RECENT OPTIMIZED DESIGN OF ILC CRYOMODULE WITH EXPLOSION WELDING TECHNOLOGY

B. Sabirov, J. Budagov, G. Shirkov, Yu.Taran, JINR, Dubna, Russia
A. Bryzgalin, S. Illarionov, E. Pekar, PWI, Kiiv, Ukraine
A. Basti, F. Bedeschi, P. Fabbricatore, INFN, Pisa/Genova, Italy

Abstract

The past few years, we have made a great deal of progress in developing and demonstrating the enabling technology needed for a linear collider for the modernization of the cryomodule for the International Linear Collider (ILC) in the frame of collaboration JINR (Dubna, Russia), INFN (Pisa/Genova, Italy) and PWI (Kiiv, Ukraine) [1-4].

INTRODUCTION

Based on our experience, the collaboration got down to creating a transition specimens between the steel shell of the cryomodule vessel and the niobium cavity (Fig. 1). Trimetallic Nb+Ti+SS specimens were produced using the explosion welding and successfully tested at liquid nitrogen and liquid helium temperatures. This version deserves special attention for its manufacturability, simpler design, guaranteed strength and reliability of the joint and above all for an appreciably lower cost. It is a promising new transition joint technology based on cladding side surfaces of a steel flange by titanium using explosion bonding and welding a Nb pipe to titanium by EBW.

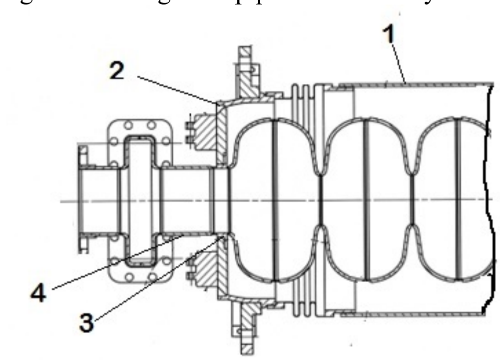

Figure 1: Scheme of combined adapter connection with a cryogenic module: 1 – steel shell; 2 - electron beam welding or argon arc welding connection of shell with steel flange of adapter; 3 - steel flange; 4 - niobium tube.

PROBLEM DEFINITION

It is known that welding of similar materials gives the best results. The adapter should consist of at least two metals, niobium and stainless steel. No fusion welding, including electron beam welding is suitable for joining niobium and stainless steel because it results in formation of intermetallic compounds like Nb_xFe_y, which do not allow the required adapter tightness to be obtained. In addition, this compound does not withstand the thermal load at cryogenic temperatures and fails.

Earlier experiments showed that electron beam welding of niobium and titanium did not result in formation of intermetallic compounds and ensured the required helium and vacuum tightness. In this connection the following adapter manufacture procedure was proposed [5]. First, the stainless steel disc is clad with titanium on both sided by explosion welding, the resulting trimetal is shaped as required (by planishing and turning to the size), and a hole is cut for the niobium pipe. The pipe is inserted in the hole and electron-beam welded to titanium (Fig. 2).

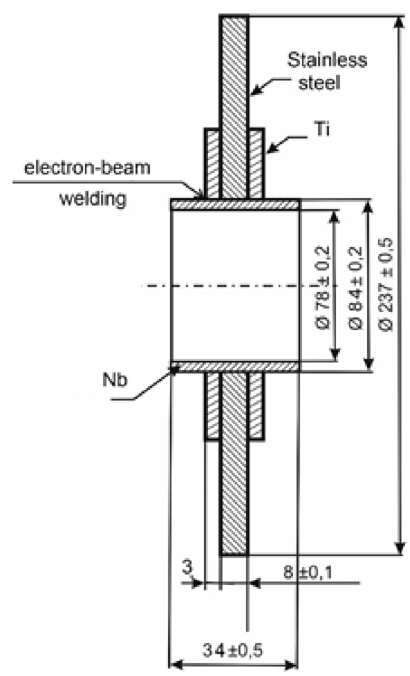

Figure 2: The design of the adapter, ensuring the absence of niobium intermetallic formations during welding.

Advantages of this adapter manufacture procedure are as follows:

- electron beam welding of niobium and titanium did not result in formation of intermetallic compounds and ensured the required helium and vacuum tightness;
- possible formation of intermetallic compounds in the explosion weld steel–titanium joint does not affect helium tightness;
- explosion welding of flat pieces is technologically much simpler than welding of pipes and allows joints with quality as much stable as possible;
- expenditure of steel and niobium decreases.

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EXPLOSION WELDING OF METALS AND ITS MAIN PARAMETERS

Explosion welding is a process of making a permanent joint through metallic bonding [6]. It does not require a heat source because the energy comes to the joint area from the collision of the plates (Fig. 3). In optimum explosion welding regimes the heat-affected zone is very small, as is the existence time of high temperature.

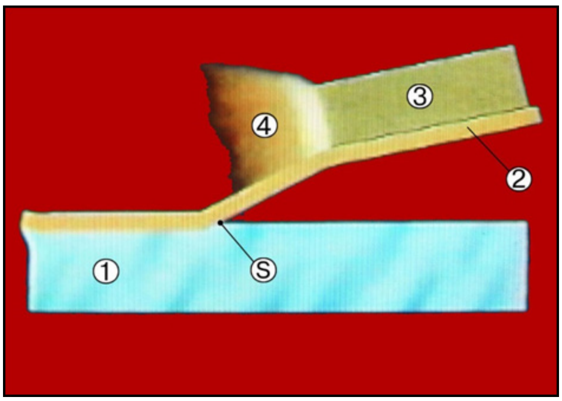

Figure 3: Principal schemes of explosion welding process with an angle between metal sheets 1 - base plate; 2 – cladding plate; 3 - explosive; 4 - detonation products; S - point (line) of contact of surfaces during welding.

The surfaces of the metals to be joined suffer plastic deformation creating a wave pattern bond line. An increase in the welding energy (collision energy of plates) increases wave parameters.

Since explosion welding is a complicated and high-velocity process, there is so far no universal mathematical model capable of precisely describing all its details. It is worth noting that titanium forms intermetallic compounds with almost all metals except niobium, tantalum, and vanadium

Explosion welding regimes for fabricating the titanium–steel–titanium trimetal were selected experimentally. The titanium was 3 mm thick and the steel was 8 mm thick. Plates with dimensions 250x250 mm (Ti) and 300x700 mm (SS) were welded. After the explosion and after the fabrication of the trimetal the planishing was performed on an industrial rolling mill to eliminate local deformation to make the billet flat.

Discs 237 mm in diameter with a central hole 84 mm in diameter for the niobium pipe were cut and electron beam welding (EBW) process of niobium tube with titanium clad occurs in a high-vacuum chamber in the deepest penetration regime (Fig .4).

The Vickers microindentation test was performed. The results of measuring microhardness at a load of 100 g are presented in Fig. 5.

The layer shear tests (Fig. 6) showed the strength at a level of 350 MPa considered satisfactory.

Obtained test results are rather optimistic and encouraged : the joining density characterized by absence of leak at background leak rate ~4.7·10^{-9} mbar·l/sec, measured at variety extreme conditions: thermocycles at temperature 77K and 2K, at pressure 6.5 atm; test at high temperature thermoload, exposure to ultrasonic radiation.

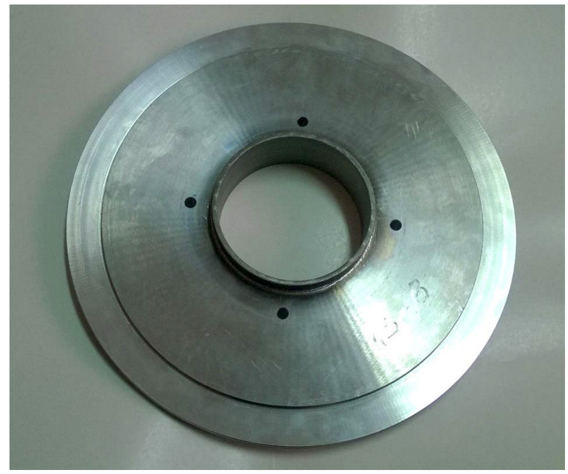

Figure 4: Appearance of combined adapter.

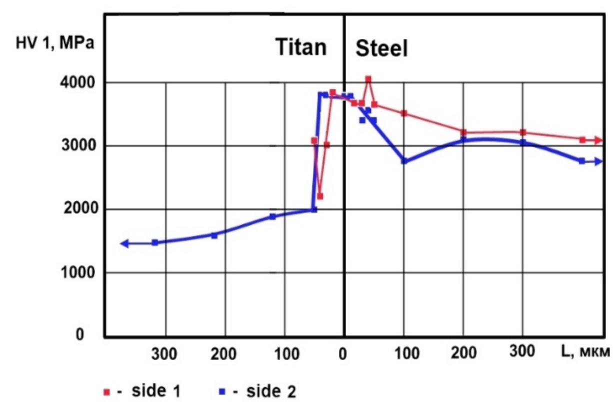

Figure 5: The microhardness of the steel-titanium boundary after explosion welding.

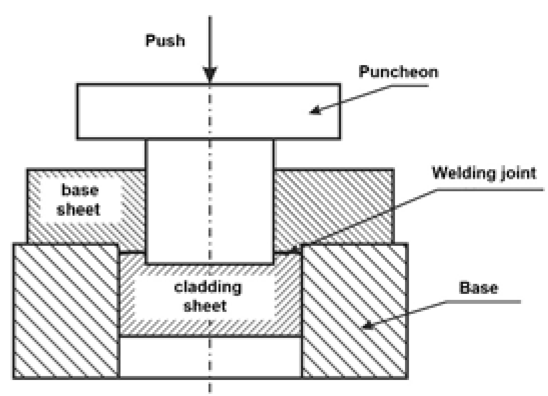

Figure 6: The scheme of layer tear test.

The next test is **main crusial** one: for imitation of use transition sample in real working position, connected with Nb cavity, Nb rings were joint with Nb pipe of samples by EBW. The welded joint experienced various internal stresses, first, due to the explosion welding, then due to the

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thermal load from the electron beam welding (niobium melting point is 2460°C), and ultimately due to the thermal load at an extreme low helium temperature of 4°K. Superposition of all these residual stresses may result plastic deformation, failure of welds, and consequently occurrence of a leak. Test result ussued absence of leak at background leak rate ≈$0.5 \cdot 10^{-10}$atm·cc/sec.

We have measured residual stresses in Ti+SS joint using the neutron diffraction method. Measurements were carried out with the POLDI stress diffractometer on the neutron beam from the ISIS reactor of the Paul Scherrer Institute (Switzerland) [4].

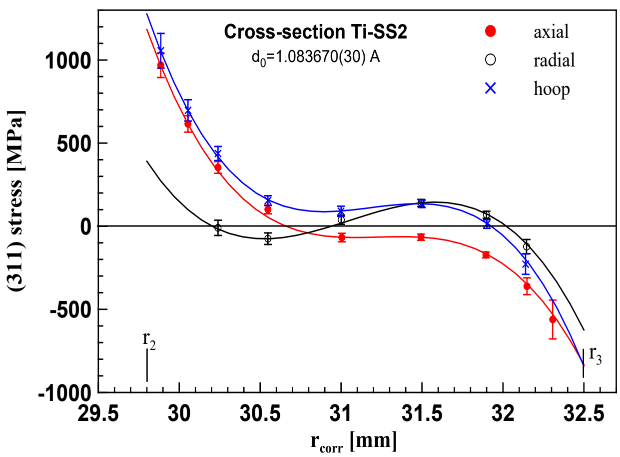

Figure 7: Measured (points) and fitted (curves) radial dependence of the stress . tensor components obtained for the peak (311) in the Ti+SS cross section.

Measured (points) and fitted (curves) radial dependences of the stress tensor components obtained for the peak (311) in the Ti+SS cross section ultimate result of residual stress measurements in the bimetallic Ti+SS joint in the process of scanning the titanium-to-stainless steel joint (Fig.7). As is evident from the plot, the residual stress is quite considerable, amounting to ≈1000 MPa. Considering that foregoing residual internal stresses superposition can make titanium turn into the state which corresponds to the deep plastic region. This may cause local microcracks in the Ti+SS (or Nb+SS) joint, which in turn may adversely affect tightness of the transition element when it is used in the cryomodule.

CONCLUSION

The adapter is designed which is suitable for manufacturing a linear collider cryomodule and eliminates the necessity to weld niobium to steel.

An explosion welding technology is developed that allows a trimetallic billet for manufacturing an adapter to be made such that the niobium–titanium bond is free of intermetallic compounds and the effect of the difference in the linear expansion coefficients of the ensemble components is eliminated. Regimes for EBW of steel to niobium and titanium are chosen which tentatively meet the adapter operation requirements.

The results showed the full eligibility of suggested design Nb+Ti+SS transition sample not for only Linear Collider, but for any cryogenic systems [7,8].

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