Mechanical Testing of Alternative Brazing Materials for CANDU® Fuel Bundles

K.N.Potter[1*], G.A. Ferrier[2]and E.C. Corcoran[2]
[1]Queen's University, Kingston, Ontario, Canada, *k.potter@queensu.ca
[2] Royal Military College of Canada, Kingston, Ontario, Canada

An Undergraduate Level Submission

Summary

Currently, a beryllium brazing alloy is used to connect appendages to CANDU® fuel bundle elements. However, because of a possible reduction of the occupational limit on airborne beryllium particulates, several alternative materials have been proposed. Appendages brazed using alternative materials must be tested thoroughly to ensure stability under the forces typically encountered during a refuelling operation. Consequently, an impact testing method was developed at the Royal Military College of Canada to compare the impact strengths of bearing pad joints brazed with beryllium and alternative materials.

1. Introduction

Canadian nuclear fuel manufacturers assemble fuel element bundles using a beryllium (Be) brazing alloy. Unfortunately, the process of manufacturing these brazes can create airborne Beparticles, which are a potential health hazard to workers. Currently, the time-weighted average (TWA) limit for Beis set at 2.0μg m^{-3} of total airborne particulates [1]. However, the Ontario Ministry of Labour is expected to lower this limit to 0.05 μg m^{-3} based on the 2001 recommendation of theAmerican Conference of Governmental Industrial Hygienists [2,3].The lower TWA level may severely limit or preclude the use of Be in CANDU® fuel manufacturing, necessitating a substantial change in the fuel bundle design and manufacturing. Consequently, the Canadian nuclear industry (through a CANDU® Owners' Group (COG) initiative)has elected to take proactive action to determine if replacement-brazing materials can be used to decrease or eliminate airborne beryllium particles within the fuel manufacturing facilities.

One of the attributes required for a successful alternative brazing material is the ability for the brazed joint towithstand the high loading rates encountered during a refuelling operation. Consequently, impact strength is a key parameter that must be tested to determine the suitability of any potential replacement brazing material. The purpose of this project is to develop a standardized testing method for determining the impact strengths of brazed bearing pad joints. Once a testing method has been developed, an impact strength comparison between joints brazed with berylliumand alternative materials will be completed. Data gathered from these tests will be factored into the COG assessment of suitable replacement brazing materials.

2. Development of impact testing method

2.1 Initial research

Existing impact testing methods were researched to determine their suitability for evaluating the impact strengths of brazed joints. Ultimately, the pendulum-based impact test, Figure 1, is most suitable for this project because the energy absorbed by the impacted specimen can be readily measured. During a pendulum-based impact test,a striking hammer at the end of a pendulum arm is raised to a fixed height and subsequently released. Upon achieving a maximum kinetic energy at the bottom of its downswing, the striking hammer impacts the specimen, breaks it, and continues through its upswing. Since the potential energy represents the total energy of the pendulum at its initial and final heights (where the kinetic energy is zero), the corresponding height difference (initial-final) is directly related to the energy absorbed by the specimen.

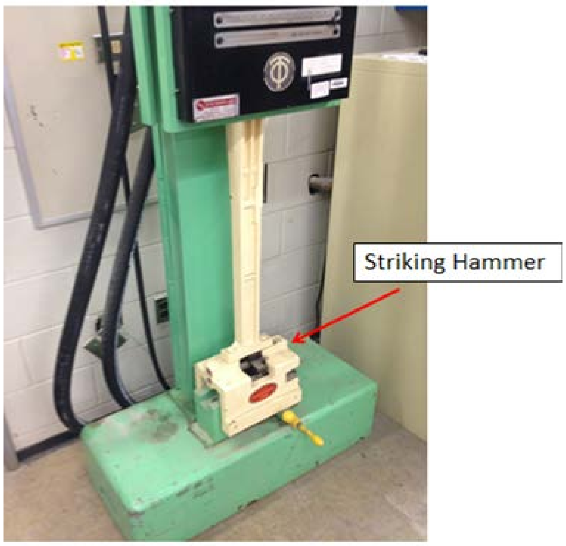
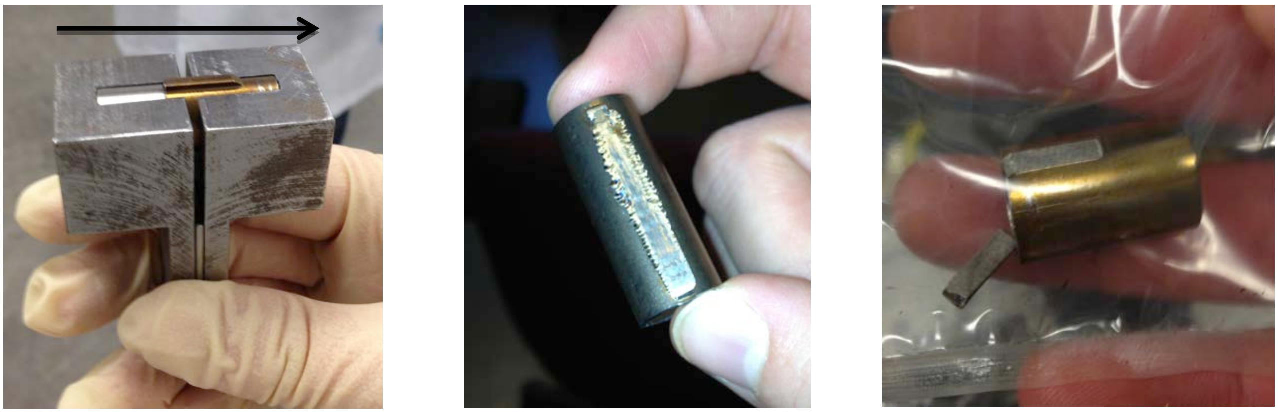


Figure 1-Charpy impacttesting apparatus.

2.2 Modifications to impact testing method

The limited height of the bearing pads necessitated significant modificationsto the standard Charpy impact testing procedure [4].Unlike standard Charpy testing, the developed test was performed on the manufactured joint rather than on a sample of the brazing alloy. This ensured that the test measured the performance of the joint, which depends on important variables (e.g., fillet size and bonded area) that are non-existent in standard alloy samples. In addition, the bearing pads were cut in half and a mandrel was placed inside the cladding tube to prevent deformation during clamping and impact. The specimens were then clamped in a specialized jig in order to allow the striking hammer to impact the bearing pad just above the brazed joint.Finally, the hammer was aligned to impact the flat cut surface of the bearing pad in the direction parallel to the axis of the cladding(Figure 2A).

Initial testing with this apparatus with the full-length bearing pads caused the pad to deform (Figure 2B). Since the brazed joint did not break, the strength of the joint could not be quantified. It was believed that the slight chamfer of the bearing pad caused the striking hammer to ride up over the pad and to deform the sample. Consequently, flat striking surfaces were made by cutting the full-length bearing pad samples into half-length samples(Figure 2A). These half-length samples were cleanly severed from the cladding with minimal deformation (Figure 2C), allowing their impact strengths to be measured.



[A] [B] [C]

Figure 2-[A] Half-length sample in a specialized jig (arrow indicates direction of striking hammer motion), [B] Deformed full bearing pad from an unsuccessful impact test, [C] Fractured bearing pad joint from a successful impact test.

3. Sample Testing and Preliminary Results

The impact testing method was finalized using the sample orientation shown in Figure 2A. The impact energy absorbed by each sample was normalized by the length of the cut sample to account for minor variations in the appendage length.Therefore,values of impact energy absorbed per cm were used for comparison. These tests were performed on 29 standard beryllium-brazed bearing pad joints, and an average impact strength value of 15 ± 5 J cm^{-1} was obtained. The relatively large uncertainty arises because some bearing pads broke very cleanly at thebraze, while others broke with more deformation at the heat affected zone. Thisoccurs because the strengths of the beryllium-brazed joint and the bearing pad are similar. As a result, slight variances in the contact height of the striking hammer may have caused different results between tests of the same sample type. Finally, since results were obtained from two types of Be samples, variations due to sample type contributed to this uncertainty.

Although tests were performed on three types of alternative material brazed joints, it is not yet possible to claim with confidence thatthe Be-brazed joints have similaror different impact strengths than each of the alternatives. This is because of the low number of alternative material samples that have been tested. Consequently, additional impact tests are required on alternative material brazedjoints in order to make astatistically significant comparison to the Be-brazed joints.

4. Conclusion

An impact testing method has been developed to evaluate the impact strengthsof brazed bearing pad joints intended for use in CANDU® reactors. This method has been employed to evaluate and compare the impact strengths of beryllium-brazed joints and alternative material brazed joints. Preliminary impact testing has obtained anabsorbed impact energy value of 15 ± 5 J cm^{-1} forBe-brazed joints. Further testing with anincreased number of samples,for each alternative brazing material, will allow for a statistically significant comparison of the absorbed impact energies.

5. Acknowledgements

The authors acknowledge the financial support of Natural Science and Engineering Research Council of Canada, the CANDU Owners' Group, and University Network of Excellence in Nuclear Engineering for financial support of this research effort. The authors are appreciative of the technical expertise and guidance of Atomic Energy of Canada Limited, Cameco Fuel Manufacturing, GE-Hitachi, Bruce Power, and Ontario Power Generation, especially, F.C. Dimayuga, A. Pant, S. Palleck, T. Onderwater, E. Lu, and T. Daniels.

6. References

[1] "Workplace Beryllium Exposure", Ontario Ministry of Labour, Available at http://www.labour.gov.on.ca/english/hs/pubs/alerts/a21.php

[2] "Occupational Health and Safety Act", Service Ontario e-Laws, Available at http://www.e-laws.gov.on.ca/html/regs/english/elaws_regs_900833_e.htm

[3] "Food and Rural Affairs, Consultation on guidelines for metals and metalloids in ambient air for the protection of human health", Department for Environment, Available at http://uk-air.defra.gov.uk/reports/cat11/0805151602_Metals_and_Metalloids_Report.pdf

[4] "ASTM E23 - 12c Standard Test Methods for Notched Bar Impact Testing of Metallic Materials", American Society for Testing and Materials, Available at http://www.astm.org/Standards/E23.htm