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STRESS ANALYSIS OF THE Ti–SS TRANSITION JOINT

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Будагов Ю. и др. E13-2008-58
Анализ напряжений переходного соединения титан – нержавеющая сталь

Биметаллический (титан – нержавеющая сталь) переходной образец в конструкции криомодуля ILC продемонстрировал высокую герметичность при проведенных тестах. Перед изготовлением и тестированием образца большего размера проведено численное моделирование методом конечных элементов. Выполнены оценки смещений и напряжений в биметаллическом переходном образце в результате охлаждения от комнатной температуры до температуры жидкого гелия. Проведено сравнение параметров для обоих вариантов (различных диаметров трубок).

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Stress Analysis of the Ti–SS Transition Joint

The bimetallic (titanium–stainless steel) transition sample in the ILC cryomodule design was found to be leak-proof in the tests. Before manufacture and tests of a larger-size sample, displacements and stresses in the transition element arising from its being cooled from room temperature down to the liquid helium temperature were evaluated, and the parameters for both versions (tubes of different diameters) were compared.

The investigation has been performed at the Dzhelepov Laboratory of Nuclear Problems, JINR.

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INTRODUCTION

The current ILC cryomodules design contains a large amount of structures made of titanium. This material creates some difficulties in the welding process (the welding process should be done in neutral atmosphere) and it is expensive. For these reasons, we have investigated the possibility to significantly reduce the amount of titanium by using a suitable titanium–stainless steel (Ti–SS) transition joints prepared with explosion bonding technique.

The Ti–SS transition samples produced in Sarov (Russia) with pipe sections having an outer diameter of 1 and 1/2 inch (or 47.2 mm), have shown excellent behaviour at room and liquid nitrogen temperatures (see Fig. 1). The same samples tested after a few thermal cycles and kept at high pressure (about 6 b), did not show sealing problems [1]. In addition, the diameter pipe is appropriated for the construction of a transition element between the helium vessel (He vessel) and helium supply line (see Fig. 2) used in the 3rd harmonic cavities, presently in the construction phase at Fermilab.

By using the same explosion bonding technique, it has been proposed to build Ti–SS transition joints for the He vessel, but with an outer diameter of 240 mm (see Fig. 3). Before starting the samples production for their experimental test, we tried to simulate by means of a Finite Element Analysis (FEA) model, evaluating the stress-strain behavior during the cool-down from room to helium temperature.

In this paper, we present the simulation results showing that stresses in the junction area are very similar either for small diameter pipes or larger diameter pipes.

1. THE Ti–SS TRANSITION JOINT

A Ti-SS transition joint sample welded by explosion bonding technique is shown in Fig. 1. It is made of two identical diameter pipe sections: one made of titanium and the other one made of stainless steel; the two pipes are connected together by means of a SS collar explosion bonded on their external surface.

In Fig. 2 a sketch of the transition joint between the He vessel and helium supply line in the 3rd harmonic cavities is shown. While in Fig. 3 a technical drawing of 1.3 GHz Tesla RF cavity is shown, where a possible use of a Ti–SS transition joint is presented. In this case adopting two bimetallic transition joints with larger diameter (240 mm), it should be possible to assemble a RF cavity with the He vessel almost completely made of stainless steel.

Fig. 1. The bimetallic (Ti–SS) transition joint produced in Sarov with 1.5 inch diameter pipes

1.1. FEA Model and Boundary Conditions. We have developed a model of the Ti–SS transition joint devoted to a Finite Element Analysis (FEA). The purpose of these studies is the sample behaviour during the cooling down passing from room temperature (300 K) to helium temperature (4 K). Within this simulation job the material bulk stress, due to the explosion bonding process, has not been included because no detailed information on the process was available.

In our FEA model the elements of different materials are perfectly connected together through their adjacent nodes without taking into account the transition region of the materials.

To simplify the calculation we developed a two-dimensional model as shown in Fig. 4, making use of the axial symmetry with respect to the vertical axis (Y axis).

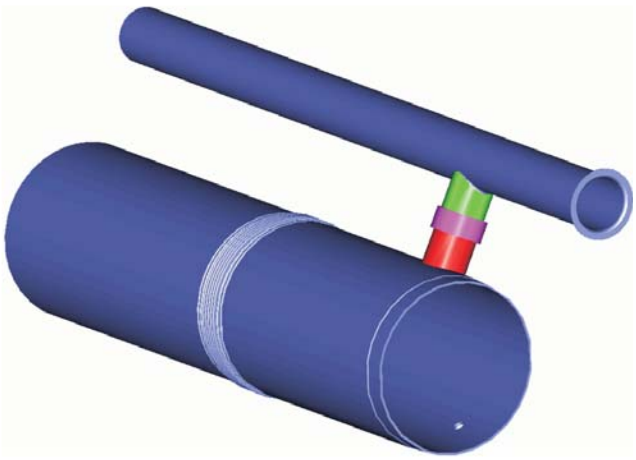

Fig. 2. Sketch of the transition joint (with colours green, pink and red) for the 3rd harmonic cryomodule

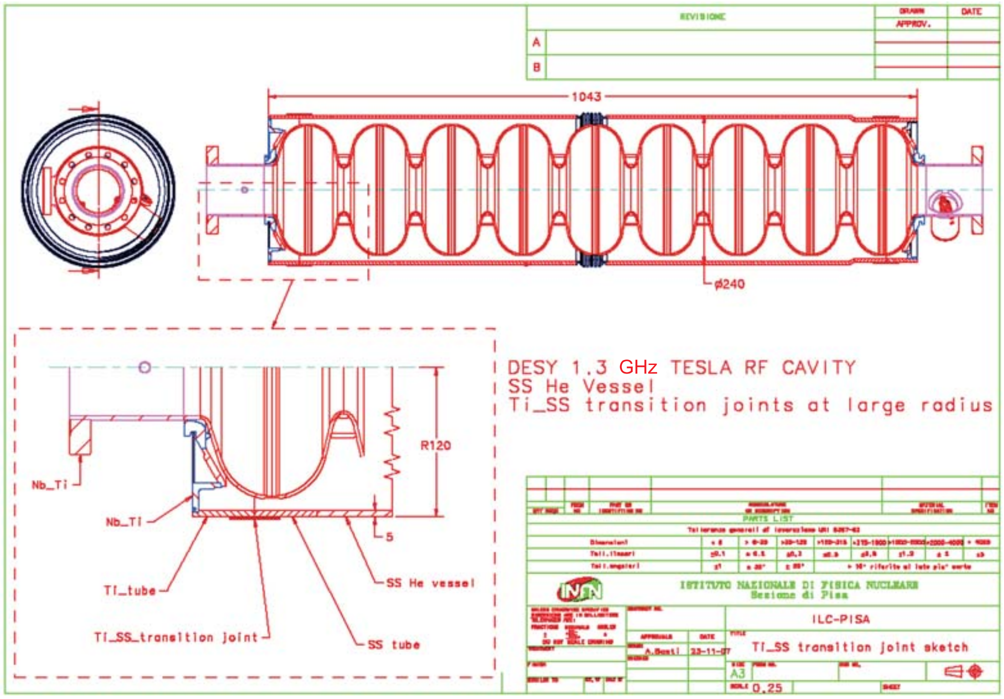

Fig. 3. Technical drawing for a possible construction of a stainless steel He vessel of the TESLA RF cavity. Two bimetallic transition joints (240 mm in diameter) are used for this application

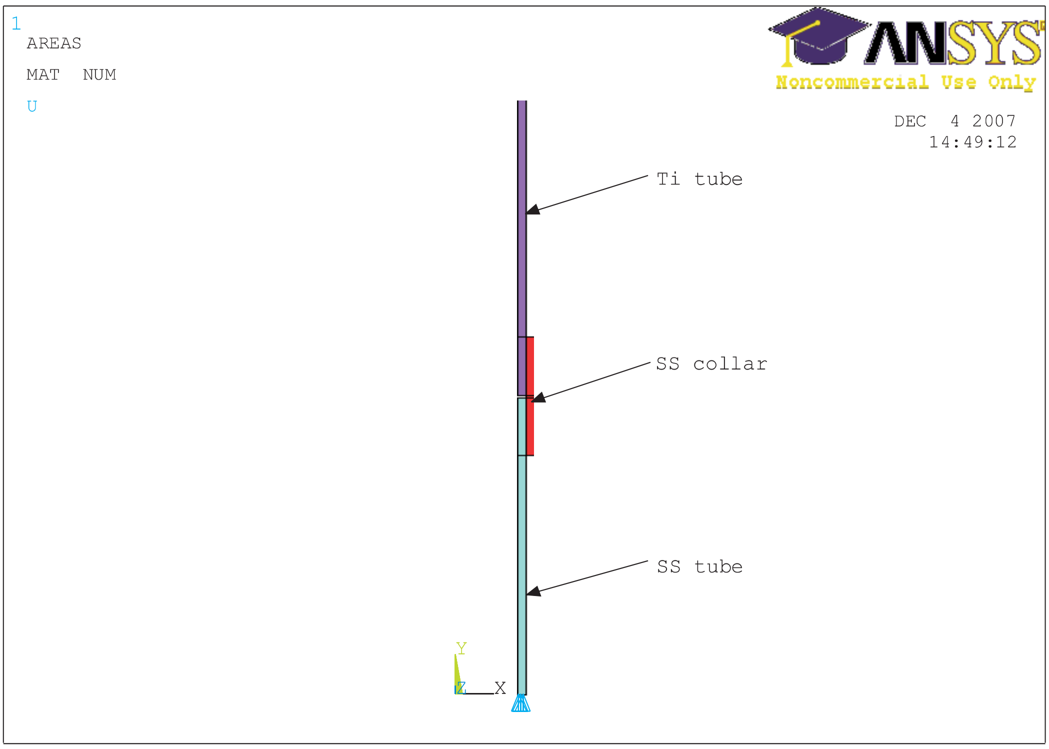

Fig. 4. FEA model of the bimetallic transition joint

The simulation has been done by using ANSYS 2D model consisting of the pipe sections and the collar as described above. The mechanical characteristics of bottom pipe section are those ones of the Stainless Steel 316L as well as for the material of the collar, while for the upper pipe section material has been used those ones of the Grade-2 Titanium. Since SS and Ti tubes are not directly connected along the *Y* direction, a small gap between the SS and Ti elements has been introduced within the model.

Table 1. Dimensions of the transition joints used within the simulation program

	Case I	Case II
Outer diameter of the tube, mm	47.2	240
Length of the tube, mm	100	100
Thickness of the tube, mm	2.5	5
Vertical gap between the tubes, mm	1	1
Outer diameter of the collar (sleeve), mm	52.5	248
Length of the collar (sleeve), mm	40	40

In Table 1 all the dimensions of the joints used in the simulation program are summarized for both cases: small diameter and larger diameter (240 mm diameter bimetallic joint to be used in the construction of the He vessel for the TESLA RF cavity).

The model has been obtained by means of PLANE82 elements. These elements are defined by eight nodes having two degrees of freedom per node: two translations in the *X–Y* nodal plane. Each element may be used either as a plane element or as an axis symmetric element. The element has plasticity, creep, swelling, stress stiffening, large deflection and large strain capabilities. The model has been mapped with quadrilateral mesh. The constraint has been posi-

Table 2. Material properties at $T = 4$ K

Material	Modulus of elasticity E, GPa	Poisson's ratio ν	Secant coefficient of thermal expansion α, 1/K
Stainless Steel 316L	210	0.2	9.85e-6
Titanium	129	0.287	4.98e-6

Table. 3. Stress-strain pairs values for stainless steel and titanium at 4 K

	Stainless Steel (316L)		Grade-2 Titanium	
Strain	0.002	0.4	0.002	0.08
Stress, MPa	420	1400	1193	1214

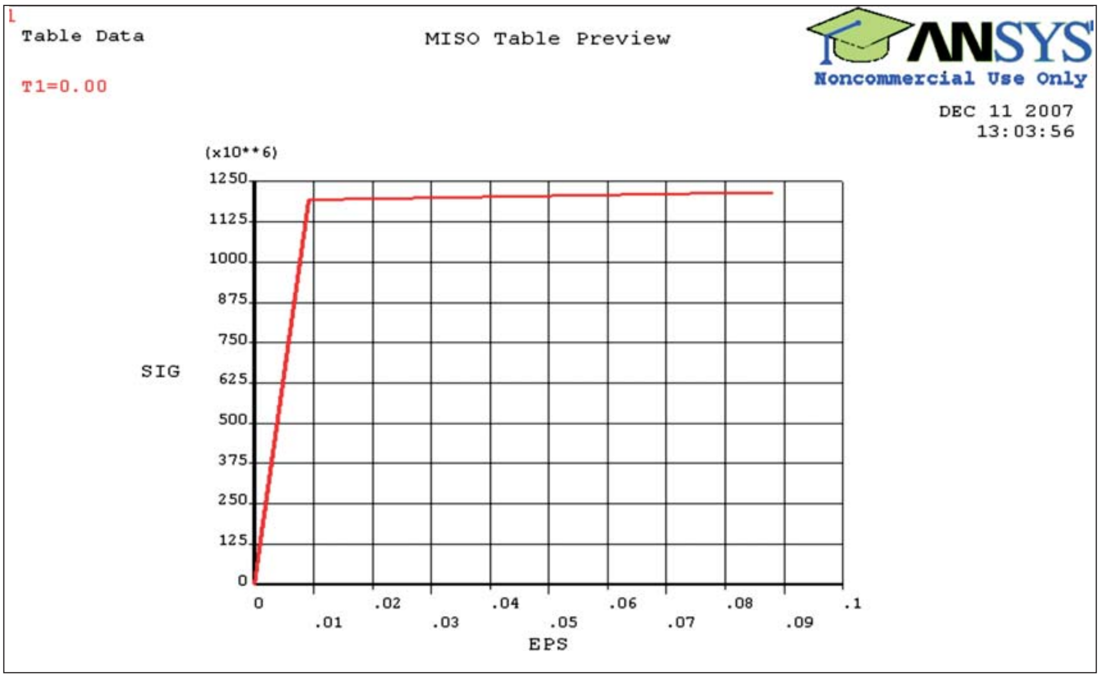

Fig. 5. Stress-strain curve for Grade-2 Titanium at 4 K

tioned only at the lower end of the SS tube, while the displacement along the *Y* direction has been fixed at zero (no displacement at all). The elements in contact made of different materials are considered rigidly connected. With this model a structural static analysis has been performed.

1.2. Material Properties. The material properties used within the code of our simulation are reported in Table 2.

To take into account the plasticity of the materials, a multilinear relationship between stress and strain for each element has been introduced within the simulation code. The implementation of this function can be done knowing the values of stress and strain at the beginning of elastic region and at the breaking point for a fixed temperature value of 4 K.

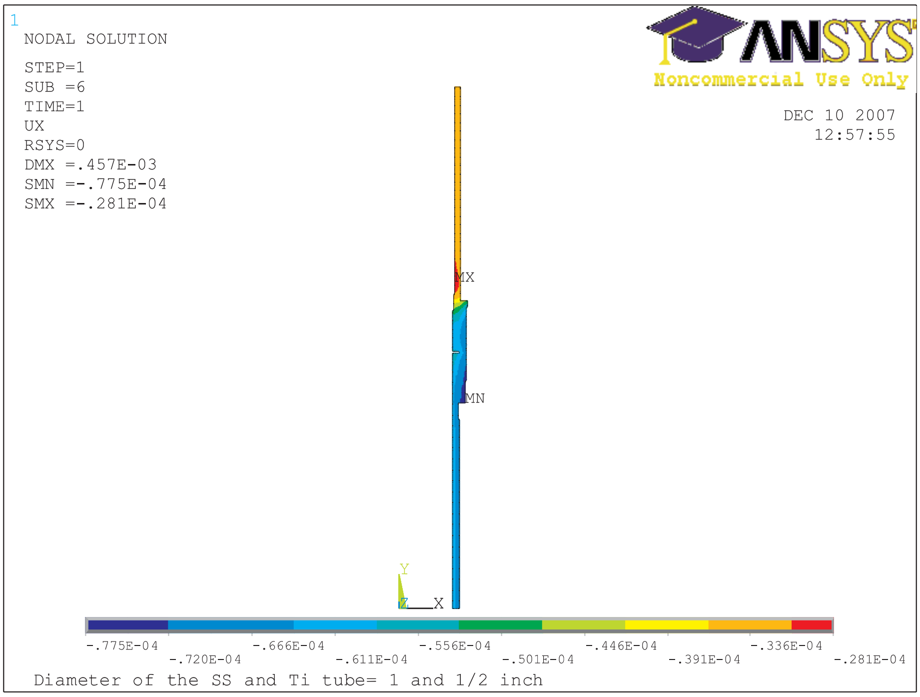

Fig.6. Deformations along the *X* direction for the case I

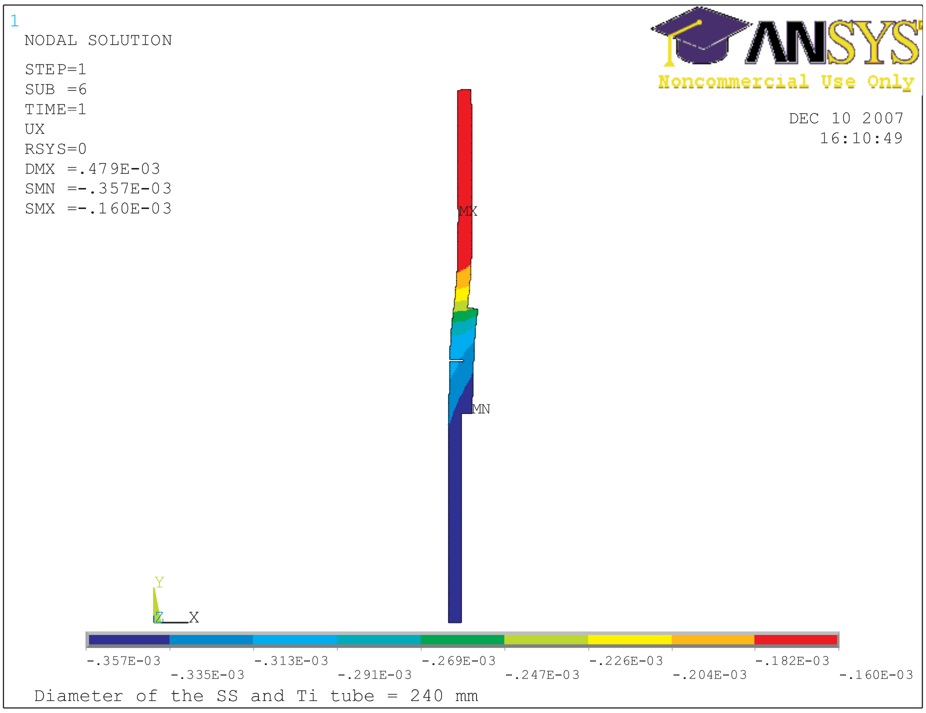

Fig.7. Deformations along the *X* direction for the case II

The values of elastic module, Poisson's ratio and thermal expansion reported in Table 2 for both materials (stainless steel and titanium) are valid at 4 K temperature only, while in Fig. 5 the stress-strain curve for Grade-2 Titanium at 4 K is plotted.

In Table 3 are reported two pairs of stress-strain for the two mentioned materials, which have been used to interpolate the linear region of the stress-strain curve at 4 K. A more complete data sheet of Grade-2 Titanium and Stainless Steel 316L can be found in [2, 3].

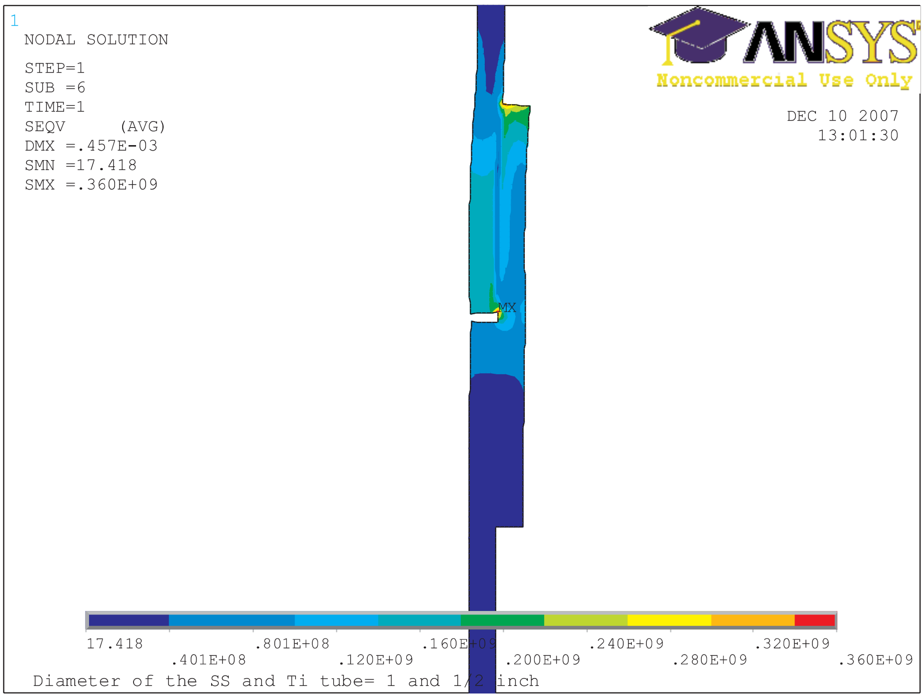

Fig. 8. Equivalent Von Mises stress for the case I

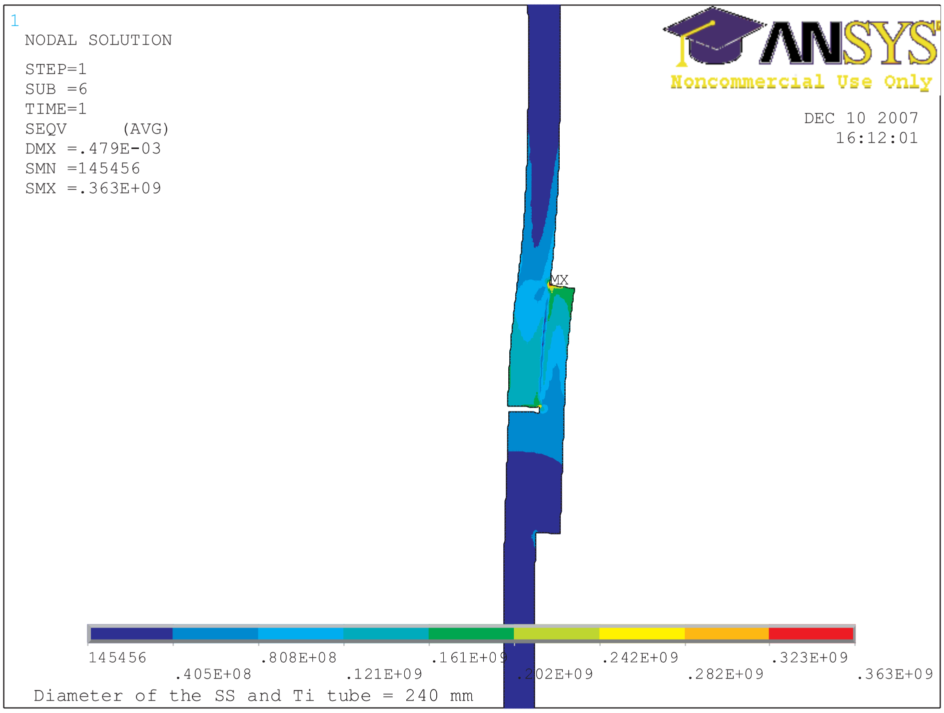

Fig. 9. Equivalent Von Mises stress for the case II

2.3. Load and Solution's Options. The bimetallic transition joint has been proposed as a part of the ILC cryomodules construction. A deeper investigation on the Ti–SS transition sample behavior is of great importance for ILC applications considering that this part will be thermally stressed passing, in standard working conditions, from room temperature down to cryogenic temperatures.

For these reasons in our simulation job, the initial temperature of the joint has been assumed to be 300 K and after that the temperature was decreased to 4 K.

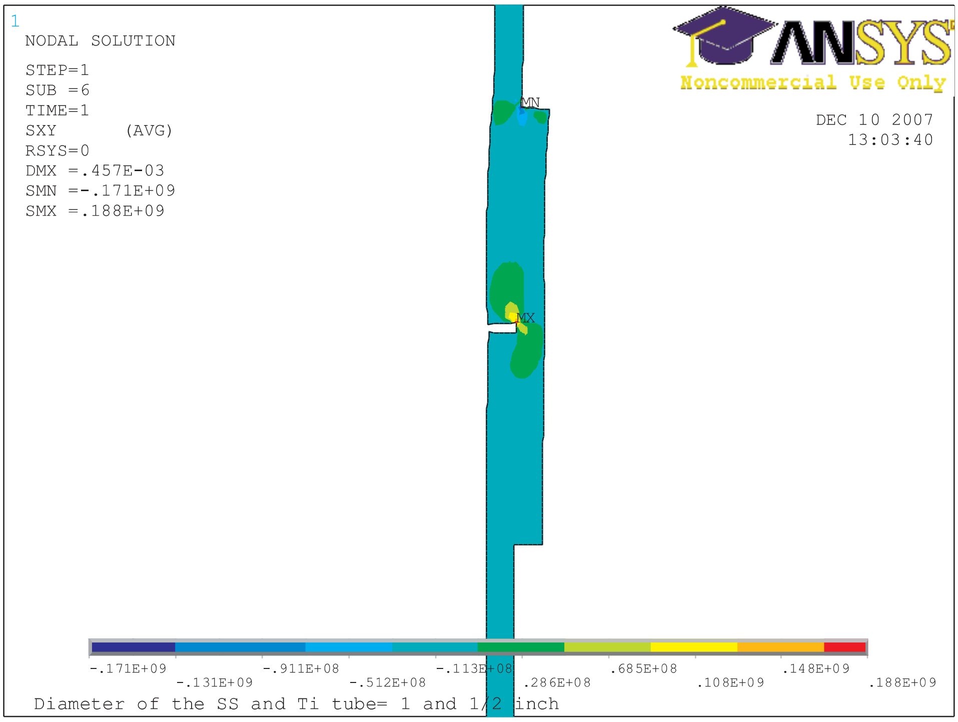

Fig. 10. Shear stress *XY* for the case I

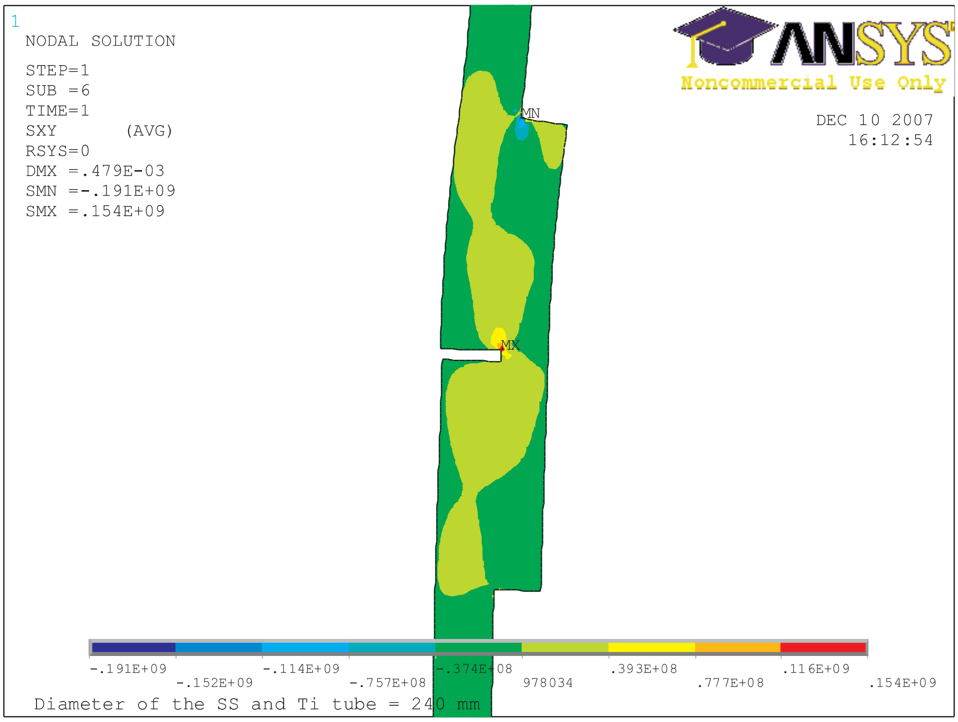

Fig. 11. Shear stress *XY* for the case II

Nonlinear solution option has been activated taking into account the material plasticity in the corner regions between the two different metals. The program chooses automatically the number of sub-steps reaching convergence criteria.

A parametric input file using APDL script has been prepared. In this way it has been easy to change the diameter and the thickness of the tubes for the behavior studies of the joint with different sizes.

2. RESULTS OF THE CALCULATIONS

2.1. Deformations. In Figs. 6 and 7 the deformations (units in meter) obtained with the simulation program for the case I and case II are shown (see Table 1). The maximum one along the *X* direction in the case I (diameter of the pipes 47.2 mm) is 0.077 mm while the maximum deformation in the case II (diameter of the pipes 240 mm) along the same direction is 0.357 mm.

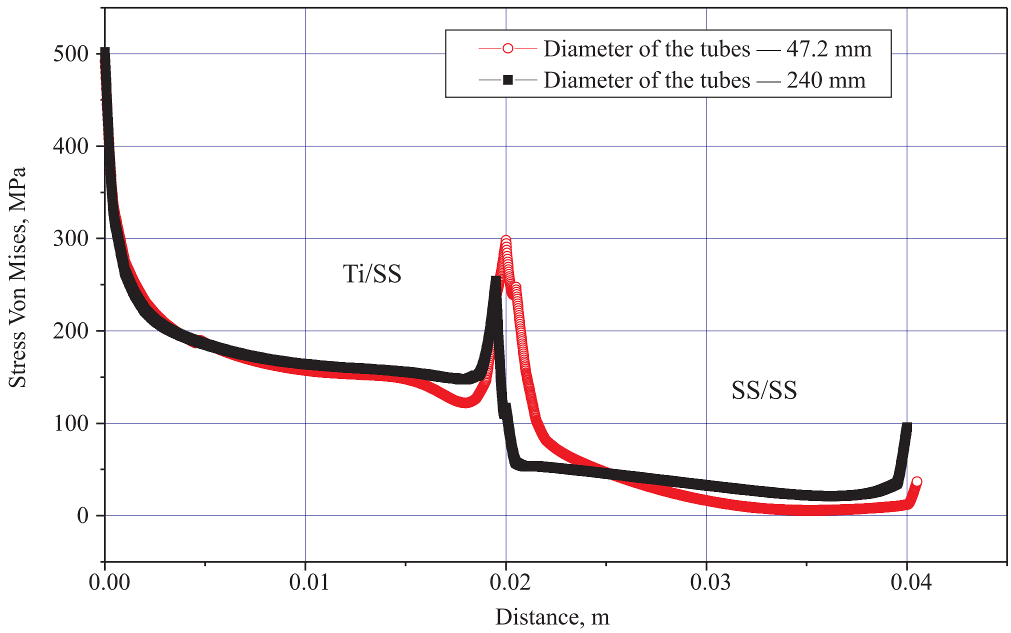

Fig. 12. Equivalent Von Mises stresses

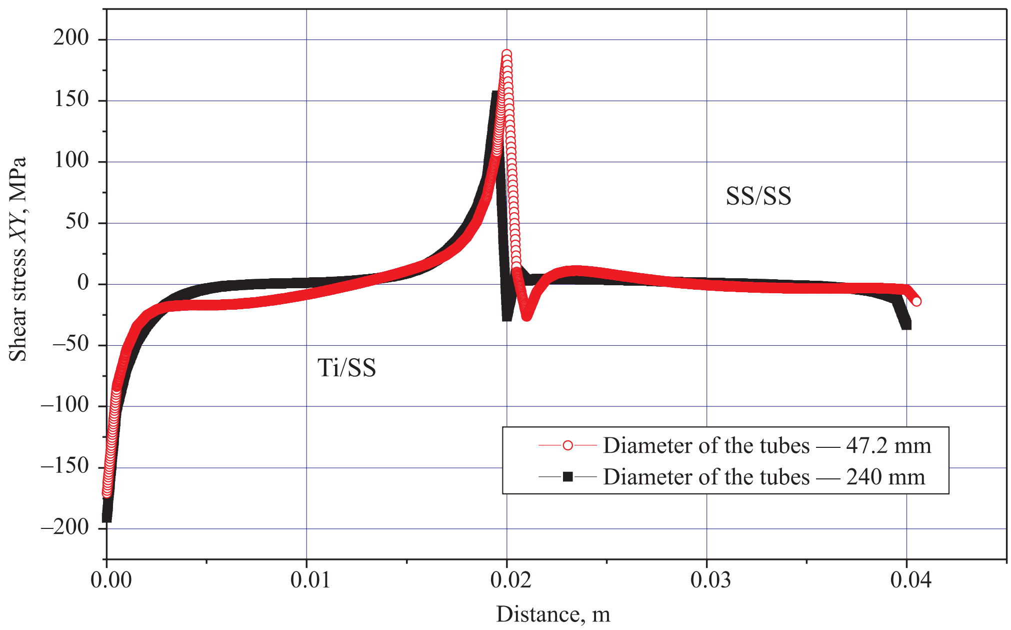

Fig. 13. Shear stresses

As expected, these deformations scale approximately with the pipe diameter (their ratios are approximately equal to 5).

2.2. Stress Von Mises. In Figs. 8 and 9 the equivalent Von Mises stresses (in Pa) for both cases are shown. Except for the corner regions where the model suffers from divergences the stress value is very low comparing it with the material yield point. In the stainless steel pipe the maximum Von Mises stress is about 80 MPa and it is 240 MPa in the titanium pipe. These values should be compared with 420 and 1193 MPa, respectively, for stainless steel and titanium at 4 K.

2.3. Shear Stress. By definition, the shear stress is the stress acting along the tangent direction to the material surface. As for normal stresses, the shear stress has a unit of a force per unit of area (Pa).

In Figs. 10 and 11 are shown the shear stresses *XY* for both cases.

The maximum shear stress has been evaluated in the corner areas between the Ti pipe and SS collar. This value is always below 188 MPa for the case I and 154 MPa for the case II. According to the Nobelclad Technical Bulletin NT200 the shear strength value for explosion bonded plates in the interface area between titanium and stainless steel should be in the range 240–340 MPa, with an average value of 270 MPa (see [4, 5]).

3. STRESS COMPARISON

In Figs. 12 and 13 the results of the equivalent Von Mises stress and shear stresses are plotted for both cases in the region along the length of SS collar (*X* axis).

The coordinate $X = 0$ corresponds to the starting point of the SS collar in the titanium pipe region, while the coordinate $X = 0.04$ corresponds to the SS collar end point in the stainless steel pipe region. This comparison pointed out similar stresses in both cases.

Moreover, these results are in accordance with theoretical predictions based on a model without any radial constraints and considering the stress as originated only from the mismatch of the material thermal expansion coefficient.

CONCLUSIONS

While the stresses obtained with this simulation are approximate (due to the unknown magnitude of the residual internal stresses generated by the bonding process and the incomplete modelling of the transition between the two materials) the model prediction should reliably track the components due to the cooling-down only.

The encouraging result is represented by the fact that even with a coarse model of the joint, the stress values obtained are well below the material and bond-type limits. In addition, the similarity of the stresses predicted in the two cases analyzed makes us confident that a larger sample will perform just well as the existing smaller transition joint, provided that the explosion bonding technology can be reliably extended to a larger pipe dimension.

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