To be presented at the 2nd International Conference on Trends in Welding Research in Gatlinburg, Tennessee, May 14-18, 1989.

CONF-8905118--2

The Effect of Heat Sinks in GTA Microwelding*

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SAND--88-3025C

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ABSTRACT

When miniature devices containing glass-to-metal seals are closure welded it is accepted practice to incorporate thermal heat sinks into the fixturing. This is intended to assure that the heat from gas tungsten arc (GTA) welding will not cause thermal stress-induced cracking of the seals and loss of hermeticity. The design of these heat sinks has never been systematically studied; instead only "engineering horse sense" has been applied. This practice has been successful in the past; however, the components being GTA welded have become smaller and more complex (i.e. more pins) and glass cracking problems are being encountered. The technology of producing glass seal-containing lids (called "headers") has benefited from finite element analysis in deciding how to optimally dimension pin-to-glass seal diameter ratios and glass-to-metal thickness ratios in order to minimize thermal stresses locked in during manufacture. It appeared likely that an analysis of the stresses generated by welding would also be beneficial. Recently, computer speed and code capabilities have increased to the point where finite element analysis of a close simulation of real hardware can be made, including the effect of external heat sinks. The work reported here involves an analysis (with some supporting experimental data) of a miniature thermal battery which encountered glass cracking problems. In the course of the analysis various heat sink practices were examined. Among other findings, through-thickness thermal gradients in a header with a heat sink were found to equal in-plane thermal gradients in a header without any heat sinking at the glass seal positions. Also noted were significant variations due to relatively minor changes in the weld preparation geometry. A summary of good practice for heat sinking will be presented.

INTRODUCTION

HERMETIC CONTAINERS are used to package many types of devices used in modern technology. The usual reason for requiring such a comprehensive environmental barrier is to ensure long life and reliability of the component being packaged. The final step in producing such devices is the closure welding of the package. If defects are encountered at this stage, expensive scrap can result, or at the very least, expensive rework procedures may have to be developed. One of the more troublesome defects involves the cracking of the glass or ceramic electrical insulation medium, since the cracking may take some time to develop (though it usually is evident right after welding) and it is not usually repairable except by the use of anaerobic sealants.

Measures taken to avoid glass cracking involve i) designing special weld joint geometries which act to minimize required weld heat inputs, ii) using high power density, low total heat input welding processes such as laser, electron beam and non-consumable electrode inert gas shielded arc welding, iii) keeping the seals as distant from the weld as possible, and iv) using heat sink fixtures. As miniaturization keeps shrinking sizes and increased system complexity keeps increasing the numbers of feedthroughs, the ability to keep glass seals away from the weld diminishes, and weld process development becomes more and more important.

Gas Tungsten Arc Welding (GTAW) is a very versatile, high quality process often used to produce closure welds in hermetic packages. Admittedly, GTAW does not have as high a power density as laser welding; however, it is not as capital intensive and it is more forgiving of imprecise part tolerances. The work reported here was stimulated by GTAW closure weld induced cracking of glass seals in miniature pulse output thermal batteries. Part of the effort to solve the cracking problem was guided by calorimetric experiments (1), the other part was numerical in nature, and was aimed at understanding the thermal histories of the headers and how they affected the production of residual tensile thermal stresses in the glass-to-metal seals. In this respect our work differs from other researchers; we are not primarily concerned with what is happening in the immediate region of the fusion zone (we are not concerned with predicting the weld fusion zone size or geometry). In addition to looking at the details of the weld joint geometry, the effect of varying heat sink practice i.e.: materials and location, was investigated.

PROCEDURE

The geometry of the thermal battery header (lid) to case weld and details of the glass-to-metal seals are shown

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*This work performed at Sandia National Laboratories supported by the U.S. Department of Energy under contract number DE-AC04-76DP00789.

DISCLAIMER

in Figure 1. The materials used for the battery include: 304L stainless steel (Fe-18Cr-10Ni-0.03C) for the header and case, Corning 9010 or Kimble TM-9 for the glass insulators, and Alloy 52 (Fe-52Ni) for the pins (all compositions given in wt.%). Ideally, one wishes to obtain a hermetic weld that is cosmetically acceptable, with its minimum ligament equal to the case wall thickness. It has been conventional practice to heat sink both the header and the outer case, in order to minimize the temperature rise in the battery during welding. Decreased weld heat input is clearly desirable (in addition to the glass-to-metal seals there are also pyrotechnic materials inside the case); however, the misfit in part diameters due to machining tolerances sets a lower bound on the heat input. Low heat inputs which work well with "perfect" parts do not in practice bridge the gap in less-than-perfect production parts.

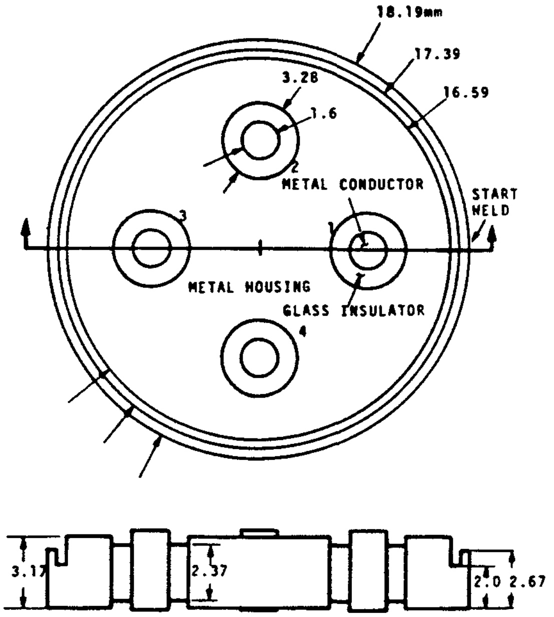

Figure 1 - Geometry and dimensions of header. Dimensions are in mm.

The numerical approach taken was to solve sequentially the thermal and stress problems by use of the computer programs JACQ and JAC3D (2)(3). JACQ is a three dimensional (3D) finite element computer program for non-linear heat conduction problems using the conjugate gradient method. JAC3D is a 3D finite element computer program for the non-linear quasistatic response of solids also using the conjugate gradient method. Calculations were run on a Cray computer. The thermal calculations were straightforward; however, the stress calculations are very computer time intensive and only partial results have been obtained to date. Material physical properties were input as a function of temperature; an elastic/plastic material model was used for the metals, and an elastic model was used for the glass. The welding heat flux was simulated by applying trapezoidal-shaped heat flux pulses in 15 degree arcs sequentially around the weld circumference. The magnitude of the peak heat flux was adjusted to obtain the melting temperature in the weld region. The total heat input consisted of 24 "pulses" plus one extra pulse to simulate an overlap region. Each individual pulse ramps up and down between zero and maximum flux in 0.1 second. The full width half maximum length of each pulse was 0.4167 seconds. The ultimate goal of our calculation was to determine stresses in the glass seals relatively distant from the fusion zone, so these simplifications in the weld zone were not thought to introduce significant error. Of course, temperature and stress predictions in the fusion zone region cannot be expected to be too accurate or detailed. The stress calculation includes determination of the residual stresses resulting from the glass sealing process. These were obtained by assuming a linear uniform cool down from the glass softening temperature (445 C). The glass and the 304L do not have matching thermal expansion coefficients; the 304L contracts more than the glass, sending both into compression.

The finite element idealizations used for the case, header, glass seals, pins and heat sinks are shown in Figure 2. Also shown is the geometry of the component-heat sink assembly. A number of heat sinking variations were tried. In addition to the Al heat sinks used in practice, Cu and stainless steel heat sinks, as well as deleting one or both heat sinks were tried to see how the thermal histories were affected. As would be expected, these variations required different total heat inputs. For computational purposes, the thermal resistance of the part/heat sink interface was set to zero, i.e. the heat sink is being idealized as "perfect". Where no heat sink is applied, an insulating boundary is assumed. This latter simplification is justified (for the header location) by the fact that the real device is assembled under axial compression. Even if no heat sink were present, some other (presumably insulating) material would be present preventing convection or radiation.

Prior to commencing the full 3D thermal calculations 2D axisymmetric runs were made using the thermal analysis computer program COYOTE II (4) to determine the effect of the weld groove geometry on the thermal field. For these calculations, the heat input representing the weld was applied simultaneously around the entire circumference. It was found that the temperatures reached at the edge of the glass were affected by the depth of the relief groove. A groove of 62% of the header thickness versus 31% caused the maximum temperature to reduce from 111 C to 91 C. For the full 3D calculations a 31% groove was used. These groove dimensions were indicative of contemporary practice for the production part.

The calculated thermal contours were animated for viewing on a color monitor. These were observed and selected mesh points chosen to allow significant thermal excursions to be measured and reported in this paper. Two examples of the animation are given in Figure 3. A series of thermal histories at the top and bottom outermost glass locations on the four pin seals are shown in Figure 4. Data from these plots are abstracted in Tables I and II, where the maximum temperatures, temperature differences and temperature gradients in both the radial and through-thickness directions (outermost to innermost, and top to bottom at the outermost location, respectively) and the total heat inputs are collected as a function of heat sink practice.

DISCUSSION

The actual welding practice used a pulsed weld schedule with an rms current of 22.1 Amps, at a travel speed of 10 seconds per revolution (total weld time of 10.2 seconds, equivalent to a linear travel speed of 5.76

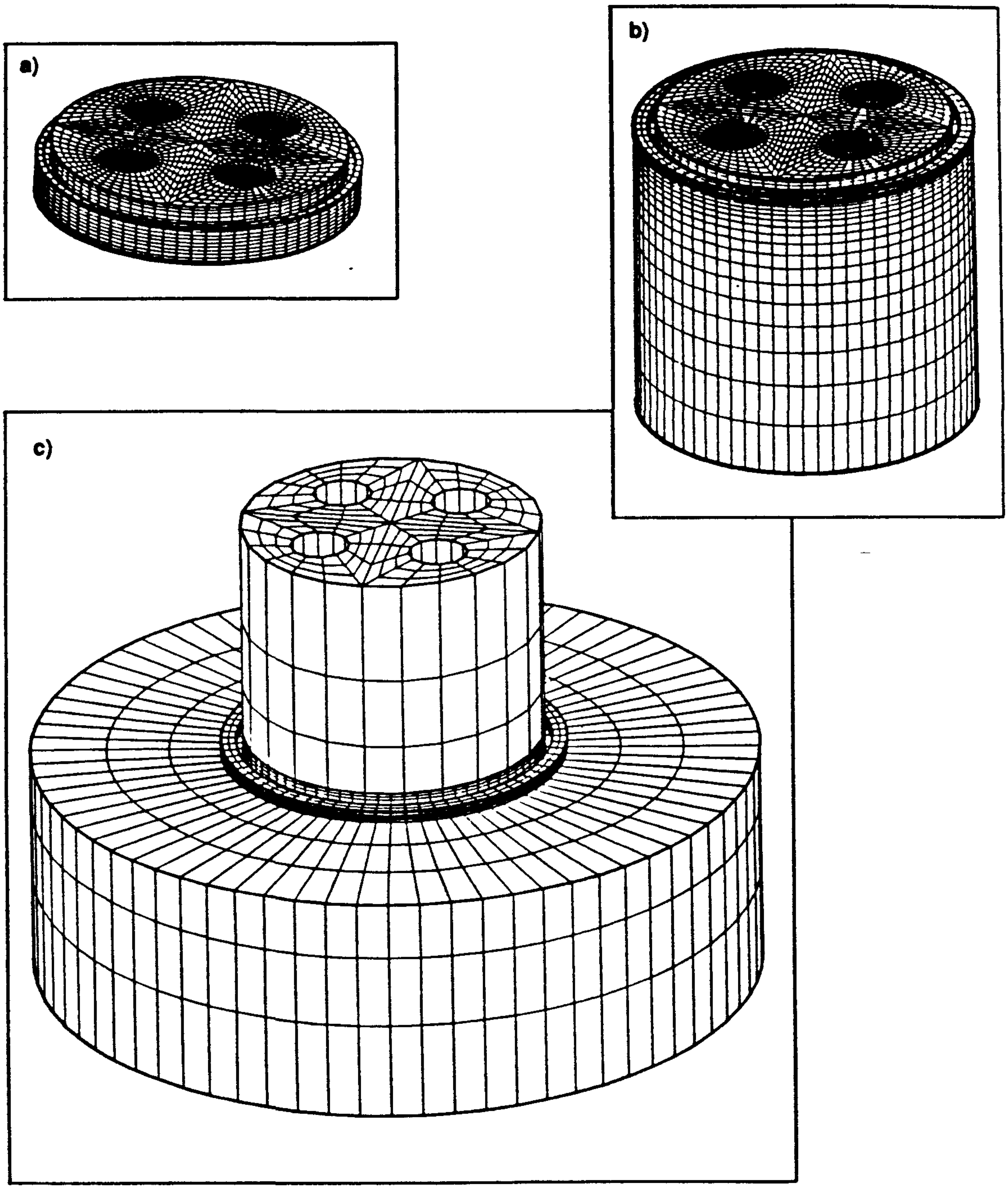

Figure 2 - Finite element meshes for a) header, b) header/case assembly, and c) top and side heat sinks in place on the header/case assembly.

mm/second). Aluminum heat sinks were used. Assuming that an arc voltage of 8 volts is present (an arc gap <1 mm is used), and that an arc efficiency of 70% obtains, this translates to an estimated actual heat input of approximately 1260 Joules (J). The calculated weld heat input requirement for the Cu and Al heat sink cases (both good conductors) were 1,117 and 1,111 J, whereas for the stainless steel heat sink case (a much poorer conductor of heat) 1067 J was required. Considering the simplifications made, this seems to be quite reasonable agreement. With no heat sinks (insulated boundary condition) only 768 J was necessary. The outer heat sink seems to be most important, as the condition: no top sink/Al side sink also required 1,111 J, and no side sink/Al top sink required 768 J. The maximum temperatures reached in the header were decreased as the heat sinking was improved. The simulated welds for these cases were usually started and stopped at the no. 1 pin angular location. This was always found to be the hottest

Table I - Weld Heat Input, Maximum Temperatures, & Temperature Differences

Heat Sink	Heat Input	Max Temperature		Max Temperature Difference		
top/side		top	bottom	thickness	radial	
					top	bottom
Cu/Cu	1,117(J)	85 C	152	71 C	33	99
Al/Al	1,111	97	165	69	36	103
Al/Al#	"	93	162	"	"	102
SS/SS	1,067	133	188	57	64	116
Al/--	768	154	250	101	63	156
--/Al	1,111	223	212	12	147	135
--/--	768	375	365	21	215	198

#Started between pins 1 & 2.

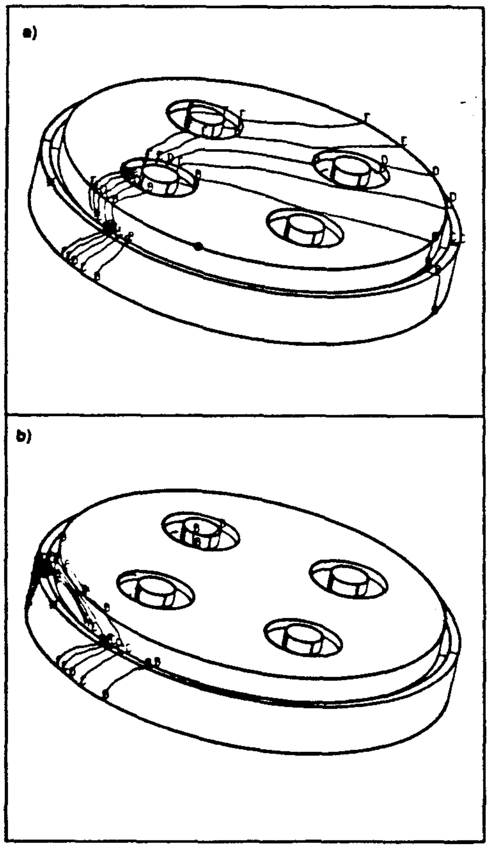

Figure 3 - Two examples of calculated thermal contours. The weld begins at the three o'clock position, and travels ccw. a) No heat sink case at 5.0 seconds of elapsed weld time, b) Al/Al heat sink case, also at 5.0 seconds. The temperature contours are as follows: A = 20 C, B = 50, C = 80, D = 110, E = 140, F = 170. * = max temperature [a) 1,170, b) 807], o = min temperature [a)21, b) not visible].

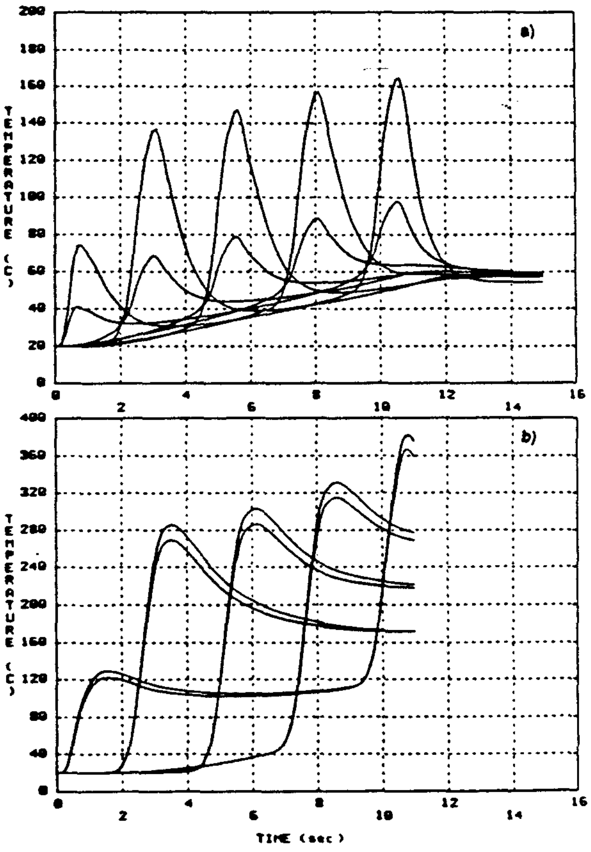

Figure 4 - Temperature excursions at the top and bottom outermost glass node of each pin. a) Al/Al heat sink case, higher values of paired curves correspond to the bottom node, peaks refer to pin 1, pin 2, pin 3, pin 4, pin 1, respectively, b) No heat sink case, higher values refer to top node, with same sequence of peaks referring to pins as a).

Table II - Gradients

Heat Sink	Average Temperature Gradient@		
		radial	
top/side	through-thickness	top	bottom
Cu/Cu	41.8 C/mm	10.7	30.2
Al/Al	40.6	11.0	30.5
SS/SS	33.5	19.5	35.4
Al/--	59.4	19.2	47.6
--/Al	-7.1	44.8	41.2
--/--	-12.4	65.6	60.4

@Positive means getting hotter when going from top to bottom or innermost to outermost position.

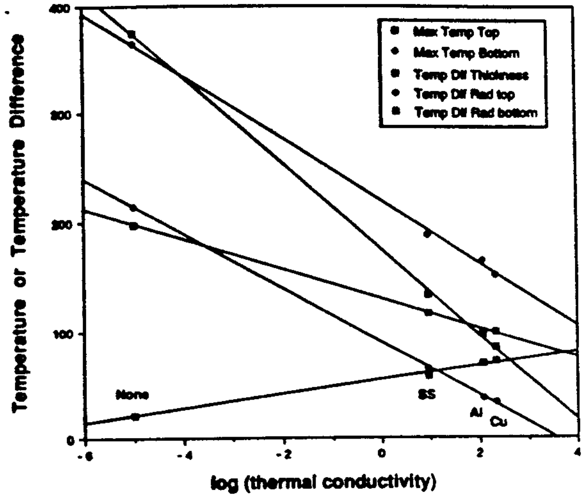

Figure 5 - Maximum temperatures or temperature differences resulting from different heat sink practices. No heat sink case set arbitrarily to 0.00001.

region. As the weld progressed around the circumference, the maximum temperature at the outermost glass location increased in order: pin 2-pin 3-pin 4-pin 1. We attribute this effect to the preheating at the pin locations from the beginning of the weld. Starting the weld between the pins did decrease the maximum temperatures by a small amount (3-8 C), but had essentially no effect on the thermal gradients.

The various parameters collected in Tables I and II are plotted versus thermal conductivity of the heat sink material in Figure 5. Only those cases where both (or no) heat sinks were present are plotted. This may be useful to provide interpolations for other materials.

In Table II the calculated thermal gradients listed are average values, calculated by dividing the temperatures when the outer location reaches peak temperature by the thickness or diameter of the glass annulus. The through-thickness gradient is only calculated at the outermost position.

It appears that the presence of a top heat sink tends to not only increase the magnitude of the through-thickness gradient, it actually changes its sign. When a top heat sink is present, the through-thickness gradient exceeds the radial gradient, or at least is comparable to it (SS case). However, the presence of a heat sink always decreases the peak temperatures reached quite dramatically. The case of an Al top heat sink without a side heat sink (Al/--) gave somewhat unexpected results, in that the through-thickness gradient developed was the greatest of all cases studied. A rationalization of this behavior is as follows. Clearly, the amount of heat entering the central region of the header must be greater than that of the no heat sink case (--/--) where both had identical heat inputs. The overall temperature of the header central region is kept cooler with the Al top sink in place than would be the case without it, establishing a greater temperature gradient between the weld zone and the central region, which extracts a larger portion of heat from the weld zone. Less obviously, in the case where both heat sinks are in place (Al/Al) and higher weld energy is input, the Al/-- case must still have a higher absolute value of energy transport into the central region of the header. This follows from the higher average temperatures reached in the header. The volume of the top sink is only about one fourth that of the side sink. Hence, even though approximately 30% more heat is input in the Al/Al case, the large, effective side sink removes such a preponderance of the weld heat (when it is in place) that less total heat goes to the central region. Following this reasoning, the Al/-- case channels the largest quantity of heat through the header. If greater heat flows through the header, then greater temperature gradients must result.

Some implications of our calculations are that in order to minimize temperatures, the most effective heat sinking possible (i.e. large sinks made of Cu) should be employed. This will increase the amount of weld heat necessary, and will increase the magnitude of the through-thickness thermal gradients. If on the other hand, overall minimization of thermal gradients is desired, then employing heat sinks of the same conductivity as the material being welded would appear to be the best approach.

It is hoped that our stress calculations will distinguish which approach yields lowest tensile stresses in the glass seals.

Calculated stresses resulting from the uniform cooldown from the glass softening point show that the glass is strongly in compression, with the magnitude of the maximum compressive principal stress increasing towards the mid-thickness of the glass. At the same time, the metal header has yielded plastically, with three lobes of plasticity associated with each glassed hole. Two of these lobes are aligned towards the two nearest neighbor pins, with the third pointing radially outward. Because of the header plasticity, on reheating the header uniformly, one encounters tensile stresses in the glass well before the glass softening temperature is reached. Figure 6 shows the effective (von Mises) stresses calculated to exist at 0.0 (these are the residual stresses from the glassing cycle), 2.4 and 3.2 seconds after the start of the weld (this is as far as our stress calculations have progressed at the time of writing). This scenario is for the Al/Al weld condition. Compared to the stresses before welding, the stress field is distorted, with the effective stresses at the outer part of the central header region (the region inside the relief groove) increasing at a location corresponding to the heat flux position, causing the outer lobe to reach all the way to the relief groove at 2.4 seconds. Meanwhile, most of the other plasticity lobes around the pins have shrunk. At 3.2 seconds, with the heat flux having

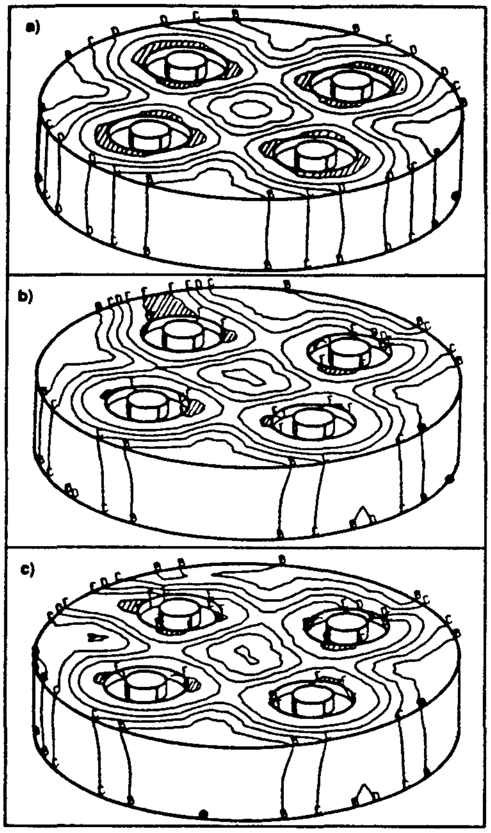

Figure 6 - Effective stresses in header central region at: a) after cool-down from glassing, before weld begins, b) after 2.4 seconds of weld, and c) after 3.2 seconds of weld. Contours represent: A = 0.0 MPa, B = 41, C = 83, D = 124, E = 166, F = 207 (yield stress of 304L). * = max stress location (234.6), o = min stress location (3.9). Cross-hatched regions have plastically yielded.

passed pin 2, the large plastic region is shrinking, though the lobe which had disappeared at 2.4 seconds has reappeared. Also, the stress contours lose their vertical symmetry, probably because of the sharp through-thickness temperature gradients which are present (note the location of the "D" stress contour on the edge near pin no. 4).

CONCLUSIONS

Based upon calculations made to date, the choice of whether temperatures or gradients are to be globally minimized will strongly affect heat sinking practice of glass-to-metal seal containing headers. To minimize temperatures, the traditional engineering approach used for many years is indeed correct: i.e. put as much mass of as good a conductor as possible as close to the weld as possible. This practice however, will result in the production of large thermal gradients in a through-thickness direction. To minimize temperatures and thermal gradients, it appears that using material with a similar thermal conductivity to the parts being welded is a better approach. Calculations to determine which approach is more appropriate to reducing tensile stresses in the glass seals are still ongoing.

BIBLIOGRAPHY

1. G.A. Knorovsky, P.W. Fuerschbach, "Calorimetry of Pulsed versus Continuous Gas Tungsten Arc Welds", Advances in Welding Science and Technology, ed. S.A. David, ASM International, Metals Park, OH, 1987, p 393.

2. D.K. Gartling, "COYOTE II - A Finite Element Computer Program for Non-Linear Heat Conduction Problems; Part II- User's Manual (2D)", SAND86-2725, Sandia National Laboratories, August, 1987.

3. personal communication with J.H. Biffle, Sandia National Laboratories, 1988.

4. J.H. Biffle, "JAC3D - A Three Dimensional Finite Element Computer Program for the Non-Linear Quasi-static Response of Solids with the Conjugate Gradient Method", SAND87-1305, Sandia National Laboratories, to be published.