ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-WEPMN008

MATERAL TEST OF PROTON BEAM WINDOW FOR CSNS

Haijing Wang#, Donghui Zhu, Huamin Qu, Ling Kang, Lei Wu
IHEP, Beijing, China

Abstract

The proton beam window (PBW) is one of the key devices of China Spallation Neutron Source (CSNS). Material selection of PBW is of particular importance. A5083-O was chosen in the previous work, and recently the material tests are done. The tests show the material has good microstructure, physical and mechanical performance. Creep lifetime is analyzed based on the creep test. All the experiments show the selected material is qualified.

INTRODUCTION

The PBW is one of the key devices of CSNS. It is located at the boundary of transport line and target, separating the high vacuum in the accelerator and helium atmosphere in the Helium Vessel. The material selection of the window is important. The heat dissipation, mechanical properties, scattering effect on proton beam, lifetime and so on should be considered. A single-double layered PBW was proposed for CSNS with the beam power of 100 kW in our previous work. A5083-O was chosen as the PBW material mainly for its low effect on beam, and allowable thermal and mechanical properties [1].

As the window is important to the CSNS project, the material should be tested before the window manufactured. The PBW suffers thermal increase because of the energy deposition. And under the comprehensive effects of temperature, boundary fixation, pressure from helium and cooling water and so on, there will be stress and deformation of the window. Generally, the creep temperature of materials is about 30-50% of melting temperature [2]. The working temperature of the window is 73 °C, about the 40% of the melting temperature, then the creep effect should be verified. The material tests contain chemical components, microstructure, physical properties, tensile experiments and creep experiments.

CHEMICAL COMPONENTS

Chemical components are tested by optical emission spectrometric analysis method. There are three samples from different locations and plates. Compared with the standards of GB/T 7999-2007, the materials are all up to standard.

MICROSTRUCTURE

The microstructure is inspected by metalloscope. The results show that the material microstructure is fiber texture. The procedure should be hot rolling and then homogenizing annealing. The plates are annealed completely, and have no defects such as slag inclusion, air hole or loosen. Figure 1 presents the microstructure.

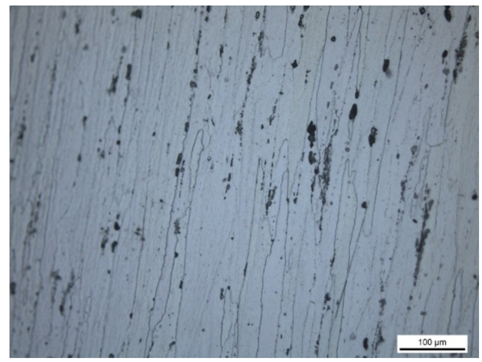

Figure 1: Microstructure (200×).

PHYSICAL PROPERTIES

The physical properties tested conclude density, coefficient of thermal conductivity, coefficient of thermal expansion, Poisson's ratio, modulus of elasticity and heat capacity, of which the results are showed in Table 1. All these items are tested from three samples from different locations and plates. And the results are the average values of each items separately. All these parameters will affect the thermal and structural conditions of the window, and are necessary for finite element analysis by ANSYS.

Table 1: Results of Physical Properties

Item	Results
Density ($g \cdot cm^{-3}$)	2.66
Coefficient of thermal conductivity ($W \cdot (m \cdot °C)^{-1}$)	119.7
Coefficient of thermal expansion ($10^{-6} \cdot °C^{-1}$)	24.2
Poisson's ratio	0.32
Modulus of elasticity (GPa)	70.3
Heat capacity ($J \cdot (kg \cdot °C)^{-1}$)	901

TENSILE PROPERTIES

The tensile properties should be estimated to make sure the window can work normally. There are two types of tensile experiments, at room temperature and high temperature separately.

#wanghaijing@ihep.ac.cn

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For the room temperature tensile experiment, the sample is broken by tensile force which is increasing evenly. For the high temperature tensile experiment, the sample is broken by the increasing tensile force in the high temperature hearth after 15 minutes heat preservation.

For every case, there are three samples from different locations and plates, and the results are the average values, which are listed in Table 2.

Table 2: Results of Tensile Tests

Temperature (°C)	Tensile strength (MPa)	Yielding strength (MPa)	Elongation (%)
25	285.8	164.3	27.0
100	297.5	150.3	36.3
150	231.0	138.3	48.4
200	194.5	128.7	55.8
250	162.9	104.0	73.2

The experiments present that the tensile properties of the material are up to the properties of annealed aluminium A5083-O. Due to insensitivity at low temperature and difference between each sample, the tensile strength is a little lower at 25 °C than that at 100 °C.

Take the tests at 25 °C and 100 °C for examples, the alloy presents the typical ductile fracture. So the Von Mises yield criterion should be used. There are lots of dimples at the fracture cross sections. And the character becomes more significant with the temperature increase. Figure 2 and Figure 3 present the tensile curve and scanning at fracture cross sections.

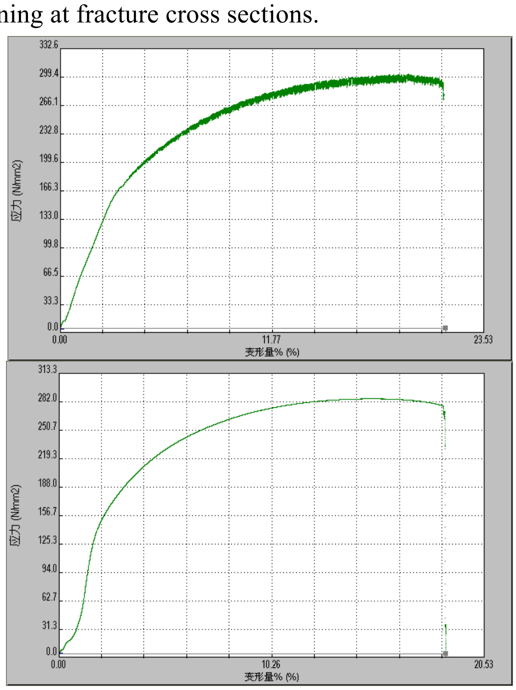

Figure 2: Tensile curve (U: at 25 °C; D: at 100 °C).

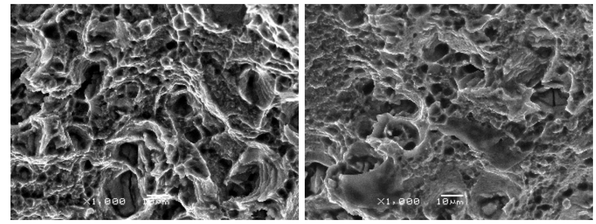

Figure 3: Scanning at fracture cross sections (U: at 25 °C; D: at 100 °C).

CREEP TEST

Creep is the tendency of deformation when exposed to temperature, structural load and time. It was first proposed by Andrade in 1910 [3]. The operating temperature of PBW is 73 °C, about 40% of the melting temperature of A5083-O, at the creep temperature generally considered. But there was no effective data available about the creep of A5083-O. Based on this, the creep properties are experimented.

The middle of the PBW where the highest temperature located at is cylindrical shaped with a thickness of 2 mm. So the rectangular sample with the thickness of 1.5 mm is chosen rather than a round one. The sample is shown in Figure 4.

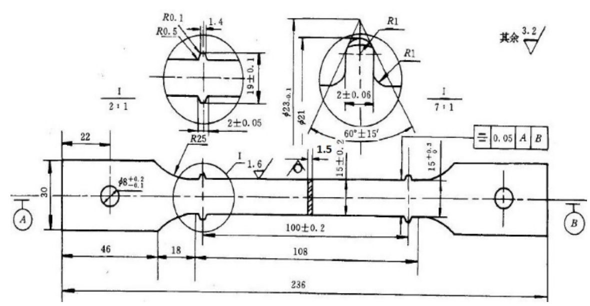

Figure 4: Sample dimensions for creep experiment.

There are 11 samples tested, and 8 of them are effective. The results are presented in Table 3. The creep curves at different temperature are shown in Figure 5. From the results we can see that the creep at 100 °C belongs to the low temperature creep, while the one at 200 °C belongs to the high temperature creep. As the temperature and stress of the PBW is relatively low, the creep is stable, that is to say, there is an equilibrium between work-hardening rate from deformation and restore rate from temperature. The elongation is linear to time, which can be described as Eq. 1.

$$\varepsilon = \varepsilon_0 + \dot{\varepsilon}\, t\,. \qquad (1)$$

The relationship at 100 °C and 60 MPa is described as Eq. 2, which can be obtained from Figure 6.

$$\varepsilon = 5.87053\times10^{-4} + 2.19322\times10^{-7} t. \qquad (2)$$

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Table 3: Results of Creep Tests

Temperature (°C)	No. of sample	Stress (MPa)	Time (h)	Elongation (%)	Steady creep rate (s^{-1})	Remarks
100	1-1	60	1000	0.075	6.09×10^{-11}	No fracture
	1-2	80	490	0.123	8.35×10^{-11}	No fracture
	2-1	130	498	0.177	1.60×10^{-10}	No fracture
150	1-3	80	450	0.138	2.15×10^{-10}	No fracture
	2-2	120	270	0.422	2.05×10^{-9}	No fracture
200	1-4	60	190	10.891	1.01×10^{-7}	No fracture, significant necking, elongation reaches the measure range of extensometer
	2-3	80	74	9.830	3.52×10^{-7}	
	2-4	100	35	10.005	6.19×10^{-7}	Fractured

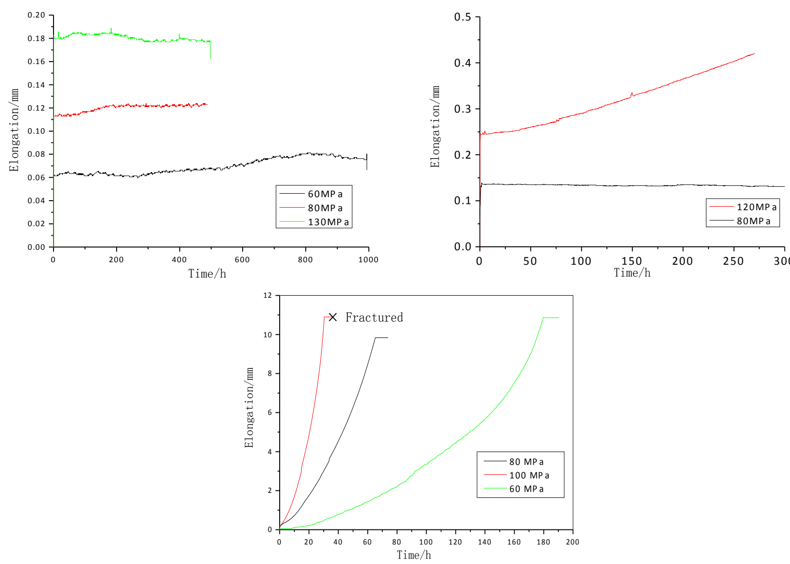

Figure 5: Creep curves (L: at 100 °C; M: at 150 °C; R: at 200 °C).

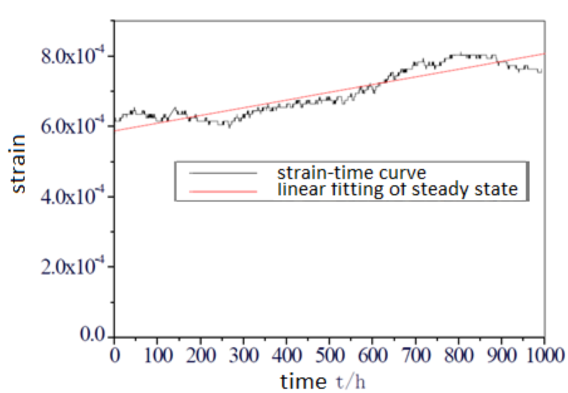

Figure 6: Linear fitting for creep curve at 100 °C and 60 MPa.

According to Equation 2, the elongation is 0.65% in 3 years, which has slight affection on the PBW. The PBW is safe under designed operation condition.

The CSNS is designed to have the upgrade capability to 500kW, and there may be a medium period of 200kW. For the beam power of 200 kW, if the same PBW structure is applied, the temperature will be higher than 100 °C and the stress will be about 100MPa, there will has danger. Then new structure or materials should be considered, also for the beam power of 500 kW.

CONCLUSION

The detailed tests of the PBW material are done for safe consideration. The material is well annealed and has good microstructure. The tensile and creep experiments demonstrate there is no danger of the PBW for CSNS.

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