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CLAD VENT SET CUP CLOSURE-WELD-ZONE GRINDING EVALUATION

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SUMMARY

Clad vent set (CVS) cups were ground in the closure-weld zone to reduce the wall-thickness variation created by the cup deep-drawing process. A significantly more uniform wall thickness would be beneficial for the CVS closure-weld operation. The goal was to reduce the average within-cup wall-thickness variation (defined as the range of wall thicknesses in the closure-weld zone) approximately 50% from the Cassini production value of 42 μm. This goal was shown to be achievable but, unfortunately, not with the existing blank and formed cup thicknesses.

INTRODUCTION

Matched pairs of clad vent set (CVS) cups are used to encapsulate individual plutonium dioxide ($^{238}PuO_2$) fuel pellets for the U. S. Department of Energy (Office of Space and National Security Programs) General Purpose Heat Source - Radioisotope Thermoelectric Generator (GPHS-RTG) program. The heat from the radioactive decay of ^{238}Pu is used to produce electrical power thermoelectrically for deep space missions such as the upcoming National Aeronautics and Space Administration Cassini mission to Saturn and the on-going Galileo and Ulysses missions.

Lockheed Martin Energy Research Corp. (Oak Ridge National Laboratory) has completed CVS blank production for the Cassini mission, and cup production is nearly complete by Lockheed Martin Energy Systems, Inc. (Energy Systems) at the Oak Ridge Y-12 Plant. The $^{238}PuO_2$ pellet fabrication and the fueled CVS closure weld (autogenous gas tungsten arc) are performed at the Los Alamos National Laboratory (LANL). Minimizing wall-thickness variations in the closure-weld zone would help to achieve consistency in the closure-weld process.

Ideally, the closure-weld-zone wall thickness should be constant so that the required heat input would be the same at all weld locations. LANL has reported three types of welding anomalies:

1. a step condition (lack of penetration or incomplete consumption of both cup walls) on the inside weld face as a result of thick wall regions in one of the cups;

2. weld-shield fusion as a result of high heat input, thin wall regions, and/or intimate contact between the weld shield and the CVS, and

3. CVS weld-zone bulges/blowouts from high heat input and/or inadequate venting.

A more uniform wall thickness would reduce the need for a heat input high enough to ensure that a step condition is not produced in thick-walled regions. Concomitantly, lowering the heat input would reduce the potential for weld-shield fusion and bulges/blowouts.

The DOP-26 iridium alloy used for CVS cups is very difficult to machine; therefore, key dimensional features are established during the two-draw warm-forming process at Energy Systems. Unfortunately, anisotropy in the forming blanks produces four ears at the open end of each cup. These ears are removed during subsequent fabrication; however, axial and circumferential variations in wall thickness remain in each finished cup. The cup certification requirement is that the wall thickness in the closure-weld zone, defined as the 2.5-mm band at the cup open end, measure from 0.63 to 0.73 mm, inclusive. For this report, cup wall-thickness variation is defined as the range of wall thicknesses in only the closure-weld zone. The average plus or minus one standard deviation for the closure-weld-zone wall-thickness variation (the grand average of the wall thickness ranges of each cup) of the CVS cups produced for the Cassini mission is 42 ± 11 μm.[1] Although this fact indicates that the open-end wall thicknesses are well controlled during forming, reducing this variation by 50% or more potentially would lower the welding heat input requirement and thus improve the consistency of the closure-weld process.

Initial closure-weld-zone grinding work, which involved grinding only on the inner diameter (ID) of bare-formed (experimental) cups, was described earlier.[2] These results were encouraging; however, the authors thought that even better wall-thickness uniformity could (and would have to) be achieved with production-formed cups.

PROCEDURE

Fifteen scrap production cups were resized and then ground (in two setups) in the closure-weld zone to full cleanup on both the ID and the outer diameter (OD) without regard to the minimum wall-thickness requirement. They were ground on the ID using a Dumore Corp. (Mauston, Wisconsin) tool post grinder mounted on a Hardinge Brothers, Inc. (Elmira, N.Y.) tool makers lathe and held with a precision Hardinge step chuck with a tapered nose. In the second set-up they were ground on the OD using the same lathe and a precision Hardinge expanding collet. Aluminum oxide grinding wheels were used to remove about 5.1 to 7.6 μm (about 0.2 to 0.3 mil) each pass. In-process measurements were made using a three-point internal micrometer for the ID and a two-point micrometer for the OD. Each finished cup was inspected using either a Zeiss model UPMC 850 or a Mauser model KMZ-P151210 (both supplied by Carl Zeiss, Inc., Minneapolis,Minnosota) coordinate measuring machine (CMM). Thirty-six inside and outside radii were measured and converted to 18 IDs, ODs and wall thicknesses. The CMM also was used to measure the inside and outside roundnesses. The CMM probe size was 1.5 mm diam. Measurements were made 1.2 mm from the open end of the cup. They started ~5° clockwise from the vent notch and proceeded counterclockwise. The wall thicknesses of the cups also were inspected using a ball micrometer, which is the standard production inspection method.

The same 15 cups were ground again to full cleanup on the ID and OD in one setup instead of two. The cups were held on the outside using the precision Hardinge step chuck with a tapered nose. They were reinspected as has been described.

An additional 15 cups (vent cup assemblies returned from LANL with decontamination covers subsequently removed) were resized and reinspected. The inspection results were used to determine grinding diameter targets to maximize the grinding cleanup without reducing the wall thicknesses below the production certification minimum of 0.63 mm. The diameters selected were 28.45 mm for the ID and 29.77 mm for the OD. Grinding was done in a single setup based on in-process measurements made using a three-point internal micrometer for the ID and a two-point micrometer for the OD. Note, however, that three cups were known before grinding to have thin wall regions below 0.63 mm and that one cup was incorrectly ground to full cleanup on the OD. The postgrinding inspection results were used to determine the suitability of closure-weld-zone grinding for CVS production use. This task was accomplished by statistically summarizing the data from 11 of the cups and qualitatively considering the results from the four "abnormal" cups.

RESULTS AND DISCUSSION

Table 1 contains the averages and standard deviations for the wall-thickness ranges and minimums of the cups ground by different techniques and measured using the production micrometer inspection. It also shows the corresponding percentage of reduction from the Cassini production value, 42 μm, of the average wall-thickness ranges for each grinding technique. These data indicate that the most significant reductions in wall-thickness variation were achieved with the ID/OD grinding to full cleanup in one setup. Unfortunately, the current blank dimensions and cup forming parameters, make it impossible to grind cups to full cleanup in the closure-weld zone and still meet the minimum wall-thickness requirement of 0.63 mm. The data in Table 1 show that ID/OD grinding (in one setup) to target diameters to meet the cup wall- thickness requirement was not successful. The wall-thickness variation was not improved over the Cassini production (no grinding) value. The reasons for this will be discussed further.

Table 1. CVS cup closure-weld-zone wall thickness ranges and minimums by grinding technique and also reductions from Cassini production value

Grinding technique	Wall-thickness range Avg. ± 1 std. dev. (μm)	Wall-thickness minimum Avg. ± 1 std. dev. (mm)	Reduction in variation (range) from Cassini production value of 42 μm (%)
None (Cassini production)	42 ± 11	0.667 ± 0.013	---
Full ID cleanup only	34 ± 12	0.646 ± 0.015	19
Full ID/OD cleanup (2 setups)	29 ± 9	0.632 ± 0.010	31
Full ID/OD cleanup (1 setup)	22 ± 6	0.611 ± 0.020	48
ID aim - 28.45 mm OD aim - 29.77 mm (1 setup)	45 ± 15	0.637 ± 0.017	0

Table 2 summarizes the closure-weld-zone dimensional inspection data from the 11 CVS cups both before and after grinding to the target diameters of 29.77 mm OD and 28.45 mm ID. The data show that the resizing operation (before-grinding data) rounded the OD and moved most of the variation to the inside of the cups. This finding is supported by comparing the following before-grinding data:

- the OD and ID standard deviations (up to four times greater for ID);
- the small difference between the minimum and maximum ODs (0.025 mm) versus the large difference between the minimum and maximum IDs (0.090 mm); and

- the roundness values, outside (0.023 ± 0.008 mm) versus the inside (0.061 ± 0.016).

The target diameters actually were selected by considering the minimum and maximum diameters and wall thicknesses for each of the individual cups before grinding; however, the values in Table 2, which are averages for all of the cups, support those selections as well. The 29.77- mm-OD target matches the before-grinding minimum OD, and the 28.45-mm-ID target matches the before-grinding maximum ID.

Also, data in Table 2 indicated that more material would be ground from the ID than from the OD, as desired. The average before-grinding ID, 28.410 mm, was within 0.040 mm of the target, whereas the average before-grinding OD, 29.785 mm, was within 0.015 mm of the target. Furthermore, the minimum before-grinding ID, 28.365 mm, was within 0.085 mm of the target, whereas the maximum before-grinding OD, 29.796 mm, was within 0.026 mm of the target.

Table 2. Dimensional inspection summary (average ± 1 standard deviation) before and after grinding CVS cups to target diameters of 29.77 mm OD and 28.45 mm ID

		Outside diameter (mm)	Inside diameter (mm)	Wall thickness (mm)	Outside roundness (mm)	Inside roundness (mm)
Before grinding	Minimum	29.771 ± 0.012	28.365 ±0.026	0.652 ± 0.010	---	---
	Maximum	29.796 ± 0.005	28.455 ± 0.020	0.698 ±0.008	0.023 ±0.008	0.061 ± 0.016
	Average	29.785 ± 0.005	28.410 ± 0.022	---	---	---
After grinding	Minimum	29.758 ± 0.006	28.408 ±0.009	0.637 ± 0.017	---	---
	Maximum	29.786 ± 0.007	28.475 ± 0.013	0.681 ± 0.007	0.027 ±0.009	0.057 ± 0.009
	Average	29.773 ± 0.004	28.438 ± 0.013	---	---	---

The ID target of 28.45 mm was nearly achieved based on the average ID of 28.438 mm in Table 2, and the OD grinding target of 29.77 mm was achieved based on the after-grinding average OD. Table 3 shows that more grinding was done on the ID than on the OD, as desired. The minimum, maximum, and average ID values were increased 0.043, 0.020, and 0.028 mm, respectively, whereas those for the OD were reduced only 0.013, 0.010, and 0.012 mm, respectively. Table 2 shows that grinding cut the standard deviations for the ID values approximately in half, whereas only the standard deviation for the minimum OD was cut in half, and the others for the OD stayed about the same. The difference between the minimum and the maximum OD values (0.025 mm before versus 0.028 mm after grinding) and the outside roundness values (0.023 mm before versus 0.027 mm after grinding) were virtually unchanged after grinding. All of these results were desirable or acceptable, except that not enough grinding was done on the ID to improve the wall-thickness uniformity significantly.

Table 3. Change (value after grinding minus value before grinding) in dimensions from Table 2 after grinding

Change in dimension	Outside diameter (mm)	Inside diameter (mm)	Wall thickness (mm)	Outside roundness (mm)	Inside roundness (mm)
Minimum	-0.013	+0.043	-0.015	---	---
Maximum	-0.010	+0.020	-0.017	+0.004	-0.004
Average	-0.012	+0.028	---	---	---

The following after-grinding data in Table 2 indicate further that not enough grinding was done on the ID: the still-large difference between the minimum and the maximum ID values (0.090 mm before versus 0.067 mm after grinding) and the virtually unchanged large inside roundness value (.061 mm before versus 0.057 mm after grinding). Unfortunately, the maximum *and minimum* wall-thickness values were lowered 0.017 mm and 0.015 mm, respectively, after grinding. The standard deviation for the minimum wall thickness actually increased from 0.010 mm before grinding to 0.017 mm after grinding. The authors expected that ID/OD grinding would remove excess material that would be associated primarily with thick wall regions; thus, the wall thickness would be more uniform. This expectation does not appear to have been the case for a number of reasons.

As was stated earlier, too little material was ground from the cup IDs. The amount of ID grinding was determined by in-process, three-point internal micrometer readings. The three-point internal micrometer tended to yield ID readings similar to the CMM average IDs. Based on these micrometer readings, five cups (including three with thin walls before grinding) were not ground at all on their IDs. These cups are identified in the CMM data of Table 4. They had the largest IDs before grinding based on the CMM average IDs (28.433 mm to 28.459 mm) as well. Note that grinding to full cleanup on only the ID did maintain the minimum wall-thickness integrity; however, the reduction in variation, 19% (see Table 1), was minimal.

Table 4. Coordinate measuring machine measurements of average inside and outside diameters for individual cups before grinding

Cup identity (3584-35-)	Inside diameter (mm)	Outside diameter (mm)
A2CC	28.409	29.779
A2CD	28.399	29.787
A2CE	28.420	29.783
A2CF (OD ground to full cleanup)	28.380	29.785
A2CG	28.404	29.785
A2CH	28.375	29.782
A2CJ (thin wall after grind)	28.444 (not ground on ID)	29.793
A2CK (thin wall after grind)	28.402	29.783
A2CL	28.413	29.777
A2CM	28.424	29.790
A2CN (thin wall before grind)	28.459 (not ground on ID)	29.782
A2CP (thin wall before grind)	28.433 (not ground on ID)	29.785
A2CR	28.395	29.786
A2CT (thin wall after grind)	28.450 (not ground on ID)	29.792
A2CV (thin wall before grind)	28.456 (not ground on ID)	29.786
Grand average	28.418 (15 cups)/28.412 (11)	29.785 (15 cups)/ 29.785 (11)

Another factor to explain these results was that the in-process OD measurements were made using a two-point micrometer. This meant that the high and low ODs were easier to find (less averaging) than those for the IDs, which were made using a three-point micrometer. For this reason some amount of OD grinding was called for on all of the cups. Because the ODs had been rounded (especially in comparison with the IDs) during sizing, any grinding done on the OD occurred over larger areas for even small depths of material removal. The net effect from grinding was that too many areas on the cup ODs had material removed and too few (and/or the wrong) areas on the IDs had material removed.

The most significant factor was the specific locations of thin wall areas. The IDs *and* the ODs of nine cups were at or above the grinding target diameters in their thinnest (although not necessarily below the minimum requirement) wall locations before grinding. Thus, during grinding, no material was removed from the ID in these thin locations because the diameter was already as large as or larger than desired. Material was removed from the OD to meet the diameter target, but this action just made the thin locations thinner. In fact, three cups that were above the minimum wall-thickness requirement of 0.63 mm before grinding were ground below the minimum requirement. Also, one of the three cups that had a thin wall location before grinding was ground even thinner in this location without any ID grinding.

CONCLUSIONS

The authors have shown that CVS cup wall-thickness variation in the closure-weld zone can be reduced significantly. An approximately 50% reduction from the Cassini production value of 42 μm was achieved by grinding in a single setup to full cleanup on the ID and the OD. Unfortunately, when one is grinding to full cleanup, the closure weld-zone-minimum wall-thickness requirement of 0.63 mm can not be met with the existing blank and formed cup thicknesses.

An attempt to grind to target diameters selected to ensure conformance to the minimum wall-thickness requirement and yet still reduce wall-thickness variation was unsuccessful. The wall-thickness requirement was violated for 3 of 11 cups. This lack of success in reducing wall-thickness variation resulted because the actual thickness and ID/OD (or inner/outer contour) must be considered for specific locations, especially the thin wall regions. Averages, minimums, and maximums are of little value without specific locational, or positional, knowledge. Also, the sizing operation dictates that most, if not all, of the grinding should be done on the ID.

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