flanges.

Tab. 3 - Mean von Mises stress and flange clamping force in the monitored parts

Physical quantity	Monitored part	Variant	Time point [years]			
			0	1	10	25
mean von Mises stress [MPa]	part of stub end inside lap joint flange	A	2.126	1.618	1.607	1.601
		B	2.126	1.623	1.601	1.605
		C	2.126	1.823	1.845	1.820
		D	2.126	1.784	1.794	1.781
	stub end without part inside lap joint flange	A	4.538	4.403	4.511	4.516
		B	4.538	4.441	4.469	4.560
		C	4.538	4.305	4.315	4.421
		D	4.538	4.373	4.395	4.488
	pipe	A	4.080	4.186	4.228	4.243
		B	4.080	4.175	4.217	4.234
		C	4.080	4.200	4.248	4.265
		D	4.080	4.229	4.283	4.297
clamping force [kN]	bolts	A	20.087	11.669	10.706	10.642
		B	20.087	11.827	11.296	10.698
		C	20.087	12.616	12.386	11.625
		D	20.087	12.451	12.073	11.394

The flange clamping force decreased by approximately 40% from the initial value with the most significant decrease occurring during the first year of exposure. Over the same period of time the creep modulus values decreased to approximately 260 to 170 MPa from the initial value of 800 MPa. The subsequent decrease in the flange clamping force for exposure times of 10 and 25 years is not significant.

The results of the mean von Mises stress in the monitored parts after the first year of exposure indicate that variant C is different by less than 2.2% and variants A and B are different by less than 9.3% in comparison with the results for the most detailed variant D. At the same time, the results of the flange clamping force value indicate that variant C is different by less than 1.4% and variants A and B are different by less than 6.3% in comparison with the results for the most detailed variant D.

CONCLUSION

Due to creep in the thermoplastic parts of the flange connection, there is a significant decrease in the flange clamping force during the first year of exposure. After this first year, the initial creep modulus decreased by approximately 75% and the flange clamping force by around 40%. According to numerical analysis results it is necessary to check the flange clamping force during the first year of exposure.

The mean von Mises stress and the flange clamping force at all the selected times except the initial time (0 years) for variants A to C were less than 11.5% different in comparison with the most detailed variant D. The results for variant C, which takes into account the three creep modulus values, are comparable with the results for the most detailed and the most demanding variant D. Variant C is sufficiently precise and is usable in practice.

The calculations were performed for the selected times assuming constant temperature and static load. The proposed method uses a creep modulus that takes into account the exposure time, the stationary temperature field and the static load, and can be generally used for other thermoplastic structures.

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