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Analysis of the Surface Roughness and of the Joint between Tubes and Tube Sheets of a Heat Exchanger

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Abstract

In the present paper, it has been studied the behavior of joints between tubes and tube sheets of a heat exchanger (with the analysis of the thermal expansion coefficient between the tubular element and the tubular plate). Two types of surfaces have been used, one smooth and one which had a groove (in the tubular plate). Surface roughness was also analyzed before and after jointing.

Key words: *heat exchanger, tube to tube sheet joints, loads*.

Introduction

Shell and tube heat exchangers are commonly used in oil refining industry due to a large heat transfer area [3], and they are part of the technological process of an installation, with a significant role in obtaining the finished product. Models that have been submitted to the analysis were made according to figure 1 [1]. Materials used are P265GH (SR EN 10216/2-2009) for the tubular element (TE) and P355NH (SR EN 10028/2-2009) for the tubular plate (TP).

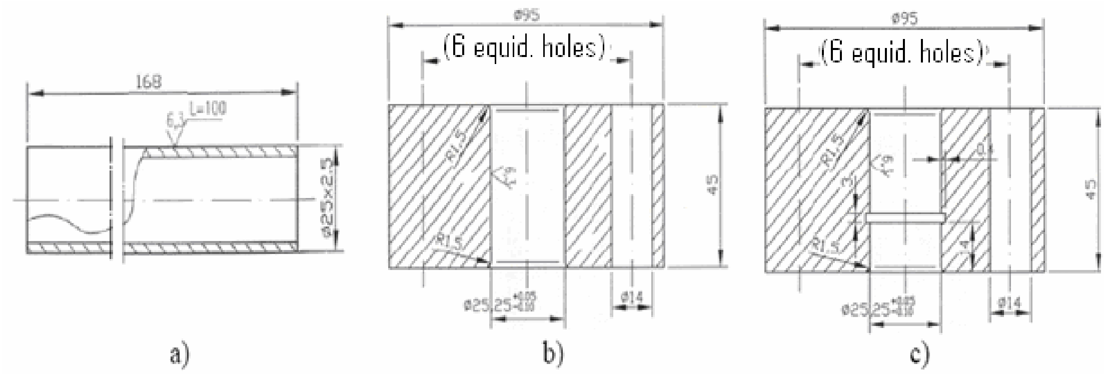


Fig. 1. Shape and dimensions of the models studied:
a - construction of tubular element;
b - overall tube – tubular plate with smooth hole geometry;
c - junction tube – tubular plate, with a groove on boring surface.

The main working parameters to consider are those in table 1, having correspondence with those of a heat exchanger in an oil refinery plant.

Table 1. The main working conditions [5]

Parameter	Shell	Tubes
Maximum working pressure [MPa]	0.115	0.065
Maximum temperature [° C]	70	38
Minimum temperature [° C]	50	30
Working medium	Technological water	Hydrofining oil
Danger	-	Toxic, Inflammable

The mechanical process of expanding the tube comprises two distinct phases [1]:

a) Pre-expanding of tube, the preliminary flexible flare or / and elastic-plastic deformation of the tubular element until it comes in contact with the tube sheet hole walls;

b) proper expanding of tube, additional enlargement mainly in the elastic-plastic field for TE, while mainly flexible, reversible broadening of the holes in TP, as shown in figure 2 [1].

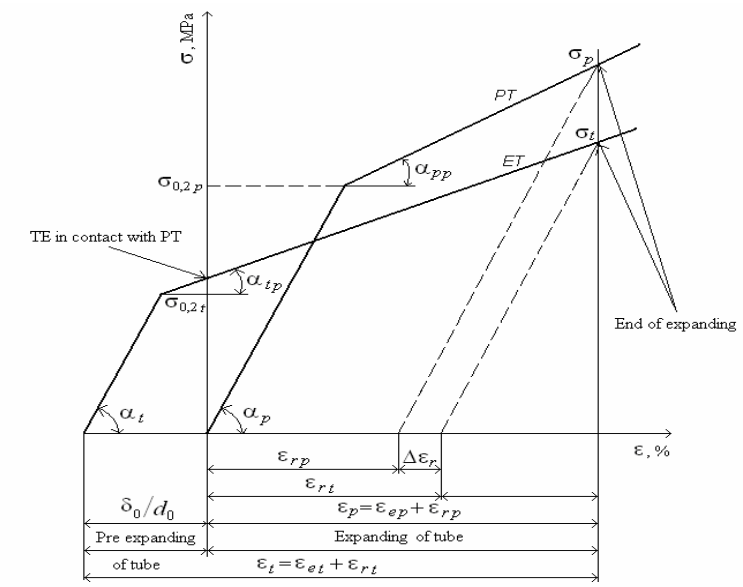


Fig. 2. Typical characteristic curves of *TE* materials and, respectively, *TP* regarded as joint materials building plastic linear hardening.

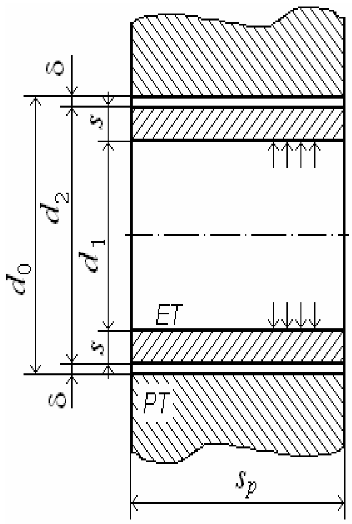


Fig.3. Dimensional schematization

The phase of pre-expanding the tube corresponds to the full depletion of the assembly $\delta_0 = 2\delta$ (fig. 3) [2].

The main requirement of a tube to tube sheet joint is to better resist to the axial stress, compressive or tensile, applied to the tube. This happens for the tube-to tube sheet joints, if tubes and tube sheet are made of steel, when the hoop stress in tube sheet is higher than those in the tubes.

In order to qualify a better resistance to loads (axial tension and compression) in the joint between the tubes and the tubular plate, another geometry (a "groove") for the tubular plate has been analyzed (fig. 1,c).

Analyses and Experiments

Analysis using Finite Element Method

For the joint analysis and the determination of loads due to axial force between the tubes and the tubular plate, the geometries from figure 1 were used. Also, the actual technological parameters of the heat exchanger in the oil refinery plant were taken into account (table 1).

The tubular plate has a diameter of 80 cm, but the expanding process does not apply to more than twice the pipe diameter, therefore it will be considered for 50 cm. The pitch in the tubular plate is 32 mm, so the portion of the plate corresponding to each tube is 3,35 mm [4, 5, 7].

For the comparative analysis of the behavior of different types of joints between tubes and tubular plate, the same degree of tightening has been considered as resulting from the expanding degree for the two types analyzed and the same force applied to the pipes $F = 31000$ N [1].

Tube sheet model with smooth hole

Figure 4 presents a TE – TP expanding model with a smooth hole; in figure 5 is presented the overall stress level developed by axial loads and pressure from the tubes (because at the TE – TP junction only the expanded section participates; for simplification only this area was introduced).

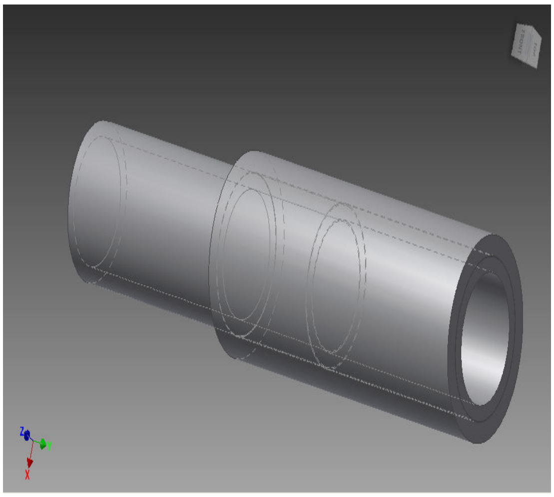


Fig. 4. Expantion joint with a smooth hole

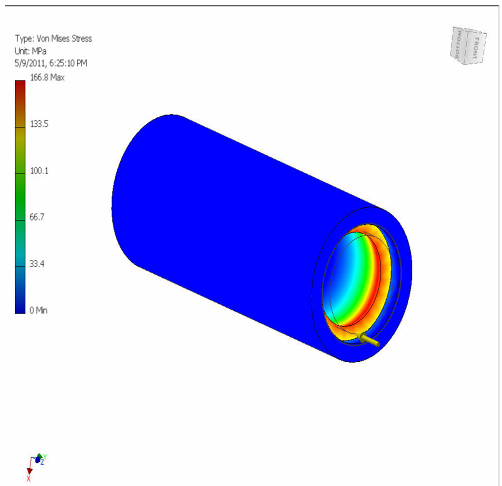


Fig. 5. General stress level from axial load

Elements were isolated to highlight the loads level [6], which are shown in figures 6 and 7.

In figures 8 and 9 are shown the values obtained for the relative displacement of the two elements, respectively the contact pressure between TE – TP.

Tube sheet model with a groove on boring surface

Figure 10 presents a model joint with a groove in the tubular plate, while the overall load level due to the axial force is shown in figure 11.

Elements were isolated to highlight the load level [6]; these are observed in figures 12 and 13.

In figures 14 and 15 are shown the values obtained for the relative displacement of the two elements, and the contact pressure between TE – TP.

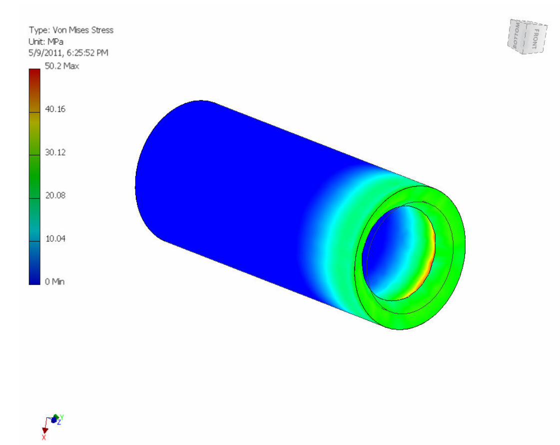


Fig. 6. Tubular Plate (maximum contact load in TP)

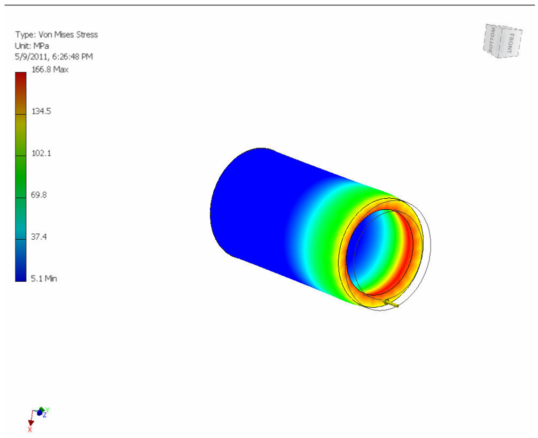


Fig. 7. Tube on expanded area (maximum load in expanded joint area)

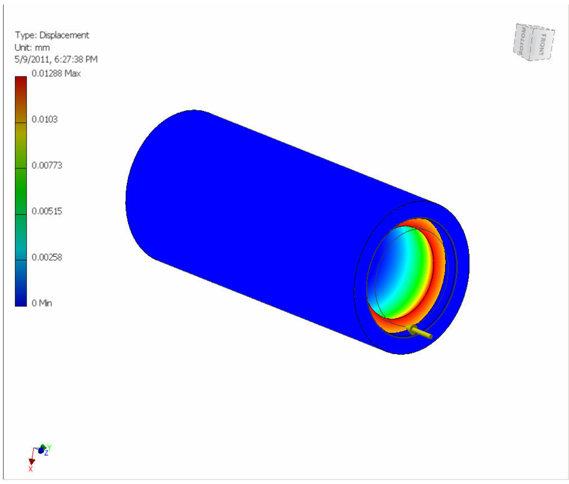


Fig. 8. Relative displacement between the two elements(ET-PT)

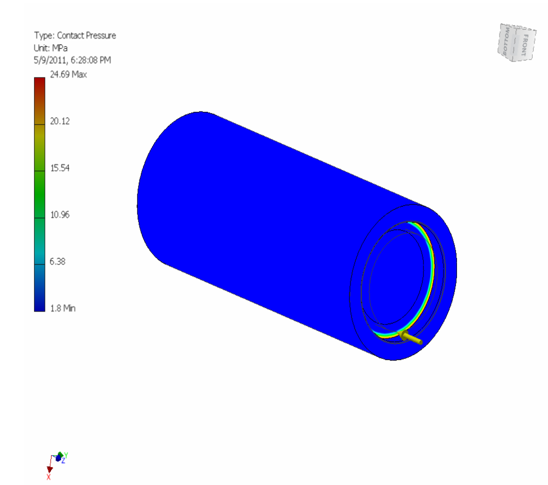


Fig. 9. Contact pressure between the two elements (ET – PT)

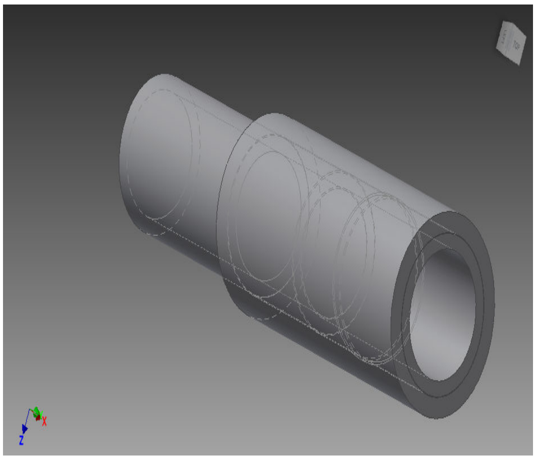


Fig. 10. View of expanded joint with one groove

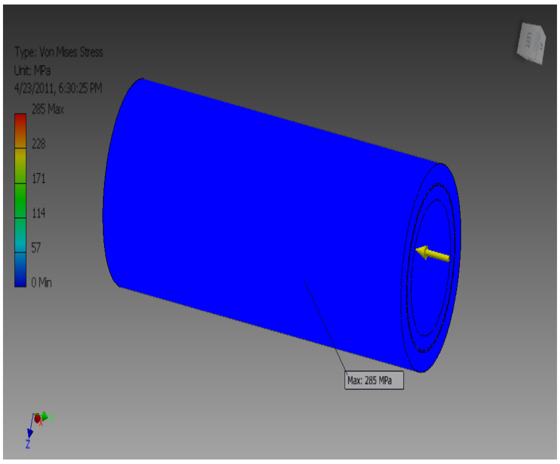


Fig. 11. General level of tubes axial load and pressure (real situation)

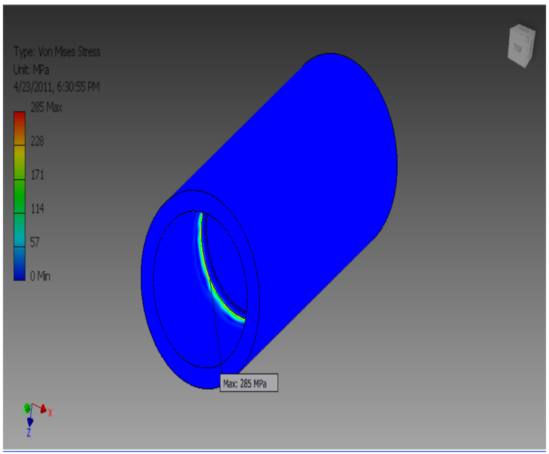


Fig. 12. Tubular plate (maximum contact load in TP)

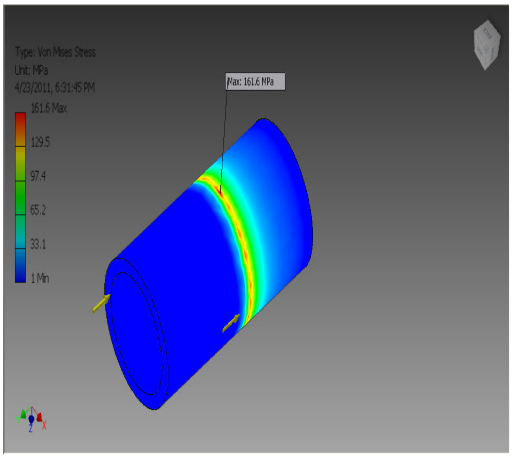


Fig. 13. Tubes in the expanded area (maximum load in expanded area)

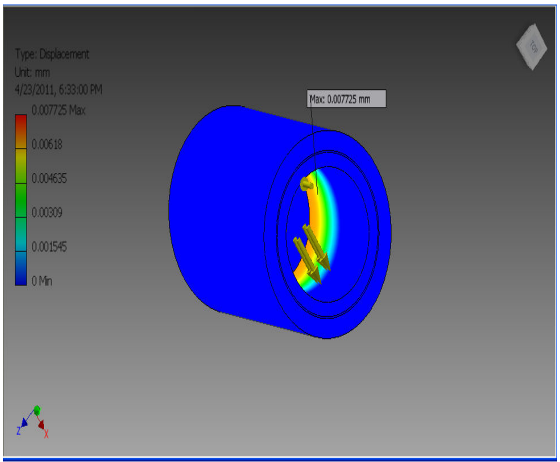


Fig. 14. Relative displacement between the two elements (ET-PT)

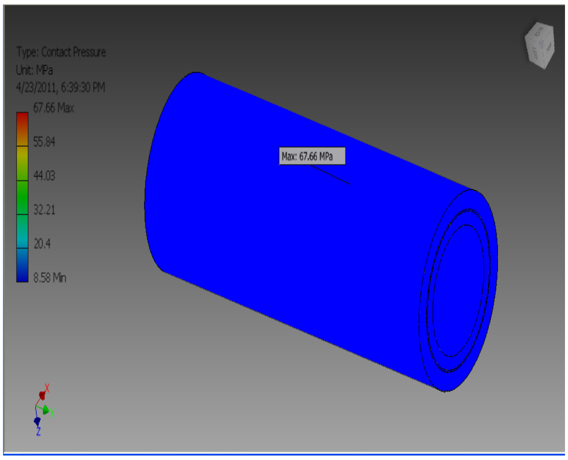


Fig. 15. Contact pressure between the two elements (TE–TP)

From these representations [6], the centralization of data is reported in table 2.

Table 2. Load values in the tubes and tubular plate

Crt. No.	**Model of the joint**	**Loads in tubes** [MPa]	**Loads in tubular plate** [MPa]	**Displacement for two elements** [mm]
1	Smooth hole	166.8	50.2	0.01288
2	Groove on boring	161.6	285	0.00772

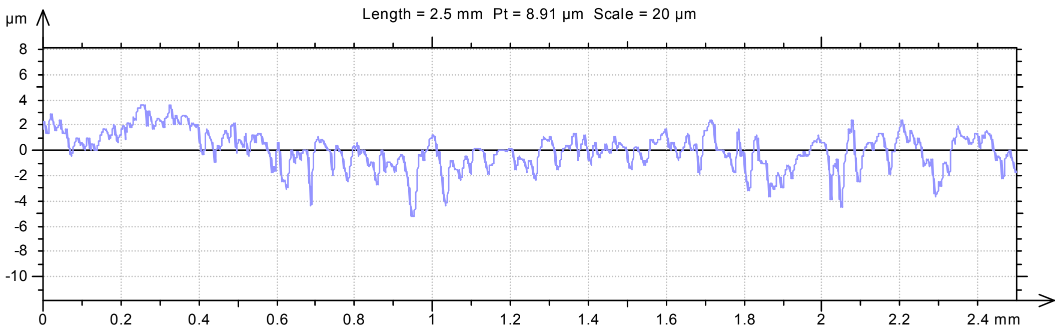
For the same loads (pressure and axial force), the stresses developed in the tubular plate and tubes are not very eloquent for the two expansion models analyzed. Relative movements between the two elements (TE – TP) are smaller in the case of the expansion with a groove.

As in the specialty literature [4], also here is noticed that it is not indicated an expansion with smooth hole (simple); if such an expansion would take place, it would be almost mandatory to be accompanied by welding (welding taking in much of the stress arising from loads, which consist of contact pressure between the tubes and tubular plate with pressure inside the tubes**).**

Measuring parameters of surfaces before and after expansion

Due to high contact pressures at joint expansion, both surface changes within the active area.

To confirm those presented about the changed surfaces, in figure 16,a is presented the roughness before the expansion, and in figure 16,b after the expansion. Roughness determination was made in the Tribology and Corrosion laboratory of UPG Ploiesti with the contact profilometry type Surtronic 3+, and registered data were processed using the software „TalyProfile Lite 2.1” attached to this device.



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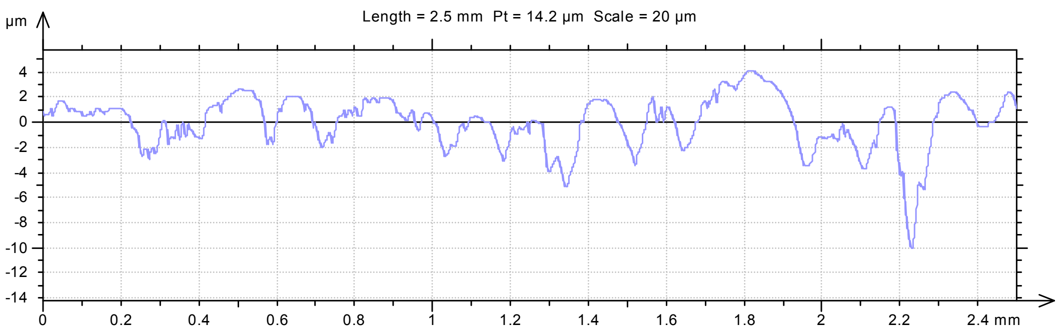


b

Fig. 16. Surface tubes before (a) and after (b) expansion

Measuring microgeometric parameters at surface samples before and after expansions with smooth hole geometry or with a groove on boring surface are shown in table 3.

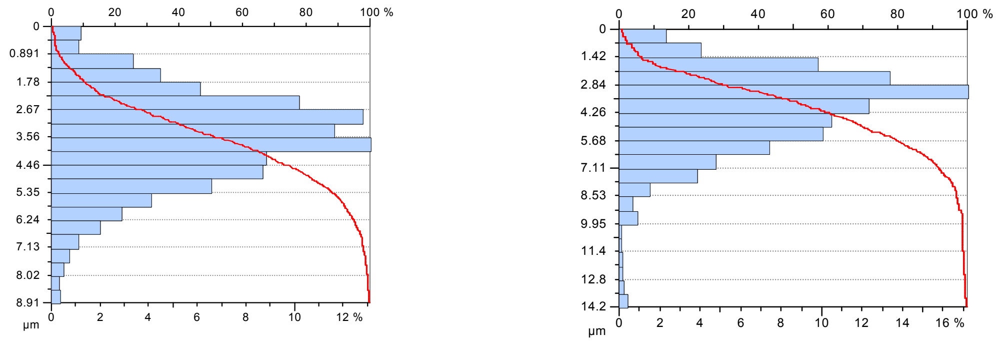
Table 3. Surface roughness of tubes

Status of tubes	R_a [µm]	R_z [µm]	R_t [µm]	R_{max} [µm]
Not expanded	0.855	6	6.93	9.5
expanded	1.3	5.78	7	14.5

R_a is the arithmetic mean deviation of the roughness profile; R_z – the maximum height of the roughness profile; R_t – the total height of the roughness profile.

By modifying the roughness profile, the profilograma and the profile change (fig. 17).

If initial tubes surface presents small peaks and dimples, after expanding, this surface has round roughs and important dimples. After the appearance of holes, it is believed that they are the result of pull material from the area where micro welding occured. After these determinations, it was found that initial tubes roughness changes outside and inside.



a **b**

Fig. 17. Profilogram and profile before (a) and after (b) expansion

Note that after cutting the joint assembly and extracting the tube, it presents rounded tips consisting of broken micro welding from the combined material of tubular plate.

Conclusions

The joints of tubes and tubular plate for heat exchangers of refinery plants is a critical area in terms of loads that appear.

Testing using finite element method and surface roughness study after compression and tension tests of tubular plate and tubes on different samples and for working conditions similar to those of the technological stream have revealed that:

- displacement between the two elements coming in contact (TE-TP), are lower still if the connection is with a groove joint;
- is not recommended to use a smooth hole joint geometry, without being supplemented with welding, this having an important in taking the axial load occurring between TE-TP;
- for the situation with tubes with no joint, roughness is less than tubes joint;
- as the design temperature for this heat exchangers is 100 °C [5], the coefficient of thermal expansion has the same value for the two materials:

$$\alpha_t^{100} = 12.1032 \cdot 10^{-6} \ N / mm / {}^{\circ}C$$

  so there are no changes in raise between the two elements due to temperature and the raise quality is not affected.

Between the two methods studied we can see that the method with groove on boring is better, although differences are not significant; nevertheless the number of groves and grove dimensions must be reconsidered in order to get a more uniform load on the whole area of contact between tubes and tubular plate.

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Analiza rugozității suprafețelor şi a îmbinării dintre țeava fascicolului tubular şi placa tubulară a unui schimbător de căldură

Rezumat

În prezentul articol s-a studiat comportarea unei asamblari prin mandrinare dintre teava fascicolului tubular si placa tubulara a unui schimbator de caldura (cu analiza coeficientului de dilatare termică dintre elementul tubular si placa tubulara). Au fost folosite doua tipuri de suprafete, una neteda si una in care s-a practicat o canelura (in placa tubulara). Totodata, s-a analizat si rugozitatea suprafetelor tevilor inainte si dupa mandrinare.