Damage tests for electron beam dumper materials

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Abstract

We are promoting damage tests for several kinds of electron beam dumper materials, such as aluminum A1070 and stainless steel SUS316L, at SPring-8, Storage Ring (SR). 8 layers of $6^H \times 25^W \times 5^T$ mm^3 sample pieces for each dumper material were assembled and irradiated with 8 GeV electron beam simulating a real beam abort condition.
Surfaces and microscopic profiles for the pieces' cut planes were observed for each material.
Furthermore, dose profiles are analyzed and compared via a Monte Carlo calculation using Geant4 assuming a realistic beam abort condition for each dumper material.

INTRODUCTION

Historical background

A vacuum leakage was happened in October 2003 at an injection chamber which was installed in the injection section as shown in Figure 1. When the stored electrons in the SR should be aborted by the safety interlock system of SPring-8, RF power to all RF cavities would be turned off because the stored electrons have to be aborted as soon as possible. The stored electron beam gradually lost its energy irradiating synchrotron radiation and eventually hit and melted down an inner 0.7 mm thick stainless steel wall of the vacuum chamber as shown in Figure 2[1].

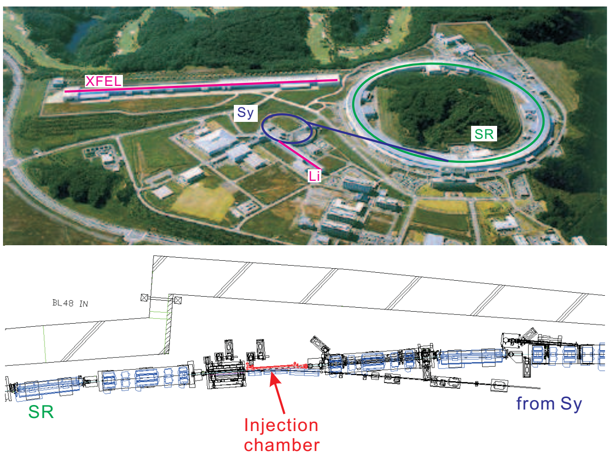

Figure 1: Bird's eye view of SPring-8 (*upper*) and schematics of the injection section in the SR (*lower*).

In Fig. 2 (*left*), a crack line could be observed on 0.7 mm thick SUS wall, which was caused by heat load associated with the discarded electron beam, and Fig. 2 (*right*) shows microscopic etched cross section of the melted part which indicated by a solid circle in Fig. 2 (*left*).

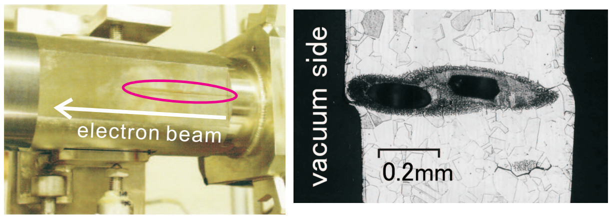

Figure 2: Schematic view of the downstream injection chamber (*left*) and a microscopic cross section of the chamber wall at the broken part (*right*) indicated by a solid circle in *left* figure.

In the SPring-8 SR, vertical beam size is small as $\sim$10 μm (σ), in order to provide extremely brilliant synchrotron radiation, thus heat load in the wall material is expected to be local and quite high.

Goal

According to all the above backgrounds, we plan to install the beam dumper prior to the upstream aluminum injection chamber in order that aborted electron beams hit it selectively.
Therefore, we assembled sample pieces with materials; aluminum and stainless steel, and promoted and compared damage tests exposing 8 GeV electron beam in the SPring-8 SR for proper dumper material selection.
Numerical heat load calculation by a Monte Carlo (Geant4[2]) code is also proceeded in parallel to these above tests to discuss the experimental results.

DAMAGE TESTS

Sample dumper pieces were assembled and mounted on an aluminum (A5052) base plate as shown in Figure 3 (*left*). The same material pieces were mounted on the base plate as one test unit and we prepared two units for A1020 and SUS316L dumper materials.
The test units were installed into the exposure chamber in the straight section and center of the unit was adjusted on the medium plane of the electron beam as shown in Figure 3 (*right*). The beam hit and passed through each dumper

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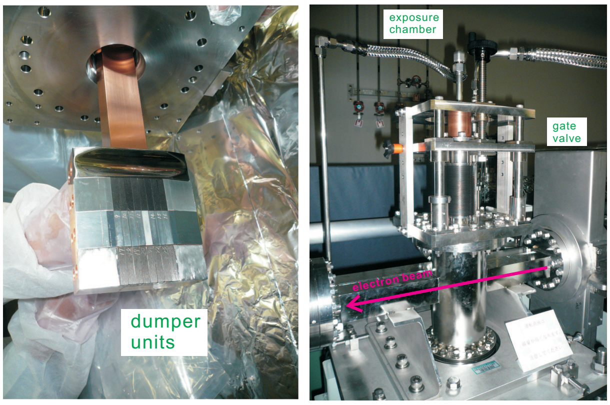

Figure 3: Overview of the mounted dumper units (*left*) and the exposure chamber on the electron beam path (*right*).

with total four different local dump orbits (Run 1 $\sim$ 4). We observed macroscopic views of each dumper and microscopic etched cross sections of individual pieces as shown in Figure 4, in order to investigate heat input histories in dumpers.

In Fig. 4, beams pass through from left to right and measured sizes of degeneration in each piece are also described. For each dumper, we can recognize hollows and traces of melt and re-congelation by heat load. In microscopic etched cross sections, the deformation sizes in each SUS316L piece grow up in first 4 or 5 pieces, then moderately decrease, while deformation size is averagely equivalent in all A1070 pieces.

ANALYSIS AND DISCUSSION

Energy deposit in the dumper, *i.e.* dose profile was calculated and compared by a cascade simulation by Geant4 for A1070 and SUS316L. Overviews of the calculated cascade processes for each material are described in Figure 5.

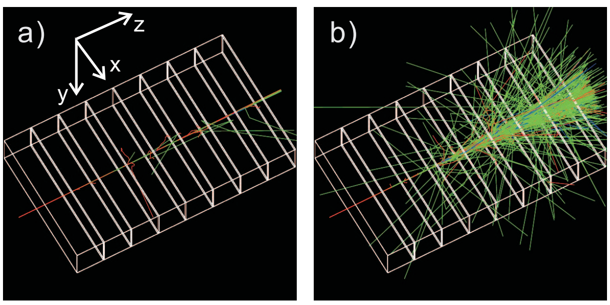

Figure 5: Schematics of the cascade calculations by Geant4 for A1070 (*left*) and SUS316L (*right*) dumpers. Incident electron beam (*red-online*, 5 events for each) passes along z-axis. *Green-online* and *blue-online* represent cascade electrons and gamma-rays, respectively. Coordinate definition in the calculation is also represented in the figure.

In this calculation, dumpers are displaced in a world volume and 0.1 mm on a side of mesh is defined in each piece. Incident electron with 8 GeV passes through center of the dumper normal to the $6^H \times 25^W$ mm^2 plane.
Once electron breaks into the dumper, electro-magnetic (EM) shower, which is associated with e$^+$ / e$^-$ pair creation by gamma-rays via bremsstrahlung, is induced and developed with multiple scattering in the dumper. Eventually, electron energy is lost by ionization process.

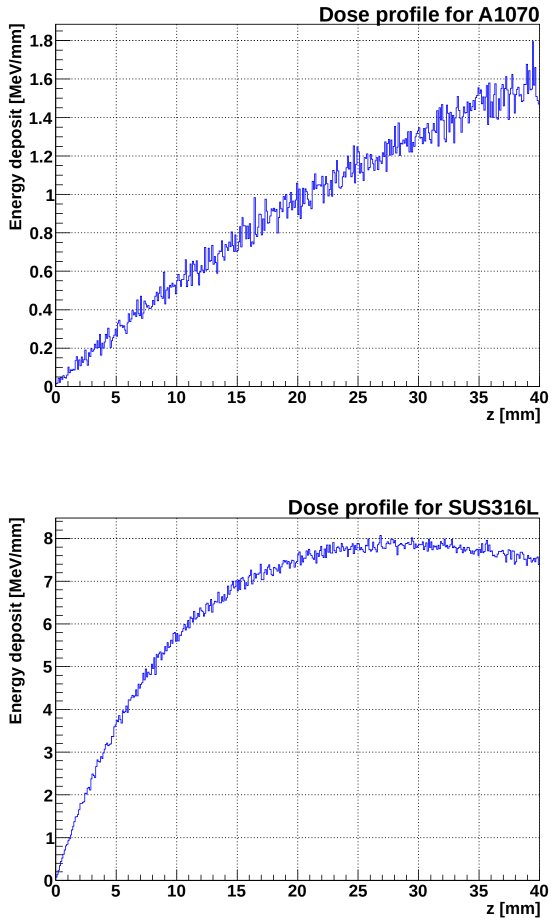

Figure 6: Calculated dose profiles along z-axis (dumper thickness) for A1070 (*upper*) and SUS316L (*lower*) per electron.

Figure 6 represents and compares calculated dose profiles along z-axis (dumper thickness) for A1070 (*upper*) and SUS316L (*lower*). Integrated energy deposit in A1070 and SUS316L dumpers are $\sim$350 and $\sim$2550 MeV, respectively.
Especially, the energy deposit in SUS316L dumper is evaluated to be much higher due to higher Z^2 comparing to A1070, and reaches a maximum around 25 $\sim$ 30 mm. This result explains quantitative trend for measured SUS316L deformation growth by microscopic observations as shown in Fig. 4 (*lower*).

We are promoting further trials to evaluate more realistic heat loads and responses in dumpers.

SUMMARY

We are conducting damage tests for A1070 and SUS316L electron beam dumpers in the SPring-8 SR reconstructing a real beam abort condition with 8 GeV of electron beam.
Surfaces and microscopic profiles of the dumper cross sections were observed and compared.
In parallel, dose profiles for two dumpers by a realistic cascade simulation are proceeded by a Monte Carlo (Geant4).
The energy deposit in SUS316L is found to be much higher according to its higher Z^2 rather than A1070 and reaches a maximum around 25 $\sim$ 30 mm along dumper thickness. The calculation explains quantitative trend for measured SUS316L deformation growth by microscopic observations.
Further efforts to evaluate more realistic heat loads and responses in dumpers are promoted.

REFERENCES

[1] T. Yorita *et.al.*, J. Vac. Soc. Jpn. **48** (2005) 7.

[2] `http://geant4.web.cern.ch`.

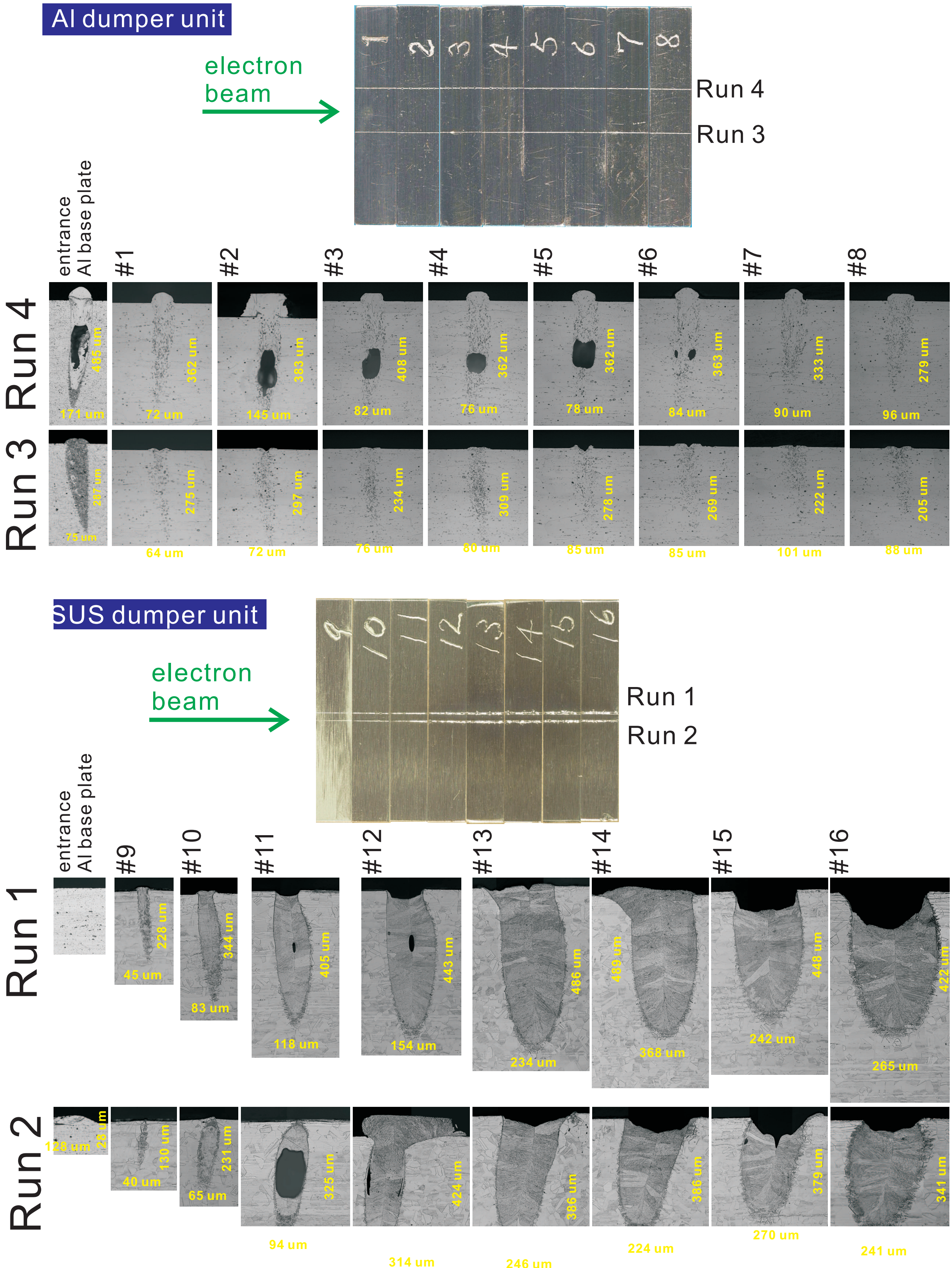

Figure 4: Top views of the damaged test units and microscopic cross sections of each sample piece for A1070 (*upper*) and SUS316L (*lower*). On the surfaces of each, two scratch lines (Run 1 $\sim$ 4) are recognized which indicate aborted electron trajectories.