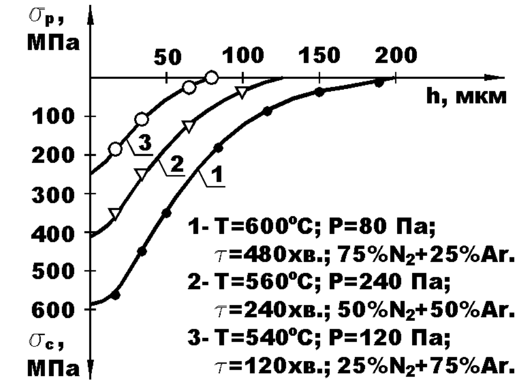

Рис. 5. Залишкові напруження в сталі Х12 після азотування за різними режимами

Таким чином, дослідженнями встановлено, що азотуванням в тліючому розряді в безводневих середовищах можна змінювати товщину, мікротвердість і залишкові напруження в азотованому шарі в широких межах і отримувати їх максимальні значення за допомогою зміни технологічних параметрів процесу азотування.

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PN-EN 12952-3 BASED CALCULATIONS OF ALLOWABLE HEATING AND COOLING RATES FOR T-PIPE MADE FROM STEEL 13HMF

1. Introduction

В статті представлено методику визначення максимальних допустимих швидкостей нагрівання і охолодження, розроблену на основі європейського стандарту PN-EN 12952-3. Об'єктом досліджень є трійник, виконаний із сталі 13 HMF. У праці приведено геометричний опис трійника, властивості матеріалів, а також характеристику робочих умов. Представлені також отримані значення максимальних допустимих швидкостей нагрівання і охолодження.

Calculation based on PN-EN 12952-3 code will be done for determination of the maximum heating or cooling rate of temperature changes. Calculated results are of great practical significance because it will be possible to use them in power plants. Temperature step change can be easily implemented by suddenly opening hot water or steam supply into the interior of a pressure element, which has a lower initial temperature. A quasi-steady state is not assumed and element geometry can be complicated.

Ключові слова: нагрівання та охолодження в металах, європейський стандарт PN-EN 12952-3.

2. Description of the approach and work methodology

2.1. Geometrical properties of the T-pipe and their mean substitutes

Calculation of allowable cooling and heating rates for a T-pipe made from ferritic steel 13HMF (Fig.1) was conducted. The T-pipe is typically utilized in pipelines of fresh and overheated steam in power unit of power plant 360 MW.

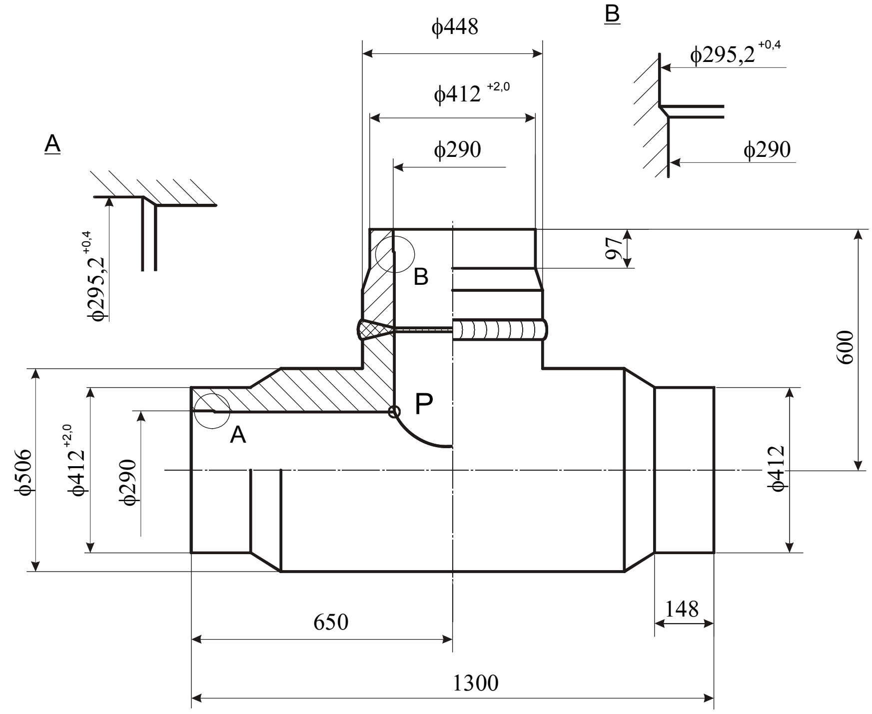

Fig.1. Geometry of the valve quarter made in ANSYS system

Dimensions of the mentioned T-pipe are as following:

- external diameter of the T-pipe d_o = 506 [mm]
- internal diameter of the T-pipe d_i = 290 [mm]
- external diameter of the ramification d_{ob} = 448 [mm]
- internal diameter of the ramification d_{ib} = 290 [mm]

Basing on this fundamental dimensions, the following derived dimensions were calculated:

- the T-pipe average diameter d_{ms}

$$d_{ms} = 381{,}8\,[mm] \tag{1}$$

- the ramification average diameter d_{mb}

$$d_{mb} = 357{,}1\,[mm] \tag{2}$$

- the T-pipe wall thickness e_{ms}

$$e_{ms} = 124{,}2\,[mm] \tag{3}$$

- the ramification wall thickness e_{mb}

$$e_{mb} = 115\,[mm] \tag{4}$$

- the quotient u_o of the T-pipe external diameter to the internal diameter

$$u_o = \frac{d_o}{d_i} \qquad u_o = 1{,}96\,[mm] \tag{5}$$

- the quotient z of the ramification average diameter to the T-pipe average diameter

$$z = \frac{d_{mb}}{d_{ms}} \qquad z = 0{,}94\,[mm] \tag{6}$$

2.2. Working environment for the T-pipe made from steel 13HMF

There was assumed that the element works in the following conditions:

- minimum pressure in a cycle p_{min} = 0 [MPa]
- maximum pressure in a cycle p_{max} = 10,87 [MPa]
- minimum temperature in a cycle t_{min} = 20 [^{o}C]
- maximum temperature in a cycle t_{max} = 318 [^{o}C]
- required start and stopping cycles n = 2000
- number of cycles (start from cold state 20^{o}C) till cracking appears n_{max} = 5n = 10000

2.3. Material properties

Material properties for the steel of 13HMF may be determined in three ways:

- read from strength tables for an assumed temperature,

- evaluated according to linear interpolation,
- calculated according to table's factors.

The basic strength properties of the steel 13HMF are presented in Fig.2.

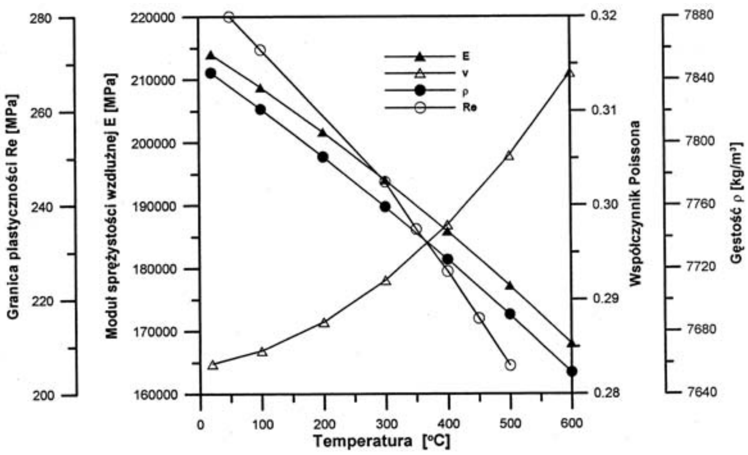

Fig.2. The basic strength properties of the steel 13HMF

The working pressure p is assigned as the greatest allowable pressure which may appears in the unit:

$$p = 10,87\,[\text{MPa}] \tag{7}$$

The minimum tensile strength at the environment temperature 20 [^{o}C] is equal to:

$$\sigma_{\min B} = 430\,[\text{MPa}] \tag{8}$$

The Poisson's ratio is equal to:

$$\nu = 0,3 \tag{9}$$

The substituted temperature is evaluated from the formula:

$$t^* = 0,75 \cdot t_{\max} + 0,25 \cdot t_{\min} \qquad t^* = 243,5\,[^oC] \tag{10}$$

where: t_{max} – maximum temperature in the cycle, t_{min} – minimum temperature in the cycle. The material's properties are determined for the substituted temperature as following:

- elastic modulus.. E_{t*} = 1,96·10^5 [MPa]
- minimum yield strength .... R_{et*} = 206 [MPa]
- linear coefficient of thermal expansion .... β_{Lt*} = 1,32·10^{-5} [1/K]
- temperature equalization ratio .... D_{th} = 528 [mm^2/min]

2.4. PN-EN 12952-3 code-based calculations

The allowable difference of a temperature (difference between the internal surface temperature and the average temperature of the wall) is calculated from formulas appropriate for four specific cases:

- beginning of the starting phase,
- end of the starting phase,
- beginning of the stopping phase,
- end of the stopping phase.

A substitute W is introduced for simplicity of formulas for allowable temperature difference:

$$W = \frac{\alpha_t \cdot \beta_{Lt^*} \cdot E_{t^*}}{1-\nu} \qquad W = 3,367\left[\frac{\text{MPa}}{\text{K}}\right] \tag{11}$$

where: α_t – stress concentration ratio for thermal stresses, β_{Lt*} – linear coefficient of thermal expansion at calculation temperature, E_{t*} – elastic modulus at calculation temperature, ν – Poisson's ratio (0,3). The stress concentration ratio α_t mentioned in the formula above is evaluated from the following formula:

$$\alpha_t = \left\{\left[2 - \tfrac{h+2700}{h+1700} \cdot z + \tfrac{h}{h+1700} \cdot (\exp(-7 \cdot z) - 1\right]^2 + 0,81 \cdot z^2\right\}^{\frac{1}{2}} \qquad \alpha_t = 0,911 \tag{12}$$

where: h – heat penetration factor (according to code in the case of steam the factor is equal to 1000 [W/m^{2}K]), z – quotient of the average diameter of ramification to the T-pipe diameter.

The allowable temperature difference at the beginning of the starting phase was determined from the following formula:

$$(p = p_{\min}): \quad \Delta t_1 = \frac{(f_{\tan g,\min} - \Delta f_{\tan g,\,p\min})}{W} \qquad \Delta t_1 = -72,741\,[\text{K}] \tag{13}$$

The allowable temperature difference at the end of the starting phase was determined from the following formula:

$$(p = p_{\max}): \quad \Delta t_1^{'} = \frac{(f_{\tan g,\min} - \Delta f_{\tan g,\,p\max})}{W} \qquad \Delta t_1^{'} = -90,294\,[\text{K}] \tag{14}$$

The allowable temperature difference at the beginning of the stopping phase was determined from the following formula:

$$(p = p_{\max}):\quad \Delta t_2 = \frac{(f_{\tan g,\max} - \Delta f_{\tan g,p\max})}{W} \qquad \Delta t_2 = 72{,}741\,[\mathrm{K}] \qquad (15)$$

The allowable temperature difference at the end of the stopping phase was determined from the following formula:

$$(p = p_{\min}):\quad \Delta t_2^{'} = \frac{(f_{\tan g,\max} - \Delta f_{\tan g,p\min})}{W} \qquad \Delta t_2^{'} = 90{,}294\,[\mathrm{K}] \qquad (16)$$

3. Achieved results

Basing on obtained allowable temperature differences, the allowable heating and cooling rates for T-pipe were evaluated from the following formula:

$$v_t = \Delta t \cdot \frac{D_{th}}{\gamma_{cyl} \cdot e_{ms}^2} \qquad (17)$$

where: D_{th} – the temperature equalization ratio, γ_{cyl} – the shape factor, e_{ms} – the average wall thickness of horizontal valve's part. The auxiliary shape factor was given by the formula:

$$\gamma_{cyl} = \frac{1}{8} \cdot \frac{(u_o^2 - 1)\cdot(3\cdot u_o^2 - 1) - 4\cdot u_o\, 4\cdot \ln(u_o)}{(u_o^2 - 1)\cdot(u_o^2 - 1)^2} \qquad \gamma_{cyl} = -0{,}469 \qquad (18)$$

The allowable heating rate at the beginning of the starting phase is evaluated from the following formula:

$$v_{t_1} = \Delta t_1 \cdot \frac{D_{th}}{\gamma_{cyl} \cdot e_{ms}^2} \qquad v_{t_1} = 5{,}307\left[\tfrac{\mathrm{K}}{\min}\right] \qquad (19)$$

The allowable heating rate at the end of the starting phase is evaluated from the following formula:

$$v_{t_1^{'}} = \Delta t_1^{'} \cdot \frac{D_{th}}{\gamma_{cyl} \cdot e_{ms}^2} \qquad v_{t_1^{'}} = 6{,}588\left[\tfrac{\mathrm{K}}{\min}\right] \qquad (20)$$

The allowable cooling rate at the beginning of the stopping phase is evaluated from the following formula:

$$v_{t_2} = \Delta t_2 \cdot \frac{D_{th}}{\gamma_{cyl} \cdot e_{ms}^2} \qquad v_{t_2} = -5{,}307\left[\tfrac{\mathrm{K}}{\min}\right] \qquad (21)$$

The allowable cooling rate at the end of the stopping phase is evaluated from the following formula:

$$v_{t_2^{'}} = \Delta t_2^{'} \cdot \frac{D_{th}}{\gamma_{cyl} \cdot e_{ms}^2} \qquad v_{t_2^{'}} = -6{,}588\left[\tfrac{\mathrm{K}}{\min}\right] \qquad (22)$$

4. Conclusion

The producer of the element recommends the allowable heating and cooling rate at the value of 2 [K/min]. The computations performed on the base of PN-EN 12952-3 showed that the range between 5,3 and 6,5 [K/min] are acceptable. On the one side, it means that the producer recommendations have a large safety margins. On the other side, it is a reason for more accurate computations based on FEM. It will make possible more precise decision on the actual marginal heating and cooling rates not leading to excessive stresses and element damaging by cracking.

5. Summary

The allowable cooling and heating rates for the T-pipe were calculated basing on PN-EN 12952-3 code's formulas. The calculation procedure and obtained results are presented with the details in this paper.

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