ANODE CAST IRON THICKNESS OPTIMIZATION

Mark D. Ohlswager and Glen E. Goeres
Aluminum Company of America
Wenatchee Works
P. O. Box 221
Wenatchee, WA 98801-0411

Richard W. Peterson
Aluminum Company of America
Alcoa Laboratories
Alcoa Center, PA 15069

Abstract

Cast iron thickness of 24 commercial anode connections was varied by using stub holes 6.5 and 6.75 inches diameter with stubs 5.6, 5.8, and 6.0 inches diameter. Half of the stubs were preheated to 150°C before cast iron was poured; the other half had no preheat. Stub temperatures and stub-carbon resistances were measured during the first two days of pot operation. Stub-carbon resistance decreased and then leveled off with increasing stub temperature. This leveling off was an indication of the tightness of the connection. To avoid anode breakage this tightening should not occur prematurely. A stub hole one inch larger in diameter than the stub was best for castings poured with unheated stubs. Preheated stubs required thinner castings and were prone to overheating during pot operation.

Introduction

Anode stub-carbon connections must be tight enough at operating temperature to minimize electrical power losses and to prevent stub damage from overheating. However, they must not be so tight as to risk breaking the anode from mechanical stress arising from stub expansion. The combination of a large stub in a vibrated anode is especially vulnerable.

Earlier work by Peterson (1) and by Brooks and Bullough (2) had shown the importance of cast iron thickness. A thin casting tended to tighten the connection too soon while a thick casting might never produce a tight joint. The thickness of the casting determines the amount of air gap between the casting and carbon after cooling to room temperature. This air gap provides some relief for the thermal expansion of the steel stub which has a coefficient of thermal expansion (CTE) about three times that of carbon. While it is possible to calculate deflections if thermal properties of the materials are known, simplifying assumptions must be made. Accordingly, this present work was done to provide an empirical evaluation of castings of varying thickness in operating pots.

Table 1
Design of Experiment

Stub temperature, °C	25	150	
Hole diameter, inches	6.50	6.75	
Stub diameter, inches	5.6	5.8	6.0

Procedure

The anodes used were about 22 inches tall x 20 x 38 inches, weighing about 900 pounds. A single steel stub of nominal six-inch diameter was used in an offset stub hole. A full-factorial experiment of the form 3×2^2 with one replicate was run. Eight stubs of six-inch diameter were used while a like number were machined to 5.8 inch diameter and to 5.6 inch diameter (Table 1). Stub hole diameter for half of the anodes was 6.5 inches at the smallest section and 6.75 inches for the other 12. Stub temperature at the time of casting was either 25°C (unheated) or 150°C from flame preheating the stubs in an enclosure. These combinations of stub and hole size provided six cast iron thicknesses ranging from 0.50 inches to 1.15 inches (Table 2). The stub holes were of a fluted design so the cast iron thickness varied. Since the thinnest section has the maximum stress, only this dimension was considered to be important. When the term "thickness" is used in this paper it refers to the total thickness of cast iron (stub hole diameter minus stub diameter). A single piece of cast iron broken from one side of a stub would be only half as thick (0.25 inches to 0.58 inches). The total thickness value is needed for calculations of thermal expansion and related effects.

Table 2
Cast Iron Thickness, Inches

Hole dia.	Stub dia.	Cast iron
6.50	6.0	0.50
6.50	5.8	0.70
6.50	5.6	0.90
6.75	6.0	0.75
6.75	5.8	0.95
6.75	5.6	1.15

The anodes and rods were placed on a stationary trailer for cast iron pouring. After the assemblies had cooled, a rough indication of connection tightness was made by attempting to wiggle the rods.

Three steel pins were embedded in each anode to measure stub-carbon voltage drop (Figure 1). Another pair of pins measured voltage drop in a section of each copper rod, as an indication of amperage. A Type K thermocouple was placed in a hole drilled in each stub. Two anode assemblies at a time were set in random interior stalls of a pot. Voltages and temperatures were measured

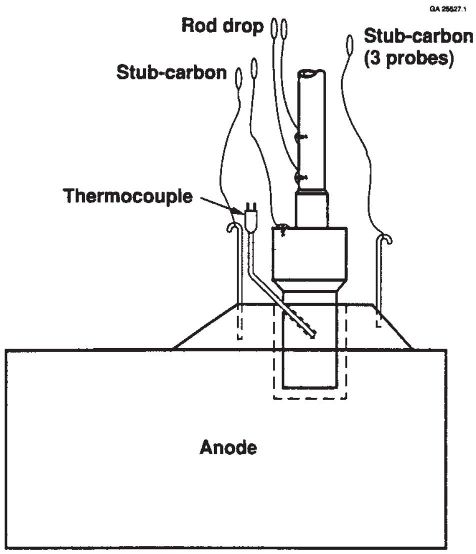

Figure 1: Temperature and Voltage Measurement

every 30 minutes for 48 hours of operation. The wiring harnesses extended above the pot hoods to facilitate readings. Problems were encountered using a data logger so all data were taken by manual readings.

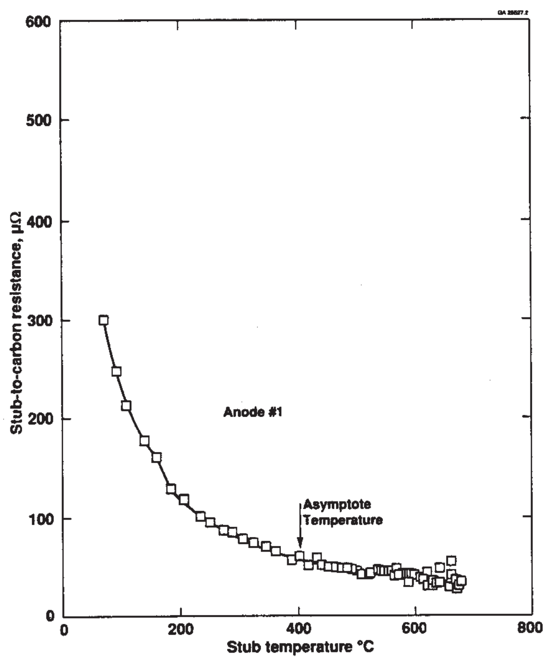

Figure 2: Stub-Carbon Resistance

Stub-carbon resistances were calculated from an average of the three voltage drop readings taken every half hour. These values were plotted against stub temperature (Figure 2). Plots were also made showing more than a single anode (Figure 3).

Statistical analysis of the data was done using the SAS program (3). An analysis of variance for a 3 X 2^2 full-factorial experiment with one replicate was done to determine the effect of stub diameter, hole diameter, and stub preheating. An analysis of covariance was done for stub temperature and cast iron thickness.

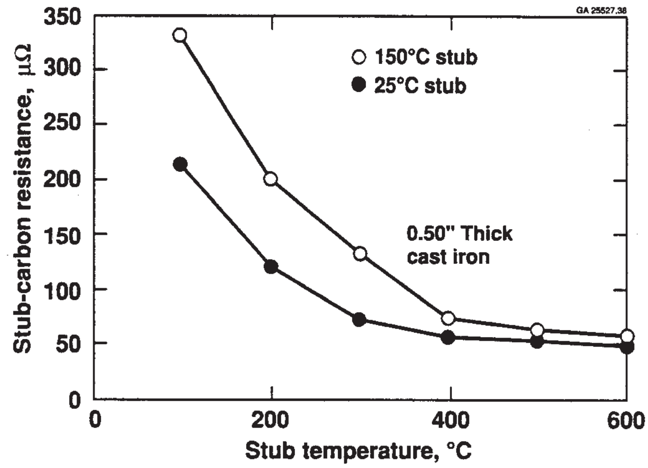

Figure 3: Stub-Carbon Resist Anode Versus Stub Temperature

Results And Discussion

Tightness of an assembly after cooling gave a rough indication of the air gap caused by cast iron shrinkage. By standing on the anodes and pushing against the top of the rods, it was possible to detect differences. A tight connection was given a value of "zero" while looser ones were rated "one", "two", or "three". Figure 4 shows a moderate correlation of tightness with cast iron thickness and stub preheat temperature. Most of the unheated stubs produced assemblies which were quite tight while most of the heated stubs resulted in assemblies which were noticeably loose. An analysis of variance showed stub preheating to have a significant effect on assembly tightness. The smallest and largest stubs were shown to have a significantly different effect but, statistically, neither could be said to be different than the mid-size stub. Stub hole diameter was shown not to be significant, but it should be remembered that this factor varied by only 0.25 inch and any effect on air gap would be commensurately small.

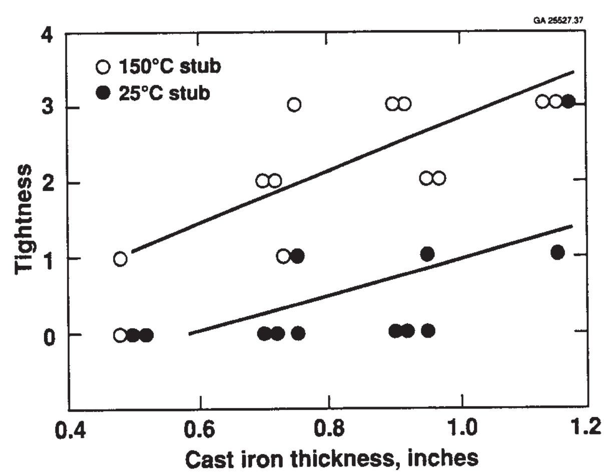

Figure 4: Connection Tightness After Cooling

Air gaps and other aspects of thermal effects are calculated in Table 4. For the unheated stubs this air gap is the product of cast iron thickness, the cast iron freezing temperature, and the CTE. In the case of the heated stubs, the thermal expansion from room temperature to 150°C was added. These data plotted as Figure 5 show that thicker castings provide a larger air gap. This figure is much like Figure 4 which was constructed from the experimental work. Preheating the stubs to 150°C produced as great an effect as increasing casting thickness from 0.50 to 1.15 inches thickness.

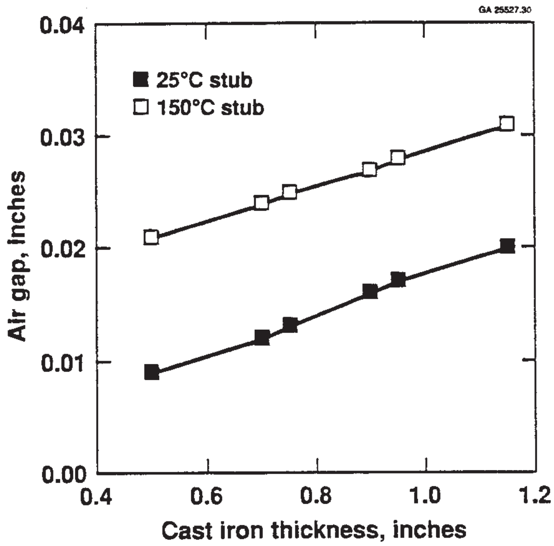

Figure 5: Calculated Air Gaps

The stub-carbon resistance was high immediately after an anode was set because the stub and cast iron were not in tight contact with the carbon (Figure 2). As the carbons heated from contact with the molten bath and from heating by the electrical current, the stubs expanded to push the castings tight against the carbons. Eventually this became an interference fit and the carbon stub holes became larger in diameter than they would have been from thermal expansion alone. The point indicating a tight connection was estimated by inspection of stub-carbon resistance curves. This was considered to be the temperature at which the stub-carbon resistance became essentially constant. That is, further stub expansion which increased contact pressure against the carbon did not result in an appreciable decrease in resistance. This point was called the Asymptote Temperature since the curve was essentially flat or asymptotic to the abscissa. This determination of the Asymptote Temperature gave reasonably good agreement in the replicated test (Table 3).

An analysis of variance applied to the Asymptote Temperature data produced conclusions similar to those for the tightness data. Stub preheating had a highly significant effect while the small change in stub hole diameter was not statistically significant. The smallest stub diameter was said to be different from the largest but neither was different from the mid-size stub in this analysis.

Stub-carbon resistance at operating temperature did not correlate with the factors in this test but rather was about equal for all cases. None of the anodes cracked during the test.

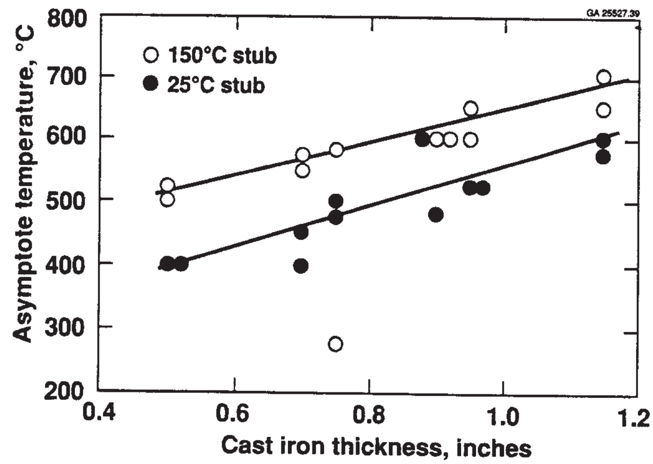

Figure 6: Asymptote Temperature Data

An analysis of covariance was done with cast iron thickness serving as the covariate. Stub temperature was also considered in the analysis. Data for Asymptote Temperatures plotted against cast iron thickness are shown in Figure 6. By omitting an obvious outlier, it was possible to construct two parallel lines correlating Asymptote Temperatures with cast iron thickness. The line for 150°C preheat lies about 100 degrees above the line for unheated stubs. Using the analysis of covariance technique, the regression lines and confidence limits in Figures 7 and 8 were constructed.

Table 3
Summary of Data

Anode	Stub Dia.	Cast Iron Thickness	Preheat Temp.	Max. Temp.	Asymptote Temp.	Tight-ness
1	6	0.50	25	680	400	0
2	6	0.50	25	660	400	0
3	6	0.50	150	860	525	0
4	6	0.50	150	670	500	1
5	5.8	0.70	25	575	400	0
6	5.8	0.70	25	650	450	0
7	5.8	0.70	150	600	550	2
8	5.8	0.70	150	800	575	2
9	5.6	0.90	25	860	600	0
10	5.6	0.90	25	560	480	0
11	5.6	0.90	150	800	600	3
12	5.6	0.90	150	930	600	3
13	6	0.75	25	570	500	1
14	6	0.75	25	640	475	0
15	6	0.75	150	785	585	1
16	6	0.75	150	640	275	3
17	5.8	0.95	25	575	525	0
18	5.8	0.95	25	580	525	1
19	5.8	0.95	150	980	650	2
20	5.8	0.95	150	1000	600	2
21	5.6	1.15	25	615	600	1
22	5.6	1.15	25	650	575	3
23	5.6	1.15	150	910	700	4
24	5.6	1.15	150	760	650	3

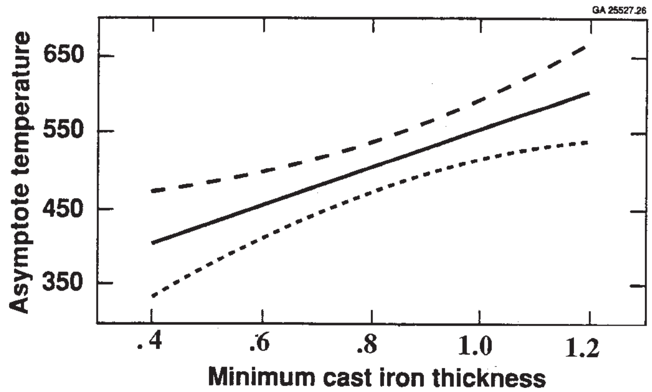

Figure 7: 95% Confidence Bands For The Mean Predicted Value At 25°C

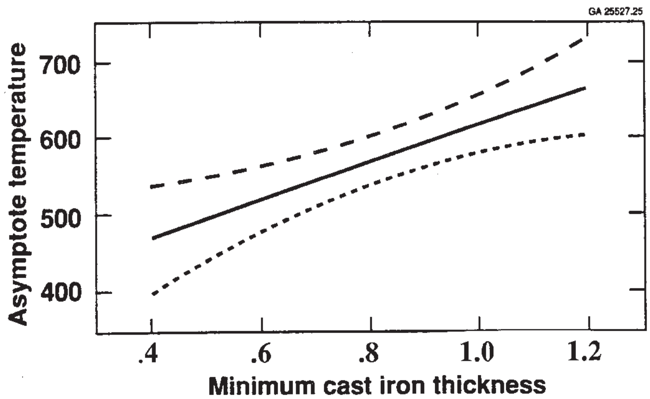

Figure 8: 95% Confidence Bands For The Mean Predicted Value At 150°C

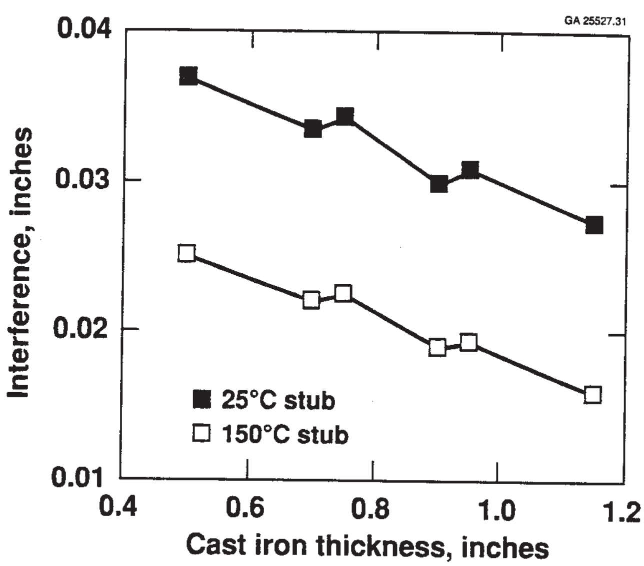

Figure 9: Calculated Interferences

Interference fit calculations from Table 4 are plotted as Figure 9. Preheating the stubs is seen to decrease interference by about 0.012 inches. Changing from the thinnest to the thickest casting had a slightly smaller effect (0.009 inches).

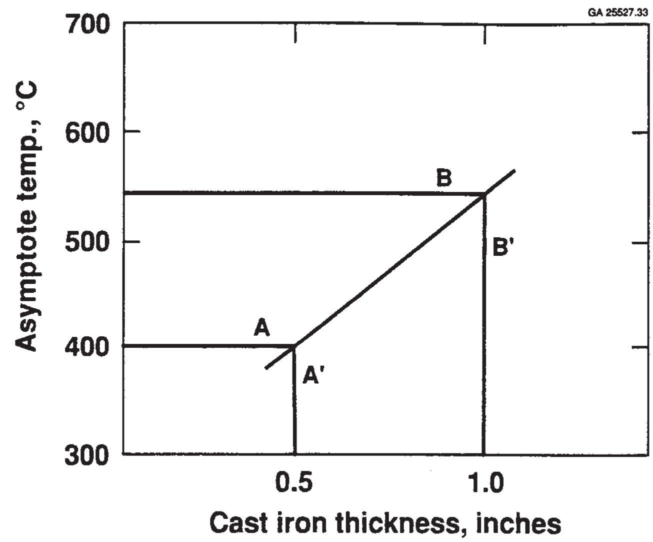

Figure 10: Selecting Cast Iron Thickness

Figure 10 was drawn from Figure 7 to demonstrate choosing a cast iron thickness. For instance, if a casting 0.50 inches thick were to be used with an unheated stub, the Asymptote Temperature would be 400 °C (Line A'-A). But if the stub operating temperature in the early life of the anode is 700°C, appreciable strain will be put on the carbon due to stub expansion. This strain can be calculated if the thermal properties and the dimensions of all the materials are known (Table 4). This shows that if the connection is tight at 400°C and then is heated to 700°C, the diameter of the carbon stub hole will be 0.037 inches larger than an unstubbed carbon would be at that same temperature.

The strain on the stub hole would be

0.037 inches/6.5 inch stub hole dia. = 0.57%.

This seems excessive. A stub hole stressed by a hydraulic jack would generally break at this condition.

However, returning to the above example and Figure 10 and specifying Asymptote Temperature of 550°C (Line B'-B), the assembly would still have adequate tightness but less strain. This would require a casting 1.0 inches thick (stub diameter 6.0 inches, stub hole diameter 7.0 inches.) The calculated interference (Table 4, Anode X) would be 0.032 inches and the stub hole strain would be 0.45%.

Similar arguments could be made for preheated stubs. For an Asymptote Temperature of 550°C, the cast iron need be only 0.64 inches thick. A 1.0 inch-thick casting would produce an Asymptote Temperature of about 650°C. This is a questionable condition, which could lead to overheating of the joint, due to inadequate tightness, and thus high resistance.

Stub temperatures after two days of operation ranged from 560°C to 1000°C. Eleven of the 12 unheated stubs operated below 700°C. The 12th one appeared to be an outlier (Figure 11). Nine of the 12 stubs preheated to 150°C operated above 700°C. For castings thicker than 0.80 inches, all six of the preheated stubs operated above 700°C. These high stub temperatures illustrate the danger of having a connection which is too loose.

While the calculations of expansions and interferences seem straightforward, they rely on accurate and unvarying material property data. Further, other phenomena outside the calculations, such as surface crushing of the carbon or stress caused by artifacts of the stub hole design, must be ignored. For this reason, the empirical test described here seems a useful adjunct to calculation.

Table 4
Stub Expansion Calculations

	ANODE 1	ANODE 4	ANODE X
Stub Diameter, Inches	6	6	6
Stub Hole Diameter, Inches	6.5	6.5	7
Stub Temperature at Pouring, °C	25	150	25
Operating Temperature, 700°C			
C. I. Freezing Temperature, 1150°C			
Steel CTE, 16E-6 in/in °C			
Cast Iron CTE, 15.5 E-6			
Carbon CTE, 5.5 E-6			
EXAMPLE FOR ANODE 1			
Air Gap = (6.5-6)(1150-25)(15.5E-6)	0.0087	0.0087	0.0174
INTERFERENCE			
Stub Hole = (-1)(6.5)(700-25)(5.5E-6)	-0.0241	-0.0241	-0.0260
Stub = (6)(700-25)(16E-6)	0.0648	0.0528	0.0648
Casting = (-1)(6.5-6)(1150-700)(15.5E-6)	-0.0035	-0.0035	-0.0070
TOTAL = 0.0372	0.0372	0.0252	0.0318

The experimental method described here should be useful for specifying cast iron thickness. If anode cracking or high-resistance connections are a problem, enough testing should be done to establish the Asymptote Temperature and a typical stub operating temperature for the stub hole design being used. If this Asymptote Temperature is more than 150°C below stub operating temperature, consideration should be given to using a larger stub hole to provide a thicker casting. If the Asymptote Temperature is nearly equal to the stub operating temperature, a smaller stub hole would be indicated. Some judgment and further testing might be needed to arrive at the optimum casting thickness. Besides looking at the Asymptote Temperatures and stub operating temperatures, other factors should be considered such as anode failure rate from cracking or overheating. The amount of deformation an anode can endure, and the availability and cost of pouring more cast iron are also factors. Stub preheating is an option, but it adds another processing step and, based on the limited data presented here, it could result in overheated stubs.

Conclusions

1. The temperature at which a stub-carbon connection becomes tight can be determined from stub-carbon resistance measurements in an operating cell.

2. Using this technique, optimum cast iron thickness can be determined for specific anode/stub configurations. The optimum casting thickness for anodes in this study was found to be one inch (0.5 inches on each side of a 6.0 inch-diameter stub).

3. Once achieved, this optimum casting should reduce anode cracking and stub operating temperatures, while maintaining a low-resistance stub-carbon connection.

4. Stub preheating was shown to raise the temperature at which a cast iron connection becomes tight, but this practice could also result in overheated stubs due to high-resistance connections.

References

1. Peterson, R. W., "Studies of Stub to Carbon Voltage," Light Metals 1978, Volume 1, pp. 367-378.

2. Brooks, D. G. and Bullough, V. L., "Factors in the Design of Reduction Cell Anodes," Light Metals 1984, p. 961.

3. SAS Institute Inc., Box 8000, Cary, NC 27511-8000.

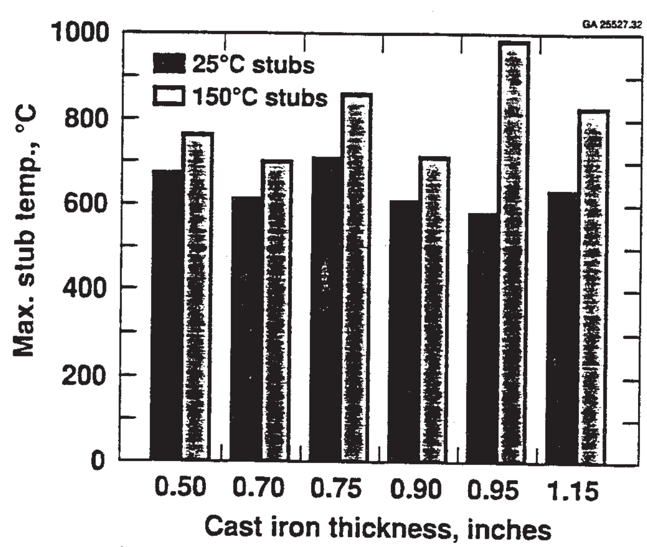

Figure 11: Maximum Stub Temperatures