

Long-Term High-Velocity Erosion of Glidcop in DI Water

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Abstract

Alumina dispersion-strengthened copper, known by the trade name of Glidcop, is used extensively for high-heat-load components of third-generation light sources. Unlike oxygen-free copper, Glidcop retains high mechanical strength at elevated temperatures and can be brazed without an appreciable loss of strength.

In high-heat-load applications the maximum temperature rise can be reduced by increasing water velocity in the cooling channels, which effectively increases the heat transfer film coefficient. However, increasing water velocity beyond a certain limit can result in unacceptable levels of erosion at the channel surfaces. Long-term tests are underway at the Advanced Photon Source (APS) to establish erosion rates for Glidcop for different deionized (DI) water velocities. This paper presents test results from 12 samples subjected to DI water velocities ranging from 1.5 m/s to 9.1 m/s for a period of two years.

1. Introduction

Glidcop® is a dispersion-strengthened form of copper containing a small quantity (0.15% – 0.25% by weight) of fine alumina particles in the copper matrix [1]. The mechanical strength properties of Glidcop are superior to that of oxygen-free copper, especially at elevated temperatures. It has been a material of choice for high-heat-load components, such as absorbers, masks, and shutters, in third-generation light sources. In addition, cooling enhancement by channel inserts has been used in some of these components to handle the high heat flux. The channel inserts, consisting of wire coils, twisted tapes, or wire meshes, increase the effective heat transfer film coefficient. A more direct and convenient way of increasing the film coefficient is to simply increase the water velocity in the channels. The increase in velocity can, however, lead to mechanical erosion and thinning of the channels' walls.

An experiment is currently in progress at the Advanced Photon Source (APS) to study the long-term erosion of Glidcop Al-15 as a function of water velocity. The experiment consists of 12 Glidcop channels subjected to different water flow rates, ranging from 1.5 m/s to 9.1 m/s. The experimental results collected since the start of the experiment in 2002 are presented in the following sections.

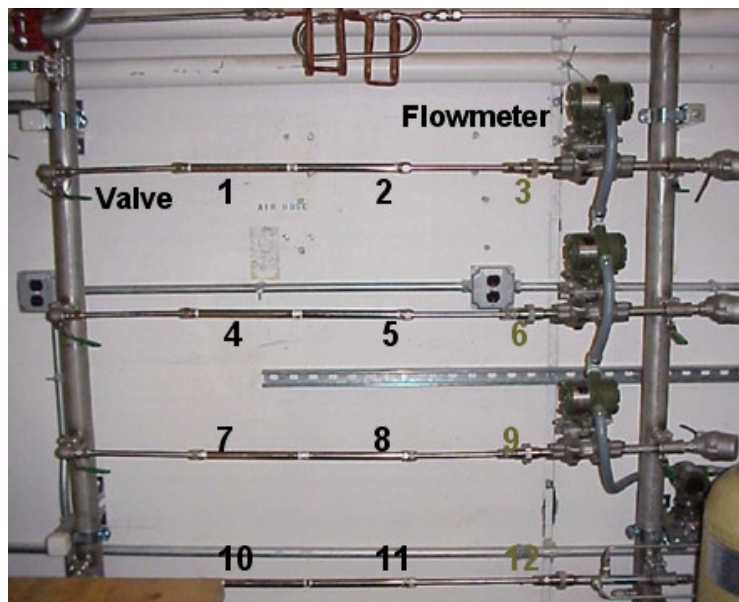
2. Experimental Setup

The experimental setup to study high-velocity erosion of Glidcop is depicted in Fig. 1. As shown in Fig. 1(a), the test stand consists of 12 Glidcop erosion samples arranged in four groups with three samples in each group. The test sample geometry is shown in Fig. 1(b). Different flow rates are maintained in each group by flow-regulating valves on both supply and return sides. The valves also allow removal of a sample in the group without affecting water flow in the other groups. Deionized water for the experiment is piped in from one of the secondary water circuits of the APS storage ring. Temperature and resistivity of the deionized water are continuously monitored and maintained at 25.6°C and approximately 8 MO.cm, respectively.

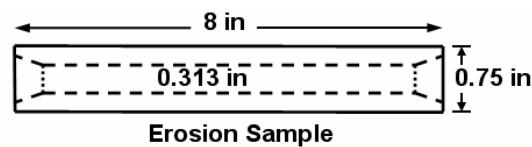
Water flows are measured with Yokogawa (model EJA115) flowmeters. Flowmeters have been monitored and valves have been adjusted periodically to maintain preset flows in the four groups. Initially the flows were set at 4.6 m/s for samples 1, 2, and 3 (identified by their locations in Fig. 1); 6.1 m/s for samples 4, 5, and 6; 7.6 m/s for samples 7, 8, and 9; and 9.1 m/s for samples 10, 11, and 12.

After running the experiment for the first six months and analyzing the results, it was decided to reduce the flow in samples 4 and 5 to 1.5 m/s to include flow in a lower range. The velocities also fluctuated by up to 10% because of changes in the water system pressure.

Erosions of the water channels are evaluated by measuring and weighing the samples as well as by measuring the diameters of the water channels. The samples are weighed in an air-conditioned room with a commercial weight scale (O’Haus Explorer, Model E16130) that has a resolution of 0.001gm and repeatability of 0.0015 gm in the weight range of the samples. Glass panels surrounding the samples isolate them from any air currents. Before usage, the scale is calibrated with a known 500-gm weight. Internal diameters of samples 6 and 8 are measured by a coordinate measurement machine, Brown & Sharp, Model X-Cel 7-10-7, with a resolution of 0.5 μm and repeatability of 3.5 μm).



(a)



(b)

Fig. 1: Experimental setup for long-term high-velocity erosion tests:
(a) test stand, (b) Glidcop erosion sample.

3. Test Results

Initial weights of the samples ranged from 371.82 gm to 382.27 gm because of manufacturing tolerances. After running the experiment for six months, the samples 3, 6, 9, and 12 were removed and weighed. All samples showed minimal weight increases of less than 0.01% (0.006 – 0.007%), which was attributed to copper oxides on the channels’ surfaces. After running the experiment for another 1.5 years, samples 2, 5, 8, and 11 were removed and weighed. The results, presented in Table 1, show weight increases of these samples were in the range of 0.01 to 0.03%. CMM measurements on samples 6 and 8 showed essentially no change in the internal diameter of sample 6 and a reduction of 1.4% in the internal diameter of sample 8.

Table 1: Weight Changes in the Glidcop Erosion Samples

Sample location	Nominal flow rate (m/s)	Exposure time to DI water	Increase in weight (%)
2	4.6	2 years	0.01
5	6.1	0.5 years	0.02
5	1.5	1.5 years	
8	7.6	2 years	0.01
11	9.1	2 years	0.03

The four samples 2, 5, 8, and 11 were cut in half longitudinally for visual inspection. Figure 2 shows copper oxides (Cu_2O and CuO) on the channel surfaces of the Glidcop samples 2 and 5 after flow exposure of two years. The brown color on sample 2 is indicative of a high percentage of cuprous oxide, Cu_2O , which also appears to be dominant in samples 8 and 11 with higher velocities. The darker cupric oxide, CuO , appears on sample 5, which was exposed to a lower flow velocity.

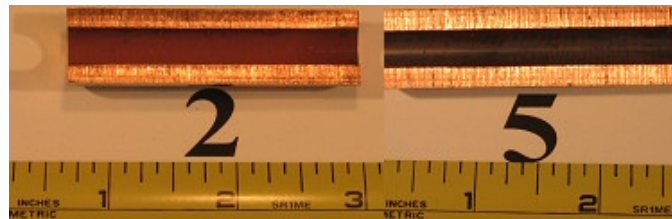


Fig. 2: Channel surfaces of Glidcop erosion samples after two years.

3.1 Macro- and Microstructural Analysis

Scanning electron microscopy (SEM) was performed on the surface of the longitudinally cut samples. All channel surfaces were originally smooth as shown in Fig. 3(a). Once exposed to the water flow, the surfaces were covered with copper oxides with patterns indicative of the flow direction, as depicted in Fig. 3(b).

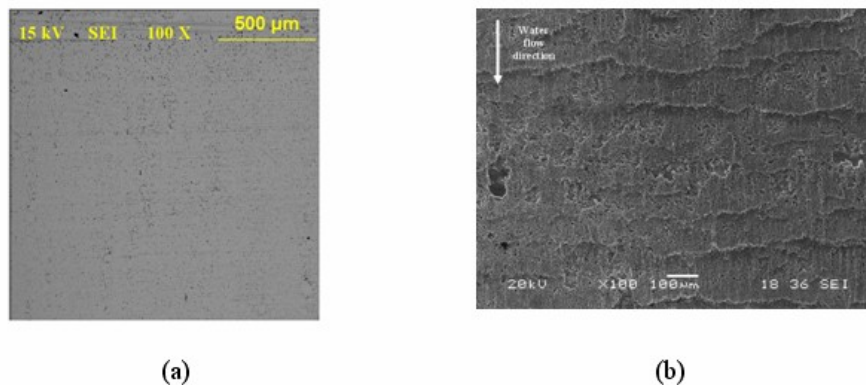


Fig. 3: SEM micrographs: (a) typical channel surface in the original condition, (b) channel surface of the sample at location 8 after two years for flow exposure.

Sample 5, which had the lowest flow rate of 1.5 m/s for 1.5 years, had a very different macro and microstructural appearance from that of other samples. The micrographs revealed a top layer consisting of aggregates of CuO , on a comparatively uniform substrate of Cu_2O as shown in Figs. 4(a) and (b).

However, an x-ray diffraction (XRD) analysis on this sample showed presence of only Cu_2O indicating a very thin layer of CuO on top of a thicker Cu_2O layer.

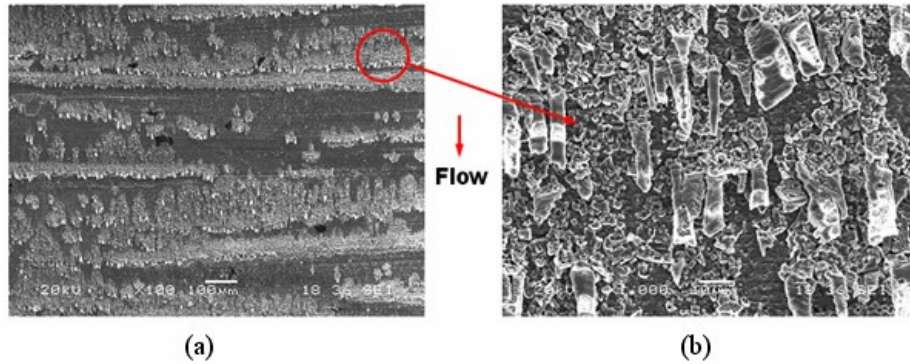


Figure 4: SEM micrographs of the water channel of sample 5: (a) CuO aggregates on top of Cu_2O substrate, (b) CuO aggregates at a higher magnification (x1000).

The oxide layers appear to get rougher with increasing flow velocity. This is confirmed by the SEM micrographs taken after two years of flow exposure as shown in Fig. 5. The oxide layer on the sample 2 exposed to 4.6 m/s flow velocity, Fig. 5(a), has a less granular structure compared to that of sample 11 exposed to 9.1 m/s flow velocity, Fig. 5(b)

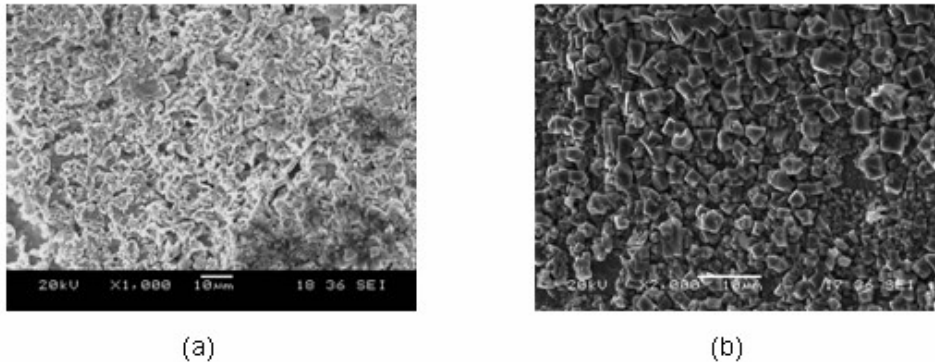


Figure 5: SEM micrographs of water channels after 2 years: (a) sample 2, flow velocity 4.6 m/s, (b) sample 11, flow velocity 9.1 m/s.

4. Discussion and Conclusions

An increase in weight was observed in all Glidcop samples due to an oxide layer of primarily cuprous oxide, Cu_2O . The oxide layer, whose thickness does not have a good correlation with velocity, protects the channel's surface from mechanical erosion. Because of a lack of oxide deposits on the connecting stainless tubes of the same diameter, it is surmised that the oxide layer is formed primarily by surface oxidation rather than from the deposition of oxide formed elsewhere in the water system. The strong adhesion of the oxide layer to the channel's surface also points in that direction.

While no mechanical erosion has been observed even at a velocity of 9.1 m/s, there is usually no significant gain in the cooling efficiency of high-heat-load components at velocities higher than 5 to 6 m/s. With the water velocity in this range it is easy to achieve a heat transfer film coefficient between 0.015 to 0.02 $\text{W}/\text{mm}^2 \text{ } ^\circ\text{C}$. The peak surface temperature as a function of the film coefficient, plotted in Fig. 6 from a finite element analysis of an APS mask, is typical of x-ray absorbers, masks, and shutters.

The figure shows a diminishing return for higher values of the film coefficient in terms of decrease in the peak surface temperature.

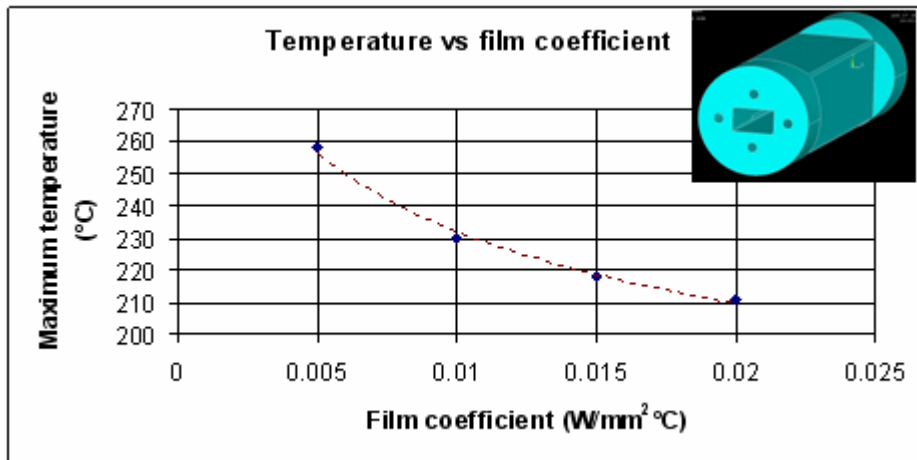


Fig. 6: Peak surface temperature versus heat transfer film coefficient for an APS mask.

Using higher velocities in smooth channels rather than channel inserts for cooling efficiency not only leads to simple and cost-effective designs but also improved reliability. There is considerably less pressure drop in a smooth channel for the same value of film coefficient [2], which allows several high-heat-load components to be included in a single flow circuit. The cost of flow instrumentation is, therefore, reduced proportionately. With a few number of flow instruments, the reliability is also improved.

5. Acknowledgments

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6. References

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