UNIVERSITY OF WEST BOHEMIA

Applied and Computational Mechanics 1 (2007) 571 - 576

Applied and Computational Mechanics

Influence of media mixing rates in T-joints upon their damage

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Received 10 September 2007; received in revised form 10 October 2007

Abstract

Mixing of media having different temperatures and velocities of separate streams often takes place in the industry. Being heated material of a pipe acquires nonuniform volume expansion as well as cyclic load, which causes pipeline lifetime decreasing. Damaged zones are to some degree dependant on the rates of mixed streams, which determine mixing process after thermo-hydraulic values are stabilized. These analyses will help to predict more effectively appearing of damaged zones.
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Keywords: CFD analysis, T-joint, pipe, stream mixing, temperature field

1. Introduction

T-joints (pipe junctions) are very often used in all branches of industry. Their introducing entails mixing of different media, which causes cyclic load of pipe material due to different temperatures and stream rates. In its turn this can significantly decrease lifetime of production units and can be a reason of an accident or medium leakage. It is important to analyze such unsafe junctions and to try to define optimal operating conditions or to change their design so that T-joint junction could be safe.

The aim of the work is conducting a thermo-hydraulic analysis devoted to the influence of mixed stream rates and inside diameters jointed pipes upon thermally effected pipe zones. The study will be focused on drafting graphical dependence which is to be applied further in industry.

2. Analysis of liquid media mixing

Three different cases of mixing can take place due to different stream rates [1]. The first one (fig. 1) can be considered if a stream rate in a jointed pipe is low and the stream is immediately ablated, thus the upper side of the main pipe is thermally effected. The second possibility (fig. 1b) is that incoming stream is dissipated into the main pipe thus not effecting sides of the pipe. The last possibility (fig. 1c) is that stream rate in a jointed pipe is high and it flows to the lower side of the main pipe thus thermally effecting it. In all mentioned cases the T-joint is thermally effected, so all three variants are to be analyzed.

In order to determine stream type there was defined cross section coefficient α and stream coefficient β in the work [1], that can be expressed as follows:

$$\alpha = \frac{inside\ diameter\ of\ a\ main\ pipe}{inside\ diameter\ of\ a\ jointed\ pipe}\ , \tag{1}$$

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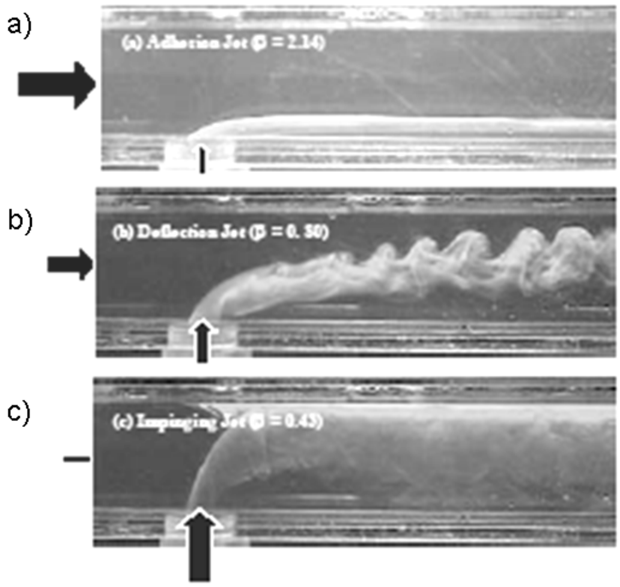

Fig. 1. The types of streams mixing depending on stream rates.

$$\beta = \frac{specific\ \ flow\, in\, a\, main\ \ pipe}{specific\ \ flow\, in\, a\ \ jointed\ \ pipe}\ . \tag{2}$$

Two variables were defined further in the work [1] by means of cross section coefficient α, stream coefficient β, Reynold's figure and coefficients found experimentally:

$$G_1 = 20{,}8\, \alpha\, \beta^{1{,}26}\, Re^{-0{,}737}\ , \tag{3}$$

$$G_2 = 2{,}01\, \alpha\, \beta^{1{,}86}\, Re^{-0{,}138}\ . \tag{4}$$

The variables G_1 and G_2 describe type of a stream (see fig. 1). The figure below shows three zones that were defined during the experiment.

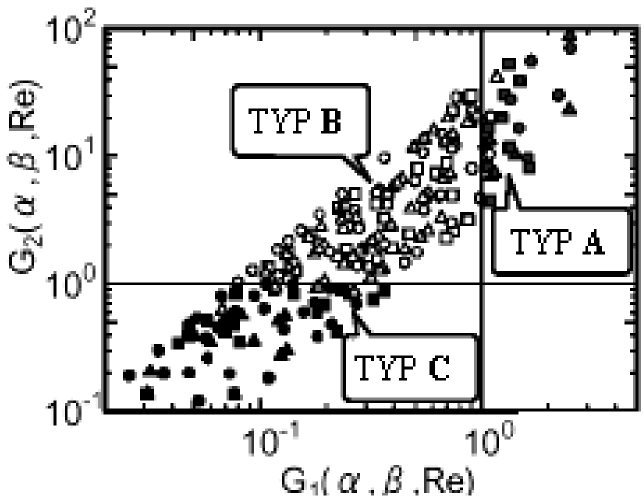

Fig. 2. Dependence of G_1 and G_2 for water.

3. Analyzed variant of pipe junction

Simple junction of two pipes was analyzed (see fig. 3). Inside diameter of the main pipe varied from 200 to 300 mm, while the diameter of the jointed pipe varied from 100 to 270 mm. Wall thickness was chosen equal 12 mm for both pipes. Stream rate in the main pipe was considered constant and equal 5 m/s, stream rate in the jointed pipe varied from 2 to 30 m/s. Temperature of a medium in the main pipe was chosen equal 220°C, in the jointed pipe equal 20°C. Dry air under the pressure of 17,8 MPa was chosen as a working medium. 24 geometrically different variants were considered (varying inside diameters) with 15 different stream rates.

Pipe and nozzle material was austenitic steel 1.4306 (EN X6CrNiTi18-10). This steel is stainless and high temperature resistant. Design, working conditions and used material were chosen on the basis of a real case.

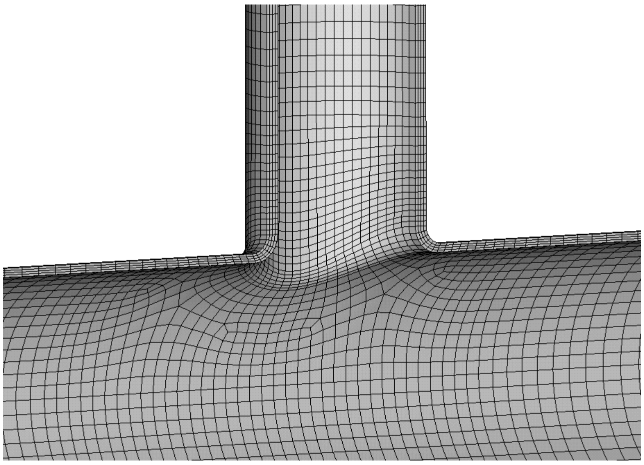

Fig. 3. Geometry of a calculated T-joint.

4. Applied calculation model

Geometry was created in the Gambit program, which is a modeler of CFD Fluent software. Since the work was devoted to stream mixing analysis, only the medium limited by pipe walls was simulated. For shortening calculation time symmetry of the model was used. Calculation web was made mainly from hexahedral elements. The reason why such elements were chosen is decreased number of node points, shortening calculation time and achieving more qualitative results. Transitional area was formed by tetrahedral elements. Number of used elements for particular variants varied in the range of 60 to 150 thousands. Boundary layer was not left out when creating calculation models.

Boundary conditions included incoming stream rate, at the outflow boundary condition was taken at pressure equal zero that means that values at the outflow are to be calculated numerically. Further data were temperatures, internal overpressure and symmetry of the plane going through the axis of the calculation model [3].

Turbulence was simulated on the basis of expanded RNG k-ε model [2]. Since database of used program contains thermo-physical properties of only some materials furthermore in ideal state, it was necessary to calculate real values and input them into the software. The problems were solved as steady states because the process of media mixing was not important.

5. Thermo-hydraulic analysis

On the basis of conducted analyses type of stream mixing was defined for particular geometrical and working conditions. It was principle to determine limits of separate zones. It was found that if a stream from the jointed pipe does not thermally influence walls of the main pipe, then B type should be considered. Graphical interpretation of separate zones location depending on the G_1 and G_2 coefficients according to the work [1] is shown on the fig. 4.

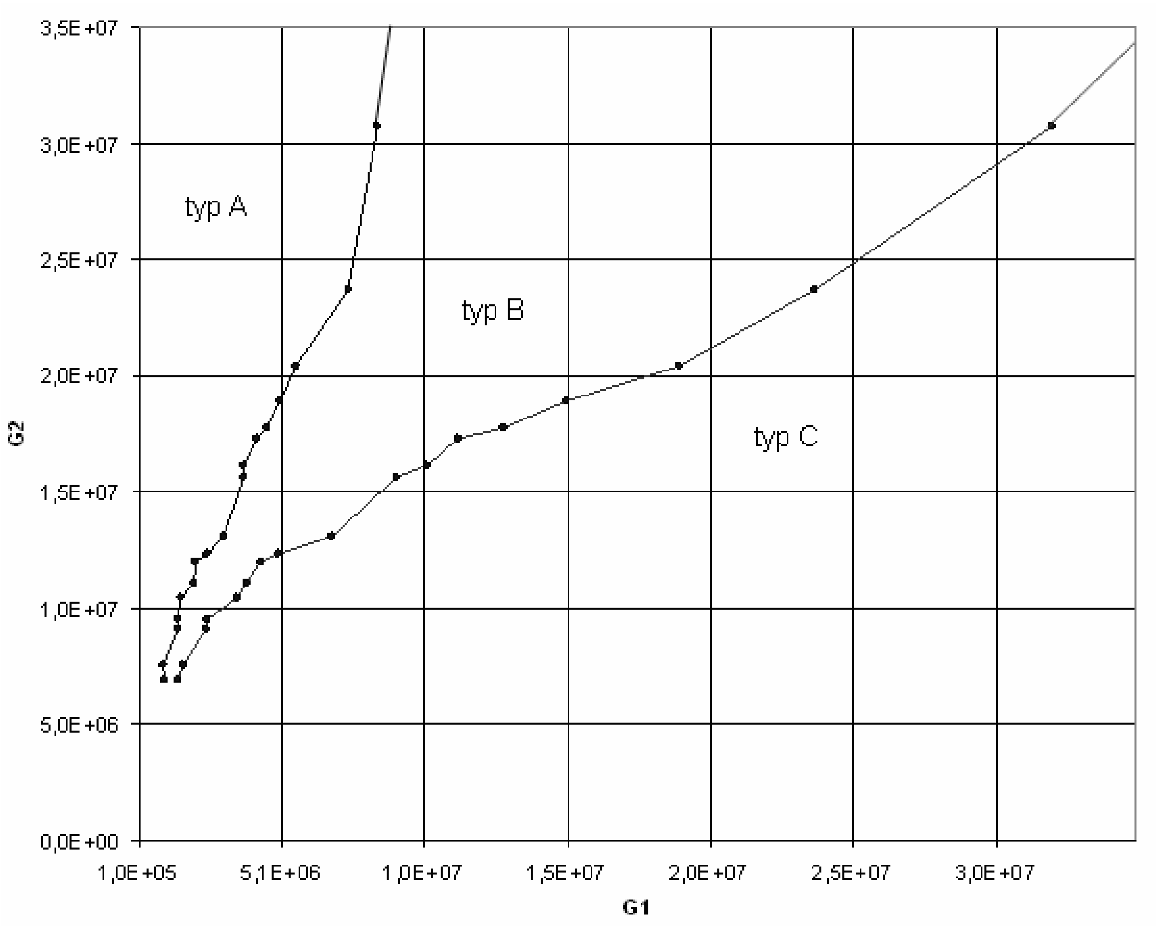

Fig. 4. Graphical dependence of G_1 and G_2 coefficients for air.

6. Damage of separate zones

In order to analyze damage of separate zones particular geometry of T-joint jointing was considered for all three possible types of streams mixing. Results of thermo-hydraulic analyses were used for strength analysis, where text data (*.cdb) containing temperature and pressure information were transferred. Axial load induced by internal overpressure was considered further. These types of analyses are called FSI (Fluid Structure Interaction).

Strength analysis was conducted under condition of elastic deformation of the material within the whole load amplitude in order to shorten time of calculation. That is why Neuber concept was used to determine relative deformation and stress for elastic-plastic stage of load. The most loaded zones were chosen according to the results of strength analysis and then considered under conditions of low-cycle fatigue. Their location can be seen on the fig. 5. FEM analyses were carried out in the ANSYS program.

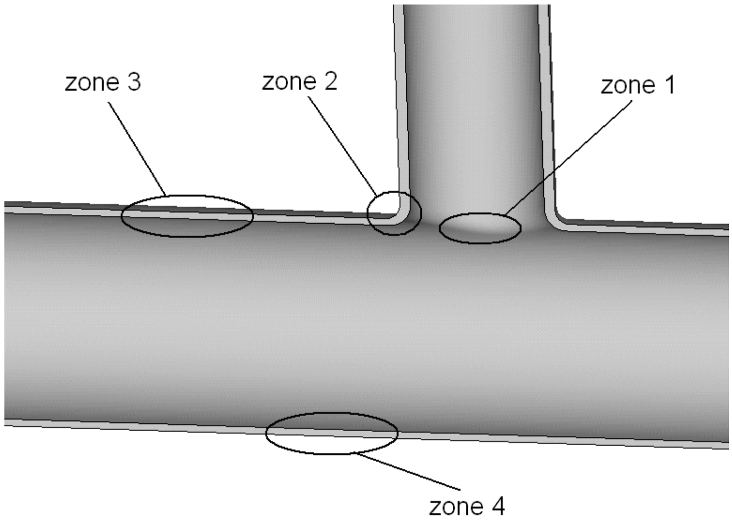

Fig. 5. The most loaded zones.

Calculation of damage from mechanical fatigue including its accumulation was carried out in the program STATES. Fatigue accumulation was calculated for low-cycle fatigue using Langer's curve [4]. The zones chosen earlier were evaluated; cyclic load for them was derived from the process of streams setting. Each zone was represented by the most loaded points. Resultant accumulation of damage is shown in the table 1 and corresponds to the load from one cycle.

Zone	Zone 1	Zone 2	Zone 3	Zone 4
Accumulation [-]	0,0092	0,0037	0,0011	0,0001

Tab. 1. Table of accumulation for separate zones.

7. Conclusion

More detailed information about vapor media mixing in T-joints was found out from the thermal-hydraulic analyses. Mixing type is greatly dependant on particular design of T-joint and working conditions. Using results of simulation graphical dependence of G_1 and G_2 coefficients was drawn, which can be used for streams mixing type determination. Hence it would be possible to find easily thermally influenced pipe zones and then control them more often.

Strength analyses confirmed the most loaded zones and low-cycle examination allowed to establish damage accumulation value. Lifetime decreasing will be maximum in the zone 1, where damage accumulation is 0,92%. It will be minimal in the zone 4. From the lifetime point of view it is important to know how often this process will happen.

Acknowledgements

We gratefully acknowledge financial support of the Ministry of education, youth and sports of the Czech Republic within the framework of research plan No. MSM 0021630502 "Waste and Biomass Utilization focused on Environment Protection and Energy Generation".

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