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FRICTION STIR WELDING AND COPPER-CHROMIUM ZIRCONIUM: A NEW CONCEPT FOR THE DESIGN OF SIRIUS' HIGH-POWER ABSORBERS

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Abstract

Sirius, the new Brazilian fourth-generation synchrotron light source, is currently under construction. Due to the high brilliance and low emittance of its source, the photon beam on each undulator beamline can have power densities as high as 55 W/mrad². To protect the components downstream, the Front-End power absorbers need to manage this power in a limited space, but also having precision in alignment and being reliable all over their lifetime. To achieve this behaviour, the selected alloy was the copper-chromium-zirconium (CuCrZr, commercially known as C18150) because of improved thermal and mechanical properties. In order to seal the vacuum chamber (path on which the cooling water flows), friction stir welding was the selected joining method. During the welding process, the material passes through a grain refinement process which results in a high-resistance joint. The manufacturing process could also result on a reduction of costs and lead times. Finally, it will be presented the final versions of the component with its support and the characterizations done to validate the welded joint under vacuum and water pressure requirements.

INTRODUCTION

Sirius is the new 3-GeV low-emittance high-brightness fourth-generation Brazilian synchrotron light source. As a research facility, it is going to provide resources for high-level scientific studies after its beamlines are finished. Also, as can be seen by the monochromators [1] and mirrors projects [2], new concepts and technologies are already being developed.

Regarding the undulator-beamlines FE (Front-end) power absorbers (*i.e.* fixed mask, photon shutter and high-power slits), their designs were already finished, tested and validated. Those are the components which manage the high power emitted by the storage ring, protecting the components downstream by blocking portions of the white beam. On [3], it can be found specifically the function of each power absorber along with their apertures and design criteria. Their design was based on brazing of Glidcop [4] and stainless-steel parts as described on [5].

Despite of their proven utility, their manufacture chain was highly demanding in some points, such as: human sources, time and machining services (in order to refine mechanical adjustments between parts). Those facts were the main motivation for the proposal of the system optimization done in the current study. A copper-chromium-zirconium alloy (CuCrZr, commercially known as C18150) was the chosen alloy for this application because of the following reasons: it is cheaper and available on national market, its mechanical and thermal properties are alike the Glidcop [6], and it is vacuum compatible [7] It should also be emphasized that other synchrotron facilities have already replaced Glidcop by CuCrZr alloy on their FE power absorbers [8-9].

On other hand, due to their high thermal conductivity, copper and copper alloys are difficult to weld using conventional techniques (*i.e.* techniques that involve fusion). Usually, a high heat input is necessary to melt the material and it is particularly compromising when working with precipitated-hardened alloys, such as CuCrZr [10], once strengthening nano-precipitates can be largely eliminated due to the welding thermal cycle. During welding, the previous thermal cycle usually effaces the heat treatment, and along with recrystallization, results in lower yield and ultimate strength than the aged base metal [10, 11]. Moreover, copper is susceptible to embrittlement due to oxygen dissolution into the melt pool. Furthermore, reference [12] points out that a long exposure of the CuCrZr alloy to high temperatures could cause over aging and recrystallization. Thus, it is necessary not only to limit the temperatures during manufacturing of the component, but also during its operation in the beamline. It was defined as a constraint because of a proposal to do the flange manufacturing on the CuCrZr workpiece itself as a manner to reduce the number of welding spots (a reduced material strength could cause a greater deformation on the flange's knife, leading to a vacuum leakage.

Differently from conventional processes, friction stir welding (FSW) is a solid-state joining technique capable of overcoming the problems related to welding of copper [13]. FSW consists of a rotating non-consumable tool, which is inserted in the material and translates along the weld path to create a joint. The tool generates heat from friction and deformation. Since maximum temperatures lay

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below the melting point of the alloy, solidification-related phenomena are eliminated. Besides, FSW promotes grain refinement, thus improving mechanical performance.

FSW of copper and its alloys has been reported in the literature by a number of authors, asserting its weldability. The effects of welding parameters have been studied in a wide range of rotational speeds, welding speeds, axial loads, and thicknesses for pure copper [13-17]. However, during cooling grain growth may take place depending on the parameters employed, which may cause grain coarsening and softening. Researchers demonstrated that accelerating the cooling rate could successfully result in higher hardness and better tensile properties in the stir zone (SZ) [18-19]. Another possibility is to use large axial forces and very low heat input parameters [17].

Available literature describes mostly plate butt-welding. In this work, circumferential lap-welding was performed on bulk cylinders of CuCrZr alloy covered by pure copper sleeves. The FE components were then machined from the welded parts, which already contained the cooling water circuit. Welding procedure was validated by means of microstructural characterization, hardness measurement, and leak and hydrostatic pressure tests. It is also presented the final version of the component with its support.

EXPERIMENTAL PROCEDURE

As quoted before, it is instrumental that the material preserves its mechanical resistance even when exposed to high power densities. Seeing this constraint, some common (GTAW and oxy-fuel) and unconventional techniques (FSW and sealing by mechanical clamping and deformation) were evaluated. The most promising one, given the temperature constraint and the results on the preliminary tests, was the FSW method.

Friction stir welding was performed in a dedicated TTI machine, model RM-1 at the Brazilian Nanotechnology National Laboratory (LNNano/CNPEM). FSW tools were machined in AISI H13 steel. A turn-table was used to perform circumferential welds. The welding parameters and their range of analysis were as follows: tool rotational speed (from 400 to 1500 rpm); tool travel speed (from 20 to 100 mm/min); lateral tool offset (from 1 to 3 mm); and power input (from 2.5 to 4.0 kW).

A solid machined round bar of CuCrZr alloy, with a diameter of 73 mm was covered by a pure copper sleeve with 1,6 mm in thickness (C122 alloy). It can be noticed that, at this point, the copper sleeve was already silver-welded on copper tubes (for was inlet and outlet) and on CuCrZr bushes (for attachment of temperature sensors and alignment targets). Also, there was an helicoidal water chamber machined on the CuCrZr bar (for cooling purposes). The welding process and the welded component can be seen on Figure 1.

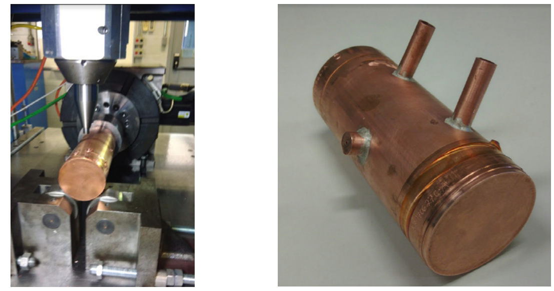
a) b)

Figure 1: (a) Friction Stir Welding (FSW) on the CuCrZr component. (b) FSW-welded component.

Joints subjected to conventional metallographic procedure were cut transverse to the welding direction for microscopy and microhardness testing.

The hydrostatic pressure test was conducted by connecting the component to a water pump. Firstly, all the interfaces between the water chamber (path inside the component through which the water flows) and the air were closed, except for two: one used to purge the air from the system and another one to pressure the inner side of the component. After the air was purged out, only one connection was left open. Thus, that valve was used to increase the water pressure inside the component until it reached a desirable level. By standards, the pressure needs to be at least 50% greater than the operating pressure of the component. Finally, the last connection valve was closed and then the component was maintained at constant hydrostatic pressure for at least two hours.

The leak test was included as a manner to keep track of the component tightness along its manufacture chain. The main advantage of this test is that it does not damage the component and can be easily done on single parts or welded components, being a comparison parameter of the product quality after a process. It should be noticed that it is not a substitute for the water pressure test, once a helium leakage does not suggest a water leakage (the size of the molecules is significantly different) and the hydrostatic pressure test is more aggressive (because of the higher differential pressure).

RESULTS AND DISCUSSION

Firstly, it should be considered that a metrology facility [20] has been built in order to create a controlled environment for the verification and validation of the manufactured components. The tests described on the current study were also conducted inside this building.

As for microstructure analysis the component must be destroyed, only leak and water pressure tests are done to guarantee the operational quality of a manufactured component. All the Sirius components that were already manufactured were approved for values of leak rate below $5 \cdot 10^{-10} \left[\frac{mbar}{L \cdot s}\right]$. Hydrostatic pressure tests were conducted during, at least, 3 hours under pressures greater than 15 bar. The validated components were approved on this test also. The operational pressure of those components will be 8 bar.

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It can be seen on Figure 2 an optical microscopy of the welded region. The sample was extracted of a prototype welded by FSW using the same materials and conditions. On the image is shown the copper sleeve (at the top of the figure), the external diameter of the CuCrZr part and the joint region. There is also a small gap between the parts, which is partly originated by the fine mechanical adjustment determined for the assembly and partly by the large forces involved on the welding process.

Furthermore, on Figure 3 there is a detail of the interface between the stir zone and the base material. On the stir zone, due to the magnitude of the forces and heat involved on the joint process, the grain size was significantly reduced (as intended for better mechanical properties). On other hand, on the bulk zone it is possible to distinguish the grain contours.

Figure 4 was originated by a micro-hardness analysis on the region illustrated on Figure 2. By that it is possible to notice: the different materials (a soft copper sleeve on the top and a harder CuCrZr bulk on the bottom); the hardening caused by the grain refinement on the welding zone; and the annealing caused to the soft copper on the sides of the joint region (shown as the dark-blue zone). It is also possible to conclude that the temperatures reached on the process had only local effects.

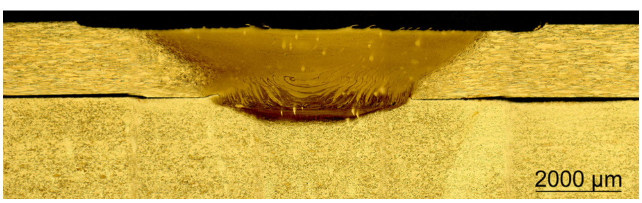


Figure 2: Cross-section image of the welded region done by optical microscopy.

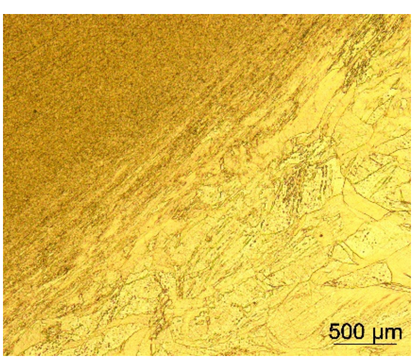


Figure 3: Microstructure of a FSW welded region.

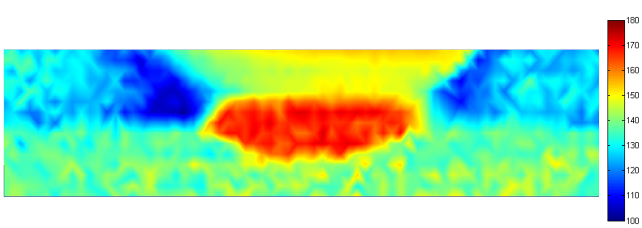
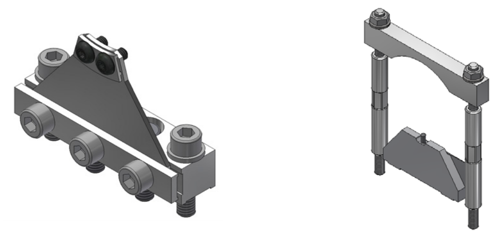


Figure 4: Microhardness analysis of a FSW welded region (in units of micro-Vickers).

Regarding the component support, as can be seen on Figure 5: one of its sides is used as a stiff reference to guarantee the alignment of the component's aperture. Pre-load and a guide pin are used to create a fixed reference for the component. On the other side it is used an elastic support, which is deformable in order to accommodate possible machining misalignments while still constraining the necessary degrees of freedom. To achieve this behaviour, a thin sheet is applied as a flexure.

Finally, on Figure 6 it is presented the final version of the welded component, including temperature sensors, support and alignment features.



a) b)

Figure 5: Front-End components support. In (a) it is represented the elastic support and in (b) the reference support.

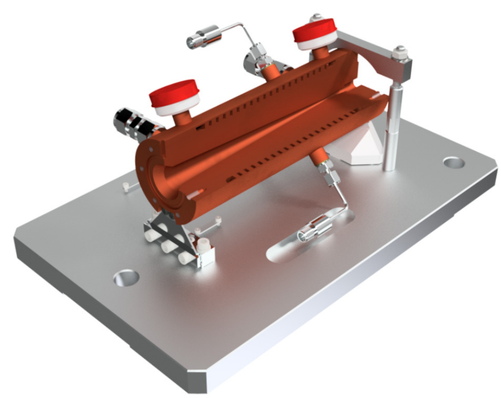


Figure 6: Final component assembly of the fixed mask for undulator-beamline Front-Ends.

NEXT STEPS

Once the integrated project, regarding the manufacture chain and the component's operational conditions, is already well developed, the next challenges are going to be related to the fiducialization and alignment in the beamline.

CONCLUSIONS

By the study conducted it is possible to observe that there are still available points of optimization in the Sirius power absorbers, but the level of quality reached for both the component and its manufacture chain is now better and more robust. The welding was already done for the first bunch of Front-End elements and the leak and hydrostatic pressure tests were conducted. They are going to be installed latter this year.

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