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CHARACTERIZATION MEASUREMENTS OF Ti–SS BIMETALLIC TRANSITION JOINT SAMPLES

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Измерения характеристик образцов биметаллических Ti–SS
переходных элементов

Небольшая партия биметаллических труб исследована при различных условиях с целью определения их характеристик с большей статистикой. В Российском федеральном ядерном центре — ВНИИЭФ (Саров) изготовлено 9 биметаллических образцов методом взрыва. В процессе тестов восемь образцов продемонстрировали прекрасные качества. Это очень хороший результат, и мы полагаем, что образцы могут быть использованы в конструкции сосуда, в который помещен резонатор. Проведены также предварительные измерения остаточного магнитного поля вокруг линии соединения двух сваренных материалов.

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Characterization Measurements of Ti–SS Bimetallic Transition Joint Samples

A small set of bimetallic tubes has been investigated for the purpose to determine characteristics of samples at different conditions of tests for more statistics. Nine bimetallic samples have been manufactured at the Russian Federal Nuclear Center — VNIIEF (Sarov, Russia) using explosion technology for welding titanium and stainless steel tubes. During the tests eight samples have shown an excellent behavior. This result is very good and we believe that these samples can be used for the construction of the cavity vessels. A preliminary measurement on the residual magnetic moment around junction line between the two materials has been carried out.

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

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INTRODUCTION

This note represents a summary of characterization measurements on bimetallic (Ti–SS) transition joints. The campaign has been done within the R&D program between INFN (Pisa) and JINR laboratory and concerning a possible use of these mechanical connections in the ILC cryomodule design.

At the end of January 2008 we received in Pisa nine transition joint samples made of Ti and SS tubes manufactured in Sarov (Russia). The two pipe sections (with external diameter of 1.5 inch) were welded together by explosion bonding technique applying an external stainless steel collar covering the junction line of the two materials.

Here below we report the results of the leak tests performed at INFN (Pisa) laboratory on these samples. The measurements have been done by using a helium mass spectrometer leak detector (model 979 by VARIAN) equipped with an internal turbo molecular high vacuum pump and mechanical external dry scroll pump. The operating range sensitivity of this machine is $1 \cdot 10^{-10}$ to $1 \cdot 10^{-4}$ atm·cc/s while minimum detectable leak is $< 5 \cdot 10^{-11}$ atm·cc/s.

A preliminary measurement on the residual magnetic moment around the junction line between the two materials is the subject of the second part of this internal note devoted to a complete characterization of these bimetallic transition joints.

1. THE Ti–SS TRANSITION SAMPLES

The dimensions of titanium–stainless steel (Ti–SS) transition samples welded by explosion bonding are shown in Fig. 1.

Like the others previously tested samples [1] they are made of two equal diameter pipe sections, one made of titanium (Ti) and the second one made of stainless steel (SS), connected by means of SS collar explosion bonded on the external surface of the tubes as represented in the technical drawing of Fig. 1.

The pipe sections have been sent to Russian company from INFN (Pisa). They were obtained cutting them from a stainless steel (316L) pipe (1–1/2" NB x sch.10S – ISO 48.3 x 2.6 mm) and titanium pipe (Ti.Gr2), bought from an Italian distributor but coming from Germany (SS) and China (Ti). The SS collars were also supplied from Pisa, the material of these rings was the same as 316L and they come from seamless standard pipes (2" NPS x sch. 40S – ISO 60.3 x 3.9 mm) cutting.

All the dimensions of transition samples were carefully checked at Dubna laboratory (see Fig. 2) before to be sent to Pisa for their characterization. It has to be pointed out that all the transition joints were externally machined after the explosion bonding process to obtain the dimensions reported in Fig. 1.

All samples have been labelled on the external surface with a progressive number. The sample No. 2 was missing.

An annealing treatment reducing the machining stress underwent by the sample during the explosion bonding process, has been done on a few joints by the Russian company. As reported in Table 1, the leak test measurements performed in Russia does not put in evidence any difference between the samples with the annealing treatment and the others without it.

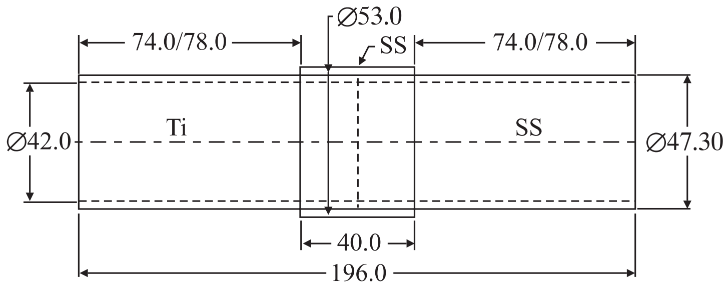

Fig.1. Dimensions (in millimetres) of Ti–SS transition samples

Fig. 2. Check of the sample dimensions at the Dubna laboratory

Fig. 3. The nine Ti–SS samples tested in Pisa

According to the temperature choice (540 °C) and the time of permanence within the vacuum oven (about 30 min), the annealing process seems to be more effective for titanium than for stainless steel.

Table 1. Annealing process and leak rate measurements performed in Sarov

Sample number	Annealing process	Leak rate, $Pa \cdot m^3/s$
1	No	$1.2 \cdot 10^{-9}$
3	No	$1.2 \cdot 10^{-9}$
4	Yes	$1.2 \cdot 10^{-8}$
5	Yes	$1.2 \cdot 10^{-8}$
6	Yes	$1.2 \cdot 10^{-8}$
7	No	$1.2 \cdot 10^{-9}$
8	Yes	$1.2 \cdot 10^{-8}$
9	Yes	$1.2 \cdot 10^{-8}$
10	No	$1.2 \cdot 10^{-9}$

2. LEAK TESTS AT ROOM TEMPERATURE

Each bimetallic sample has been connected to the leak detector by using the same set-up developed to test previous samples [1]; two blind stainless steel flanges (DN65) have been used to close the pipe on both sides and creating a small vacuum volume. One of them is connected by means of a reduction joint DN25 to a flex pipe coming from the leak detector. A handmade indium o-ring, prepared with 2 mm diameter wire, has been used to seal, on both sides, the vacuum volume of the joint to be tested.

The test results at room temperature are reported in Table 2 here below. The measurements have been performed by using a plastic bag wrapping the sample filled with He gas as detailed in Ref. [1] and shown in Fig. 4.

Table 2. Leak test results at room temperature (300 K) performed at INFN (Pisa) laboratory

Sample number	Vacuum level, mbar	Leak rate background, atm·cc/s	He leak rate, atm·cc/s
1	$< 5\cdot10^{-4}$	$0.8 – 1.0 \cdot 10^{-10}$	No variation
3	$< 5\cdot10^{-4}$	$0.1 \cdot 10^{-10}$	No variation
4	$< 5\cdot10^{-4}$	$4.0 \cdot 10^{-10}$	No variation
5	$< 5\cdot10^{-4}$	$1.2 \cdot 10^{-10}$	$1.5 \cdot 10^{-10}$
6	$< 5\cdot10^{-4}$	$0.9 –1.0 \cdot 10^{-10}$	No variation
7	$< 5\cdot10^{-4}$	$0.1 \cdot 10^{-10}$	No variation
8	$< 5\cdot10^{-4}$	$1.5 \cdot 10^{-10}$	No variation
9	$< 5\cdot10^{-4}$	$0.01 \cdot 10^{-10}$	No variation
10	$< 5\cdot10^{-4}$	$3.2 \cdot 10^{-10}$	$1.3\cdot10^{-8}$

Fig. 4. The Ti–SS transition joint wrapped with a plastic bag for the He leak test measurements

3. LEAK TESTS AFTER THERMAL CYCLING

After the leak rate test at room temperature each sample has been disconnected from the leak detector and has been putted to the five thermal cycles passing quickly from room temperature (300 K) to liquid nitrogen temperature (77 K).

Each sample has been dipped inside a Dewar filled with liquid nitrogen. This cooling process was very quick because the metallic sample reached the thermal equilibrium with the liquid environment in a few minutes (no bubbles were visible around the metallic surface). After that the sample was taken out from the Dewar and warmed up by means of a heat gun, waiting till no ice was present on metallic surfaces (also this warming procedure was very fast).

Fig. 5. A sample dipped in liquid nitrogen within a Dewar

Fig. 6. A joint before starting the heating process by means of a hot gun

As is mentioned above, this cooling-heating process has been repeated five times for each joint before connecting it again to the leak detector for the measurement of the He leak rate at room temperature. The results of the second part of the test are reported in Table 3.

Table 3. Test results at room temperature (300 K) after 5 thermal cycles

Sample number	Vacuum level, mbar	Leak rate background, atm·cc/s	He leak rate after thermal cycles, atm·cc/s
1	$< 5 \cdot 10^{-4}$	$0.4 \cdot 10^{-10}$	$0.9 \cdot 10^{-10}$
3	$< 5 \cdot 10^{-4}$	$0.8 – 0.9 \cdot 10^{-10}$	No variation
4	$< 5 \cdot 10^{-4}$	$2.4 – 2.5 \cdot 10^{-10}$	No variation
5	$< 5 \cdot 10^{-4}$	$3.7 \cdot 10^{-10}$	No variation
6	$< 5 \cdot 10^{-4}$	$0.1 \cdot 10^{-10}$	No variation
7	$< 5 \cdot 10^{-4}$	$0.1 – 0.2 \cdot 10^{-10}$	No variation
8	$< 5 \cdot 10^{-4}$	$0.8 – 1.0 \cdot 10^{-10}$	No variation
9	$< 5 \cdot 10^{-4}$	$0.3 – 0.5 \cdot 10^{-10}$	No variation
10	$< 5 \cdot 10^{-4}$	$3.1 \cdot 10^{-10}$	$2.1 \cdot 10^{-8}$

5. MAGNETIC FIELD MEASUREMENTS INSIDE THE TUBES

The explosion bonding technique adopted to weld dissimilar materials having different technical characteristics is a quite complex process. The shock wave, due to the explosive source used in the process, drastically increases pressure and temperature in the region close to the junction line changing the microscopic characteristics of the materials [2, 3]. The coarse idea is that within stainless steel core a localized phase transition from austenitic to martensitic could induce an increment of the residual magnetic moment.

For these reasons a detailed measurement campaign of the magnetic field within the Ti–SS joints has been performed. The measurements have been done by using the experimental set-up consisting of two mobile trolleys mounted in orthogonal configuration on top of which the joint is fixed by means of a cradle support made of plastic material (reduced influence on magnetic field) as shown in Fig. 7. The magnetic field sensor, connected to a mobile Gauss meter, is mounted on a fixed support at the centre of the pipe. Also this support has been built selecting nonmagnetic material. The magnetic field has been measured moving forward and backward the joint mounted on the mobile trolley without moving the magnetic sensor. The scanning has been done along the cylinder axis for a total length of 60 mm with 5 mm pitch.

Fig. 7. Tools to measure the residual magnetic field inside the tubes

The magnetic field measurements on the two materials have been performed rotating by 180° the sample position with respect to an axis orthogonal to the cylinder axis. The starting point of the scanning procedure was the pipe edge (60 mm position) going towards the explosion bonded junction (0 mm position).

Here below in Figs. 8 and 9 the magnetic moment measurements on two joints (JOINT No. 1 and JOINT No. 10) are reported as a function of the distance along the cylinder axis (going from the pipe edge toward the junction point under the collar). Two curves are present in each plot: the first one represents the values collected during the measurements (red circles), the second one is obtained from the first value subtracting the background values previously measured and due to the residual magnetic field of the metallic elements of the movable trolley (blue squares).

In Figs. 10 and 11 the magnetic moment measurements performed on the available joints (nine) are summarized for stainless steel side and titanium side, respectively. These results confirm the differences between the two dissimilar materials used in the process also for a magnetic point of view. The influence of the explosion bonding process on titanium (a-magnetic material) is uniform on all the joints: clear evidence of small magnetic moment with maximum values close to the junction line. While for the stainless steel the situation is more complex. In the region close to the junction line (between 0 and 25 mm) the trend is identical for all the joints, but far away from this zone the magnetic moment in-

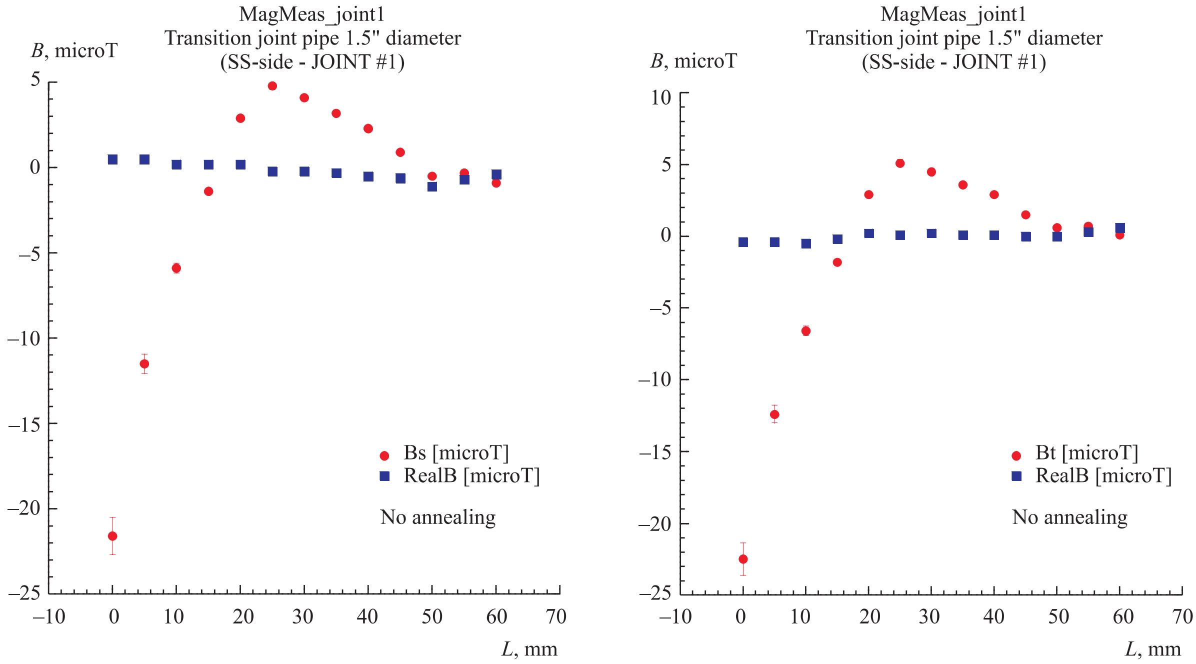

Fig. 8. The magnetic moment measurements on JOINT No. 1 for stainless steel side (left plot) and titanium side (right plot). Red circles represent the value collected during the measurements while the blue squares are obtained subtracting the background values from the previous ones

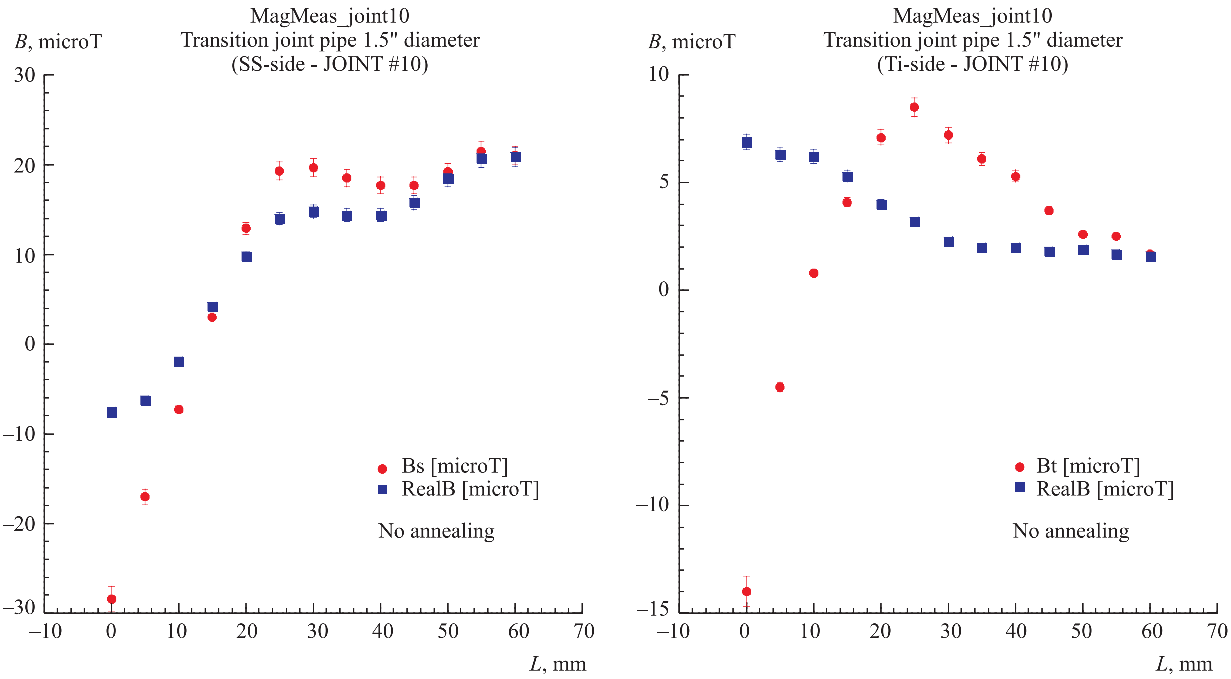

Fig. 9. The magnetic moment measurements on JOINT No. 10 for stainless steel side (left plot) and titanium side (right plot). Red circles represent the value collected during the measurements while the blue squares are obtained subtracting the background values from the previous ones

duced by the explosion welding process is added to that one present on the original material (the residual magnetic moment of stainless steel cannot be considered null at this level of measurement sensitivity) and the measurement trend is not uniform.

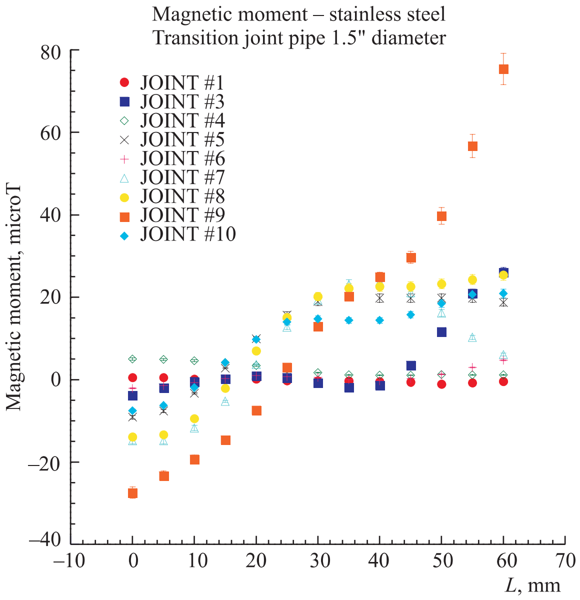

Fig. 10. Summary of the magnetic moment measurements performed on nine bimetallic transition joints. In this plot the residual magnetic moments measured on stainless steel side are shown

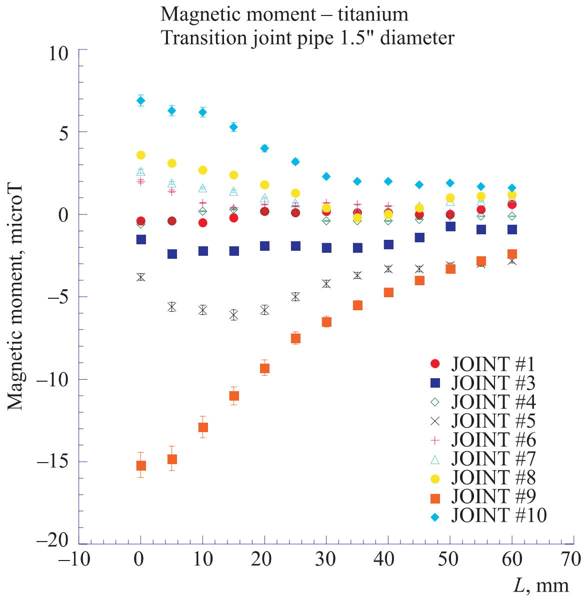

Fig. 11. Summary of the magnetic moment measurements performed on nine bimetallic transition joints. In this plot the residual magnetic moments measured on titanium side are shown

The thermal treatment in vacuum oven at 540 °C for about 30 min performed on a few samples (labelled as «Annealing» on the plots) did not put in evidence any difference on the residual magnetic moment of the joint.

CONCLUSIONS

The eight Ti–SS transition joints have been characterized. They have shown excellent behaviour both at the room temperature and after thermal cycles between room (300 K) and liquid nitrogen (77 K) temperatures. The measured helium leak rates of the samples were $(1 \cdot 10^{-10} \pm 10\%)$ mbar · l/s. No difference has been observed comparing the results obtained with the annealed samples and those without any thermal treatment, even if the thermal treatment chosen seems to be more suitable as a distension treatment for titanium material only. Only one sample shows a small leak $(2.1 \cdot 10^{-8}$ mbar · l/s) around the collar that covers the Ti–SS junction and this leak was present before and after the thermal cycles.

This result is very good and we believe that these samples can be sent to the Fermilab starting their use for the construction of the 3rd harmonic cavity vessel.

The magnetic moment measurements campaign put in evidence a clear situation on titanium side of the joint: a small magnetic moment is present after the explosion bonding process with maximum values close to the joint line. The magnetic moment trend on the stainless steel pipe is identical on all samples close to the junction line (between 0 and 25 mm), but it does not follow a general trend far away from the junction line. This fact suggests that the intrinsic residual magnetic dipoles, present in the original bulk material, play different role close to the junction line and far away from it. A possible solution for this unpleasant behaviour could be a more accurate selection of the stainless steel pipe (certified material with low residual magnetic moment).

The thermal treatment performed on a few joints did not influence the results of these measurements.

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