Investigation and Analysis of Suspect Fasteners

Event 29257

Final Report

6

Prepared by
Cardinal Industrial Products
Division of B&G Manufacturing Co., Inc.

November, 1995

9511270151 951121
PDR ADOCK 05000275
S PDR

INTRODUCTION

On July 10, 1995, B&G Manufacturing Co., Inc. ("B&G") purchased the name and certain other assets from Cardinal Industrial Products, L.P. ("CIP-LP") a limited partnership formed and operated in Nevada servicing the nuclear power industry. B&G acquired these assets to begin its own nuclear fastener business as a new division of B&G ("B&G-Cardinal").

Various owners have operated a nuclear fastener business under the "Cardinal" name at West Oquendo Road in Las Vegas prior to B&G's acquisition of assets from CIP-LP on July 10, 1995. In this report the term "Cardinal facility" is used to describe the general operations which have continued at that site independently of ownership. The reader is advised to be aware of the nature and sequence of the ownership as this report is reviewed.

Shortly after July 10, 1995, Duquesne Light notified B&G-Cardinal about nonconforming Grade B7 hex capscrews, which had been processed and sold to them by CIP-LP. Several of the suspect fasteners were tested by B&G-Cardinal and an independent testing laboratory and found to deviate from SA 193, Grade B7 mechanical requirements. Although these fasteners had been processed, sold, and shipped by CIP-LP, B&G sent notifications of the nonconformance to the NRC and to other purchasers of product from the same lot. As a result of the notifications, two other utility companies reported to B&G-Cardinal nonconforming fasteners from the same lot and one additional lot.

B&G initiated a comprehensive investigation to ascertain the scope and cause of the problem, to determine corrective actions, to keep its new customers fully informed and, as a courtesy, to be able to instruct them to evaluate the condition in light of 10CFR Part 21 paragraph 21.21(a)(1)(ii) and (b)(1).

Metallographic analysis of the nonconforming fasteners indicated improper heat treatment, which prompted B&G-Cardinal to begin testing similar lots of material from inventory that were manufactured using the same heat treatment process. This testing revealed additional nonconforming product and thereby indicated the problem was not isolated to only one lot but was related to the process.

Investigation and testing traced the problem to the heat treating furnace at the Cardinal facility, and substandard fasteners most likely can be isolated to eight lots of material processed since 1989. (The investigation could not address product processed prior to 1989 because records were unavailable.)

This report describes the problem, the investigation strategy, testing and analysis, and other actions taken by B&G-Cardinal that revealed the source of the defects to be processing deficiencies in heat treating certain material at the Cardinal facility.

THE PROBLEM

Certain lots of hex capscews that were processed and shipped per ASME SA-193, Grade B7 out of the Cardinal facility by CIP-LP were found to contain defective fasteners. The problem was initially discovered by Duquesne Light's Beaver Valley facility, which had sent several ⅜" diameter capscrews to an outside laboratory for random verification testing. The results of these tests indicated some fasteners from the lot were not in compliance with the mechanical requirements of the specification. Duquesne Light reported this failure to B&G-Cardinal. Independent test reports from the Beaver Valley facility (and later from PG&E Diablo Canyon and Washington Public Power Supply System) suggested the fasteners in question had not been properly heat treated.

The suspect lot of ASME SA-193 Grade B7 capscrews was manufactured at the Cardinal facility from AISI 4140 medium carbon alloy steel. The manufacturing process utilized by CIP-LP was to cold form capscrews from spheroidized annealed cold heading wire. The fasteners were then heat treated by a process of either normalizing, quenching, and tempering, or simply by quenching and tempering. Depending on the lot sizes, the heat treatment was either performed at the Cardinal facility or by an approved outside vendor.

IMMEDIATE ACTION

To verify the testing results obtained by Beaver Valley, B&G-Cardinal performed tensile and hardness tests on capscrews from the same lot. These tests were performed at the Cardinal facility's laboratory under the direction of B&G-Cardinal's Quality Assurance Department. The mechanical properties of several of the capscrews tested were found to deviate from the minimum requirements of Grade B7. This lot of material was immediately removed from stock, marked as nonconforming, and isolated in the nonconformance room.

Samples of both conforming and nonconforming fasteners were sent to an outside laboratory for metallographic examination. The examination of the conforming fasteners indicated the fasteners had the tempered martensite structure expected from proper heat treatment. The nonconforming fasteners, however, had a spheroidized structure that indicated the heat-treated fasteners had not reached the temperature required for the martensite structure to form.

Because the nonconforming lot was heat treated at the Cardinal facility, B&G-Cardinal decided to concentrate its investigation on the heat treating equipment and process there.

THE INVESTIGATION

Early indications suggested that the nonconforming fasteners had never been heat treated. The lot in question weighed over 250 pounds and would have been placed in several containers for ease of transport through the Cardinal facility, so it was plausible that a lone container of fasteners had bypassed heat treatment and was later intermingled with the rest of lot, which had been heat treated. B&G-Cardinal then sampled a large number of the fasteners still in inventory from the suspect lot and found, however, substandard fasteners with visible surface scale, which indicated that all the fasteners, including suspect ones, had been heat treated.

Because the fasteners definitely had been heated in the furnace, the focus of the investigation turned to the heat treatment process and equipment at the Cardinal facility. Recognizing that a problem with the heat treating facility may have affected other lots of material, the Quality Assurance Department began sampling other lots from inventory that had been heat treated through the furnace at the Cardinal facility.

During the investigation, B&G-Cardinal sent courtesy notifications to the NRC and to companies which had purchased capscrews from the questionable lot. Within a few days of these notifications, PG&E Diablo Canyon informed B&G-Cardinal of a substandard, ⅜" diameter capscrew that had come from a second lot. In addition, the inventory sampling process by B&G-Cardinal revealed a third and fourth lot that contained substandard fasteners of ⅜" and ⅝" diameters, respectively. Courtesy notifications were also sent regarding these lots.

It became apparent that the four lots found to have substandard fasteners all entered the furnace in "large" charges held at a temperature for "short" periods (relative to other charges performed at the Cardinal facility). The period in question was the duration parts were held in the furnace ("soaked") at the specified temperature for austenitizing just prior to lowering the basket of parts into a quench tank. The soaking time for A/SA 193, Grade B7 product must be long enough to allow all parts to achieve an austenitic microstructure prior to quenching them rapidly in a liquid medium at a controlled temperature of 125°F. The quenching provides a rapid temperature drop that results in the formation of a primarily martensitic structure. After quenching, parts should register hardness values of approximately 50 on the Rockwell C scale and tensile strengths between 225,000 and 300,000 psi. The parts then undergo a tempering cycle that entails heating them to a

1,100°F minimum followed by a slow cooling process. Tempering reduces the tensile strength and develops ductility as required (for A/SA 193, Grade B7, a minimum tensile strength of 125,000 psi with ductility exhibiting 16% minimum elongation and 50% minimum reduction of area).

Two primary problems can occur with the heat treating cycle. First, the charge may not be allowed to "soak" in the furnace long enough for all the fasteners to reach the temperature required to achieve an austenistic microstructure. Second, the parts may not cool rapidly enough if the liquid quenching medium is not circulating sufficiently enough to provide adequate heat transfer in the required amount of time. The lots in question were processed in heat charges of relatively heavy weight, which could be a potential factor in either problem. If the charge size was too large, some or all the parts may not have reached the required temperature in the given time period; or the temperature of the quenching liquid may have become too high to accomplish the required rapid cooling by the time the liquid reached the parts at the center of the charge upon being lowered into the quenching tank.

Heat treatment logs for charges performed at the Cardinal facility dating back to 1989 were included in the records obtained by B&G-Cardinal from CIP-LP. B&G-Cardinal examined these logs, which showed since 1989 a total of 333 charges were heat treated involving AISI 4140 medium carbon alloy steel. The data for each of these charges was entered into a spreadsheet and then sorted in descending order by weight and time (pounds per hour) with the expectation that the worst case charges (heavier charges or shorter soak times) would appear first (See Addendum 1). The charge with the previously identified ⅝" lot with known substandard fasteners was at the top of the list, and the other three ⅜" lots were all within the first 13% of charges listed. The pattern of sorted data was as anticipated and indicated that sound metallurgical principles were taking investigation in the proper direction.

Most of the product indentified in the heat treatment log had been sold and shipped prior to B&G's purchasing assets from CIP-LP, therefore lots generally were not available from inventory for testing. Thus, the strategy of investigation was to recreate the heat treating conditions that would produce known defects. Test charges were planned using times, temperatures, and weights identical to the heat charges known to have produced defective product. Other test charges were devised with the purpose of determining what combinations of weight and soak times would result in defective product. From the heat treatment log, charges with extreme weights relative to soaking times were identified for each diameter of Grade B7 capscrews, and product was either manufactured or taken from inventory to be used for the test charges.

Over a two week period, 22 test charges were heat treated. After each charge, test coupons were removed from specific locations within the heat treatment basket and were tested for hardness (See Addendum 2). From the results of the early test charges, the following hypotheses were formed:

1. Some of the fasteners in the basket were not reaching the required temperature in the allotted time. This conclusion was based upon the location of the substandard fasteners found in failed test charges. This hypothesis is supported by two separate metallographic examinations of substandard fasteners.

2. The time required for all fasteners in the charge to reach temperature is dependent upon charge density as well as overall weight. Charge density is a function of the fastener's dimensions where ⅜" diameter fasteners will pack more densely than ⅝" diameter fasteners.

In addition to performing tests to verify the integrity of past charges, other charges were specifically performed to verify the above hypotheses.

Because the problem appeared to relate in general to heat transfer and not necessarily to any specific material, the investigation was broadened to include all heat treated materials. The heat treatment logs were again reviewed, but without regard for material or heat treatment type but rather simply for what appeared to be the critical indicators of weight, time at temperature, and charge density. No other charges were found to have critical factors in the range which coincided with test charge failures.

During the investigation, the possibility of a problem with the quenching phase of the heat treating cycle was dismissed based upon metallographic analysis. The metallography comparisons of acceptable and substandard fasteners taken from the same lot showed two clearly different but identifiable microstructures. The photomicrograph of the acceptable fastener showed the proper tempered martensite microstructure with some retained austenite. The microstructure of the substandard fastener was spheroidized carbides in a ferrite matrix, which results only when alloy steel does not reach the austenitizing temperature. Either microstructure was dependent upon proper quenching. In other words, inadequate quenching in either case would have produce yet another identifiable microstructure.

INVESTIGATION FINDINGS

In the process of performing of 22 different quench-cycle test charges, B&G-Cardinal was able to recreate heat treatment conditions and substandard fasteners corresponding to the four inventory lots known to have contained substandard fasteners. Because these test charges produced the expected results and thereby substantiated the hypotheses, B&G-Cardinal ceased investigating other causes. In addition to the test charges that recreated known failures, other test charges produced substandard fasteners that paralleled four additional lots of material from the heat treatment log. While there is no conclusive evidence that corresponding actual production charges contained substandard fasteners, it was likely they did; therefore, B&G decided to send courtesy notifications to the NRC and known customers for these lots, too. The other 14 test charges done under the remaining worst-case conditions produced acceptable results and therefore strongly suggests that substandard fasteners can be isolated to the eight lots of inventory for which simulated heat-treatment charges produced failures.

The test charges containing substandard fasteners were evaluated by hardness testing of forty coupons taken from specific locations from throughout the charge. The hardness readings were documented on forms which detail the location of each coupon (See Addendum 2). Based upon the map of the hardness readings, it is apparent that the bottom layer of fasteners near the center of the basket was the last to reach temperature in larger lots. The primary heat transfer mode for the furnace is radiation. The secondary heat transfer mode is conduction. In large charges of densely packed fasteners, conduction becomes much more important. Because of the configuration of the furnace at the Cardinal facility, the bottom center portion of the basket did not receive significant heat through radiation. Fasteners at the bottom layer received their heat through conduction from the upper layers of fasteners. In the charges containing substandard fasteners, the time required for the heat to reach the bottom layer of fasteners was longer than the fasteners remained in the furnace.

This problem was not discovered earlier because the test coupons that had been used by the Cardinal facility for tensile and hardness testing were typically placed at the top, center spot of the charge. Had the test coupons been placed within the area of the charge which failed to reach temperature because of lagging heat transfer, the defects could have been detected during the normal testing performed on heat charges.

The furnace at the Cardinal facility takes approximately two hours to reach the appropriate austenitizing temperature for A/SA 193, Grade B7. After this temperature is reached, the fasteners are allowed to "soak" at temperature for at least one hour. The soak time is intended to provide even distribution of the heat. The furnace's thermocouple used to register its temperature is positioned in the upper region of the furnace (See Addendum 3). The results of the test charges demonstrated that not all the contents of a charge reach the indicated temperature at the same time. The time required for the bottom layer of fasteners to reach temperature was affected by the weight of the charge and the charge density.

One of the test charges that failed (#21) was 331 pounds of ⅜" x 1" long capscrews. This charge contained nearly 8,000 pieces and was only 2½ inches deep in the basket (the basket is 37 inches long and 25 inches wide). Another charge of the equivalent weight (#5) passed but contained ⅝" x 2½" and ⅝" x 3" long capscrews. This charge contained just over 1,100 fasteners and was 4½ inches deep. How densely fasteners were packed in the charge affected the amount of heat received through radiation as compared to conduction. In general, the smaller the diameter of the fasteners, the more the charge acts as a solid mass. In both of the above listed examples the charge was held at temperature for one hour, but the charge that failed had ⅜" diameter fasteners that packed more densely than the charge that passed with the larger, ⅝" diameter fasteners.

In another example, the diameter of the test charge was held constant and packing density was changed. 300 pounds of ⅜" x 1" long capscrews were held at temperature for one hour and contained no bad fasteners (test charge #19). Another charge (#22) contained 270 pounds of ⅜" x 4" capscrews and was also held at temperature for one hour. The four-inch long capscrews of this lot were carefully lined in rows when packed into the basket (which is a common practice to prevent shank warpage). The tightly packed charge of four-inch long screws contained failed fasteners.

INVESTIGATION CONCLUSIONS

The conclusion of this investigation is that the substandard fasteners resulted from procedural error involving the time that heat treatment charges were held at temperature for the given conditions, specifically the charge's weight and density as determined by the diameter of the products and method of packing. According to the records left behind by CIP-LP, the standard practice of CIP-LP for heat treating operations referred to Military Standard MIL-H-6875. However, the CIP-LP's standard practice made no reference to factoring the overall weight or packing method when determining the correct soaking time for a particular charge in the furnace at the Cardinal facility.

The heat treatment equipment located at Cardinal facility does have limitations. In general, the furnace has heating elements on four sides and on the ceiling (See Addendum 3). This would not be a problem except that the single thermocouple is located in the ceiling of the furnace. The temperature indicated on the display panel and recorded on the strip chart may not reflect the temperature throughout the furnace and the charge. This limitation, however, could have been compensated for procedurally by allowing charges to remain at temperature for longer periods of time.

B&G-Cardinal has been asked what the percentage of fasteners is substandard in the suspect, and what is the strength of the substandard fasteners. It should be assumed that the heat treatment of any of the suspect lots was insufficient to achieve the mechanical properties of A/SE 193, Grade B7, and that the mechanical properties of the fasteners from those lots are equivalent to annealed AISI 4140 material. This means the tensile strength is between 60,000 and 70,000 psi. Estimating the percentage of fasteners that are substandard in a given lot is much more difficult. Basing estimates upon heavy charges having five or six layers of capscrews with as many as fifty percent of the bottom layer being substandard suggests that the lot would contain 10 percent defective fasteners. However, one cannot assume that substandard fasteners are distributed evenly throughout a total lot; defective fasteners, for instance, could have been concentrated into one container when packed for warehousing or shipping. Therefore, B&G-Cardinal cannot conclusively say what *percentage* of fasteners purchased by any particular customer was substandard.

There are two other factors in connection with the heat treating equipment at the Cardinal facility which would tend to isolate suspect charges to the types of product and material investigated with the 22 test charges.

The first is the quenching medium, which is a polymer solution. The particular design of the quench tank located at the Cardinal facility precludes the use of oil because it would be a fire hazard. The polymer solution is a suitable alternate for oil for many materials such as A/SA 193 Grade B7. But a polymer solution cannot be used in the heat treatment of very high strength materials such as A490 structural bolts, A574 socket screws, F912 set screws, or A354 Grade BD (SAE J995 Grade 8) because these specifications require an oil quench. A polymer solution is also not suitable for quenching products made from medium carbon steels, such as A325 structural bolts, A449 Type 1 (SAE J995 Grade 5) bolts, A194 Grade 2H nuts, A563 Grade C, D, or DH nuts, and F436 flat washers. Consequently, there seems no reason to believe that any of these types of products would have undergone heat treatment at the Cardinal facility.

Secondly, rods and studs were generally not heat treated at the Cardinal facility because they were produced from bars which already met applicable specifications and did not require additional heat treatment. In addition, the heat treatment basket could not physically accommodate any studs or rods longer than 36 inches.

B&G-Cardinal believes that the problem of substandard fasteners discovered initially by Duquesne Light does not extend beyond the eight lots of Grade B7 capscrews already identified through testing charges based upon critical factors of weight, density, and soaking times; but B&G-Cardinal cannot guarantee this conclusion. Customers should evaluate replacing any fasteners installed from these eight lots, and should consider testing other lots if deemed necessary for further assurance.

SUMMARY

Shortly after receiving notification from Duquesne Light that capscrews sold to them by CIP-LP did not meet the specification requirements, B&G-Cardinal began an investigation into the cause and scope of the problem. During this investigation, a detailed review of records was performed as well as a duplication of past heat treatment charges. During the investigation, B&G-Cardinal recreated the heat treating conditions of suspect lots and through test charges successfully duplicated the failures in four lots of material known to contain substandard fasteners; additional test charges produced four more lots with substandard fasteners, which may indicate that corresponding lots in the field may also have substandard fasteners.

The cause of the problem was determined to be procedural error. As a courtesy, B&G-Cardinal has notified the NRC and the companies that purchased capscrews from lots containing suspect material.

B&G-Cardinal has discontinued using the heat treatment equipment at the Cardinal facility until such time that satisfactory modifications are made to both the hardware and procedures governing the heat treating operation.

Corrective action to preclude recurrence include, but are not limited to:

1. Revising or adding procedures to address minimum soak times, basket loading procedures, and placement of test specimens; upgrading training programs for operators of the furnace.

2. Adding a second thermocouple to the furnace located at the bottom-center of the furnace near the parts basket (where heat transfer can lag behind other sections of the furnace, depending on weight and density).

3. Adding a view port to the furnace so that the operator can observe the charge during the heat treatment.

4. Considering overhauling or replacing the furnace if other corrective actions are insufficient.

ADDENDUMS

1. Sorted Heat Treatment Data Showing Heavy Charges
2. Test Charge Results
3. Heat Treatment Equipment at the Cardinal Facility

Heat Treatment Log Charge Data - Sorted by Pounds per Hour

Date	Charge	Qty	Description	lbs	Total	Hrs.	lbs/hr	Notes
1/22/94	**2905**	**935 750**	**5/8-11 X 3 HHS 5/8-11 X 2 1/2 HHS**	**317.90 225.00**	**543**	**1**	**543**	**Failed Lot "TU1" Test charge 03 failed**
8/18/92	2547	2263	3/8-0 X 6 HCS	452.60	453	1	453	Test charge 22 failed
3/27/93	2696	1259	5/8-0 X 3 HCS	390.29	390	1	390	Test charge 06 failed
11/13/92	2615	318	1-0 X 4 HHS	381.60	382	1	382	Good per test charge 15
4/15/94	2952	1100 633	5/8-11 X 3 HXB 5/8-11 X 3 HXB	352.00 202.56	555	1.5	370	Test charge 04 failed
9/16/94	3075	1212	5/8-11 X 2 1/2 HHB	363.60	364	1	364	Good per test charge 07
7/7/94	3010	860	5/8-11 X 4 HHS	361.20	361	1	361	Good per test charge 07
6/16/94	2996	860	5/8-11 X 4 HHS	361.20	361	1	361	Good per test charge 07
12/14/92	2633	300 202 134	3/4-0 X 2 HHS 3/4-0 X 4 HHS 3/4-0 X 6 HHS	117.00 127.26 116.58	361	1	361	Good per test charge 10
2/15/95	3163	2115	1/2-13 X 2 1/2 HCS	359.55	360	1	360	Good per test charge 12
9/16/94	3073	1200	5/8-11 X 2 1/2 HHB	360.00	360	1	360	Good per test charge 07
5/28/93	2735	1710	1/2-0 X 3 HHS	359.10	359	1	359	Good per test charge 12
10/6/93	2825	54	1 3/4-0 X 12 HHS	523.80	524	1.5	349	Good per test charge 17
10/16/92	2595	129	1 1/2-6 X 6	516.00	516	1.5	344	Good per test charge 17
11/6/92	2609	249	1-8 X 8 HHB	512.94	513	1.5	342	Good per test charge 20
11/4/92	2606	249	1-8 X 8 HHB	512.94	513	1.5	342	Good per test charge 20
4/14/95	3216	1460	1/2-13 X 3 1/2 HCS	335.80	335	1	335	Good per test charge 12
11/11/92	2612	307	1-0 X 6 HHS	500.41	501	1.5	334	Good per test charge 20
8/25/94	3053	975	5/8-0 X 3 HHS	331.50	332	1	332	Good per test charge 07
9/21/92	2572	1500 1610	5/16-0 X 3 HCS 5/16-0 X 6 HCS	105.00 225.40	331	1.5	331	Good based upon data from charge 12, 22[(1)]
10/7/93	2826	1000 1400	1/2-13 X 1 1/2 HHS 1/2-13 X 2 HHS	120.00 210.00	330	1	330	Good per test charge 12
10/23/92	2598	785	5/8-11 X 4 HHB	329.70	330	1	330	Good per test charge 07

Date	Charge	Qty	Description	lbs	Total	Hrs.	lbs/hr	Notes
4/5/91	2242	544 54	3/4-0 X 4 1/2 HHB 1 1/8-0 X 6 HXB	375.36 109.62	485	1.5	323	Good per test charge 11
7/26/94	3024	112	2 1/4-8 HHN	469.28	470	1.5	313	Good per test charge 20
8/30/94	3058	813	5/8-0 X 3 1/2 HHS	308.94	309	1	309	Good per test charge 07
8/6/90	2098	345 335	7/8-0 X 2 1/2 HHS 7/8-0 X 3 HHS	220.80 241.20	462	1.5	308	Good per test charge 13
5/14/91	2261	1269 1694	5/8-0 X 1 1/4 HCS 5/8-0 X 2 HCS	215.73 389.62	606	[illegible]	303	Good per test charge 08
8/89	1877	284	1 5/8-0 HHN	460.00	460	3	303	Good per test charge 08
12/21/93	2882	71 63 65 24	1 3/4-8 HHN 1 3/4-8 HHN 1 3/4-8 HHN 1 3/4-8 HHN	144.84 128.52 132.60 48.96	455	1.5	303	Good per test charge 13
2/19/93	**2675**	**5350**	**3/8-16 X 1 1/2 HCS**	**299.60**	**300**	**1**	**300**	**Failed Lot "TS1"** Test charge 19 passed **Test charge 21 failed**
10/5/92	2585	703	3/4-10 X 4 HHB	442.89	443	1.5	295	Good per test charge 12, 13
10/25/90	2146	110	1 1/2-0 X 6 HHB	440.00	440	1.5	293	Good per test charge 17
4/25/92	2465	242 114	1-0 X 4 HCS 1 1/4-0 X 6 HHS	273.46 304.38	578	2	289	Good per test charge 16
11/13/92	2613	108	1 1/2-0 X 6 HCS	432.00	432	1.5	288	Good per test charge 17
6/18/93	2751	2050	1/2-13 X 2 HCS	287.00	287	1	287	Good per test charge 12
5/17/94	**2969**	**2100**	**3/8-0 X 4 HCS**	**273.00**	**273**	**1**	**273**	**Failed Lot "TS9"** **Test charge 22 failed**
3-10-94	2934	9 23 23 23 23 9 22 22 22 22	1 1/8-0 X 3 1/2 HHS 1 1/8-0 X 3 1/2 HHS 1 1/8-0 X 3 1/2 HHS 1 1/8-0 X 3 1/2 HHS 1 1/8-0 X 3 1/2 HHS 1 1/8-0 X 3 3/4 HHS 1 1/8-0 X 3 3/4 HHS 1 1/8-0 X 3 3/4 HHS 1 1/8-0 X 3 3/4 HHS 1 1/8-0 X 3 3/4 HHS	12.69 32.43 32.43 32.43 32.43 13.32 32.56 32.56 32.56 32.56	273	1	273	Good per test charge 15

Date	Charge	Qty	Description	lbs	Total	Hrs.	lbs/hr	Notes
10/24/92	2599	649	5/8-11 X 4 HHB	272.58	273	1	273	Good per test charge 07
10/7/92	2587	647	3/4-10 X 4 HHB	407.61	408	1.5	272	Good per test charge 11, 13
6/15/94	2995	216	1 1/8-7 X 3 1/4 HCS	272.16	272	1	272	Good per test charge 15
5/18/94	**2970**	**1320**	**3/8-0 X 6 HCS**	**264.00**	**264**	**1**	**264**	**Failed Lot "TS6"** **Test charge 22 failed**
3/30/95	3202	248	7/8-9 X 5.2 HHB	262.88	263	1	263	Good per test charge 10, 15
11/13/92	2614	127	1-0 X 8 HHS	261.62	262	1	262	Good per test charge 15
11/16/92	2617	98	1 1/2-0 X 6 HCS	392.00	392	1.5	261	Good per test charge 17
6/21/94	2999	620	5/8-11 X 4 HHS	260.40	261	1	261	Good per test charge 07
9/2/92	2561	161	1 1/4-0 X 5 1/4 HHB	389.62	390	1.5	260	Good per test charge 17
3/11/93	2680	1250	5/8-0 X 3 HCS	387.50	388	1.5	259	Good per test charge 09
11/6/92	2610	574 110	5/8-0 X 4 HHS 1/2-13 X 2 HHS	241.08 16.50	258	1	258	Good per test charge 07, 12
1/14/93	2649	303	7/8-0 X 6 HHS	369.66	370	1.5	247	Good per test charge 13
1/18/90	1934	178	1 1/4-0 X 4 1/2 HCS	367.00	367	1.5	245	Good per test charge 17
9/15/94	3071	275	7/8-9 X 4 HHB	244.75	245	1	245	Good per test charge 10, 15
6/26/90	2068	322 327	7/8-0 X 3 HHB 7/8-0 X 3 1/4 HHB	231.84 251.79	484	2	242	Good per test charge 8, 16
7/21/93	2769	106 121 120 120 123	3/4-10 X 2 1/2 HHS 3/4-10 X 3 HHS 3/4-10 X 3 1/2 HHS 3/4-10 X 4 HHS 3/4-10 X 6 HHS	47.70 61.71 68.40 75.60 107.01	361	1.5	240	Good per test charge 09, 13
12/23/92	2638	1050	5/8-0 X 3 HHS	357.00	357	1.5	238	Good per test charge 09
11/25/92	2622	110 1140	1/2-13 HHN 5/8-0 X 2 HHS	71.50 285.00	357	1.5	238	Good per test charge 09
11/20/90	2168	91	1 1/2-0 X 6 HCS	354.90	355	1.5	237	Good per test charge 17
5/5/90	2019	112 650	3/4-0 X 2 HB 5/8-0 X 2 1/2 HHB	39.20 195.00	235	1	235	Good per test charge 07, 10
4/6/92	2458	500 606	1/2-0 X 4 HCS 1/2-0 X 6 HCS	125.00 224.22	349	1.5	233	Good per test charge 12

Date	Charge	Qty	Description	lbs	Total	Hrs.	lbs/hr	Notes
5/30/92	2492	274 267 472	5/8-0 X 4 HCS 5/8-0 X 8 HCS 5/8-0 X 6 HCS	109.60 200.25 269.04	579	2.5	232	Good per test charge 08
5/13/92	2479	192 270	7/8-0 X 4 HCS 7/8-0 X 8 HCS	163.20 410.40	574	2.5	230	Good per test charge 14
5/15/91	2262	121 124 125	1-0 X 2 1/2 HCS 1-0 X 3 HCS 1-0 X 8 HCS	96.80 112.84 251.25	460	2	230	Good per test charge 16
12/21/92	2636	490	3/4-0 X 3 HCS	230.30	230	1	230	Good per test charge 10
6/1/91	2274	61	2 1/2-8 HHN	344.04	344	1.5	229	Good per test charge 17
9/9/94	3064	900	5/8-11 X 3 1/2 HHB	342.00	342	1.5	228	Good per test charge 09
2/25/93	2677	5550	3/8-16 X 1 HCS	227.55	228	1	228	Good per test charge 19
12/10/92	2630	305 184	3/4-0 X 3 HHS 3/4-0 X 2 HHS	155.55 71.76	228	1	228	Good per test charge 10
8/21/90	2110	1175	1/2-0 X 4 1/2 HHB	340.75	341	1.5	227	Good per test charge 12
8/26/94	3055	665	5/8-0 X 3 HHS	226.10	226	1	226	Good per test charge 07
8/21/94	3048	22	3 1/2-8 HHN	335.72	336	1.5	224	Good per test charge 17
5/28/94	2980	563	5/8-0 X 6 HHS	332.17	332	1.5	221	Good per test charge 09
1/8/93	2646	226	1-8 X 5 1/2 HCS	329.96	330	1.5	220	Good per test charge 15
3/30/95	3201	157 112	3/4-10 X 5 HHB 7/8-9 X 4 HHB	117.75 99.68	218	1	218	Good per test charge 10, 15
6/22/93	2752	1450	1/2-13 X 2 HHS	217.50	218	1	218	Good per test charge 12
4/6/94	2949	215 151	3/4-0 X 2 HHS 3/4-0 X 6 HHS	83.85 131.37	215	1	215	Good per test charge 10
7/23/93	2771	244	7/8-9 X 4 HHB	214.72	215	1	215	Good per test charge 10, 15
9/2/94	3060	760	5/8-0 X 4 HHS	319.20	319	1.5	213	Good per test charge 09
4/7/93	2701	1010 302	1/2-0 X 3 HHB 1/2-0 X 6 HHB	202.00 111.74	314	1.5	209	Good per test charge 12
2/5/91	2198	550	3/4-0 X 3 1/2 HHB	313.50	314	1.5	209	Good per test charge 09, 13
2/10/90	1947	443 449	5/8-0 X 1 3/8 HHS 5/8-0 X 2 HHS	94.00 115.00	209	1	209	Good per test charge 07

Date	Charge	Qty	Description	lbs	Total	Hrs.	lbs/hr	Notes
8/22/92	2552	1600	3/8-0 X 4 HCS	208.00	208	1	208	Good per test charge 19
4/6/91	2243	548	3/4-0 X 5 HHB	411.00	411	2	206	Good per test charge 11
10/23/91	2363	1700	1/2-13 X 3 3/4 HCS	408.00	408	2	204	Good per test charge 08, 12
2/13/90	1949	43 25 394	3/4-0 X 3 3/4 HHB 3/4-0 X 4 HHB 3/4-0 X 6 1/2 HHB	26.00 16.00 366.00	408	2	204	Good per test charge 11
6/27/92	2511	25 11	2 1/2-0 HHN 2 1/2-0 HHN	141.00 62.04	203	1	203	Good per test charge 15
11/2/92	2604	185	1-8 X 6 HHB	301.55	302	1.5	201	Good per test charge 15
10/30/92	2602	185	1-8 X 6 HHB	301.55	302	1.5	201	Good per test charge 15
4/13/95	3215	67	M42 X 4.5 CAP NUT	201.00	201	1	201	Good per test charge 15
8/3/90	2096	111 2847	1 1/4-0 X 6 HCS 3/8-0 X 1 HXB	286.38 113.88	400	2	200	Good per test charge 16
5/30/91	2270	126 126 126	1-0 X 3 1/2 HHS 1-0 X 4 HHS 1-0 X 6 HHS	138.60 151.20 205.38	495	2.5	198	Good per test charge 16
7/30/90	2092	343 105	1/4-0 HXN 1 1/2-0 X 5 HHB	24.01 367.50	392	2	196	Good per test charge 17
8/17/94	3045	52	2 1/2-0 HHN	293.28	293	1.5	196	Good per test charge 17
8/15/94	3042	52	2 1/2 HHN	293.28	293	1.5	196	Good per test charge 17
7/26/95	3282	318 160	3/4-0 X 2 HHS 3/4-0 X 2 1/2 HHS	124.02 72.00	196	1	196	Good per test charge 10
6/17/93	2749	250 900	1/2-13 X 2 1/2 HCS 1/2-13 X 2 1/2 HCS	42.50 153.00	196	1	196	Good per test charge 12
5/23/94	2974	76 136 144	3/4-10 X 3 1/2 HHB 1-8 X 4 1/2 HHB 5/8-11 X 4 1/2 HHB	43.32 178.16 67.68	289	1.5	193	Good per test charge 09, 15
4/23/92	2464	238	1-0 X 8 HCS	478.38	479	2.5	192	Good per test charge 16

Date	Charge	Qty	Description	lbs	Total	Hrs.	lbs/hr	Notes
3/29/90	1981	50	7/8-0 X 2 3/4 HHB	34.00	285	1.5	190	Good per test charge 13
		50	7/8-0 X 4 HHB	44.50				
		25	7/8-0 X 5 HHB	26.50				
		25	7/8-0 X 5 1/2 HHB	28.50				
		25	7/8-0 X 6 HHB	30.50				
		50	7/8-0 X 3 HHB	36.00				
		50	7/8-0 X 3 1/2 HHB	40.50				
		50	7/8-0 X 4 HHB	44.50				
8/2/91	2324	387	3/4-10 X 3 HXB	185.76	284	1.5	190	Good per test charge 9, 13
		146	1/4-20 X 4 HCS	8.76				
		300	3/4-10 X 1 1/2 HXB	90.00				
2/14/92	2422	696	3/8-16 X 1 3/4 HCS	41.76	282	1.5	188	Good per test charge 12, 19
		999	1/2-13 X 3 3/4 HCS	239.76				
6/27/95	3264	119	1 1/4-0 X 5 HHS	278.46	279	1.5	186	Good per test charge 17
12/30/92	2642	180	7/8-0 X 8 HHS	279.00	279	1.5	186	Good per test charge 13
3/12/91	2330	585	1 1/4-0 HHN	462.15	462	2.5	185	Good per test charge 16
8/1/95	3285	315	3/4-0 X 6 HHS	274.05	274	1.5	183	Good per test charge 10
10/28/90	2149	3160	1/2-0 X 2 HXB	455.04	455	2.5	182	Good per test charge 08
5/22/91	2266	1070	3/4-0 X 2 1/2 HCS	438.70	439	2.5	176	Good per test charge 11
11/20/90	2167	90	1 1/2-0 X 6 HCS	351.00	351	2	176	Good per test charge 17
1/26/91	2195	68	1 1/4-0 X 3 1/2 HHB	124.44	349	2	175	Good per test charge 17
		145	1 1/8-0 X 4 HHB	224.75				
5/26/93	2728	60	2-8 HHN	174.00	174	1	174	Good per test charge 15
4/7/91	2244	78	3/4-0 X 4 HCS	46.80	519	3	173	Good per test charge 14, 16
		393	1-0 X 4 HHB	471.60				
12/9/92	2629	1435	1/2-0 X 3 HCS	172.20	172	1	172	Good per test charge 12
3/6/91	2223	543	3/4-0 X 4 HHB	342.09	342	2	171	Good per test charge 11
3/24/90	1975	125	1 1/4-0 X 4 HHB	250.00	250	1.5	167	Good per test charge 17
5/20/94	2973	1676	3/8-0 X 3 HCS	166.70	167	1	167	Good per test charge 19
6/24/93	2754	770	1/2-13 X 2 1/2 HCS	130.90	247	1.5	165	Good per test charge 12
		680	1/2-13 X 2 1/2 HCS	115.60				

Date	Charge	Qty	Description	lbs	Total	Hrs.	lbs/hr	Notes
12/12/91	2393	288 226 1389	3/4-10 X 1 1/2 HXB 5/8-11 X 2 1/2 HXB 3/8-16 X 1 3/4 HCS	86.40 61.02 97.23	245	1.5	164	Good per test charge 10, 19
3/26/90	1977	353 554	3/4-0 X 2 HHS 1/4-0 X 2 1/2 HCS	137.67 22.16	160	1	160	Good per test charge 10, 19
5/29/91	2269	104	1 1/2-0 X 4 HHS	312.00	312	2	156	Good per test charge 16
6/23/93	2753	2125	1/2-13 X 1 1/2 HCS	233.75	234	1.5	156	Good per test charge 12
6/6/91	2279	1280 805	1/2-0 X 2 1/4 HXB 1/2-0 X 1 3/4 HXB	204.80 104.65	309	2	155	Good per test charge 12
4/5/95	3208	3100	3/8-16 X 1 1/4 HCS	155.00	155	1	155	Good per test charge 19
8/22/90	2111	145 475	3/4-0 X 4 HHB 1/2-0 X 4 1/2 HHB	91.35 137.75	229	1.5	153	Good per test charge 10, 12
6/14/91	2285	982	1/2-0 X 3 1/2 HXB	225.86	226	1.5	151	Good per test charge 12
7/26/94	3025	580	5/8-11 X 2 HHS	150.80	151	1	151	Good per test charge 07
5/1/92	2473	113	1 1/4-0 X 8 HHS	376.29	376	2.5	150	Good per test charge 17
3/11/91	2228	144 143	1-0 X 5 HHB 1-0 X 4 HHB	204.48 171.60	376	2.5	150	Good per test charge 16
5/22/91	2267	1072	3/4-0 X 2 HCS	375.20	375	2.5	150	Good per test charge 11

Note (1) Charge 2572 was determined to be good based primarily upon data from charge 12. In addition to test charge 12, test charge 22 was also considered as a reference. Although test charge 22 was considered to contain non-conforming parts, it very nearly passed. Test charge 22 was referenced because the diameter and length of the parts were similar to charge 2572. The additional 30 minutes charge 2572 was held at temperature, compared to test charge 22, provides adequate assurance that this was a good charge.

Test Charge Results

Test Number	Description	Weight (pounds)	Time (minutes)	Results
01	3/8 x 1" hex cap screws	50	60	Passed
02	3/8 x 1" hex cap screws	300	60	Passed
03	5/8 x 2 1/2", 3" hex cap screws	550	60	Failed
04	5/8 x 2 1/2", 3" hex cap screws	550	90	Failed
05	5/8 x 2 1/2", 3" hex cap screws	330	60	Passed
06	5/8 x 2 1/2", 3" hex cap screws	400	60	Failed
07	5/8 x 2 1/2", 3" hex cap screws	365	60	Passed
08	5/8 x 2 1/2", 3" hex cap screws	610	130	Passed
09	5/8 x 2 1/2", 3" hex cap screws	400	90	Passed
10	3/4" x various length hex cap screws	360	60	Passed
11	3/4" x various length hex cap screws	485	105	Passed
12	1/2 x 3" hex cap screws	360	60	Passed
13	7/8" x various length hex cap screws	465	90	Passed
14	7/8" x various length hex cap screws	575	150	Passed
15	1" x various length hex cap screws	385	60	Passed
16	1" x various length hex cap screws	578	120	Passed
17	1 1/2 x 6" hex cap screws	516	90	Passed
18	3/8 x 1" hex cap screws	300	30	Failed
19	3/8 x 1" hex cap screws	300	60	Passed
20	1 x various length hex cap screws	516	90	Passed
21	3/8 x 1" hex cap screws	331	60	Failed
22	3/8 x 4" hex cap screws	273	60	Failed

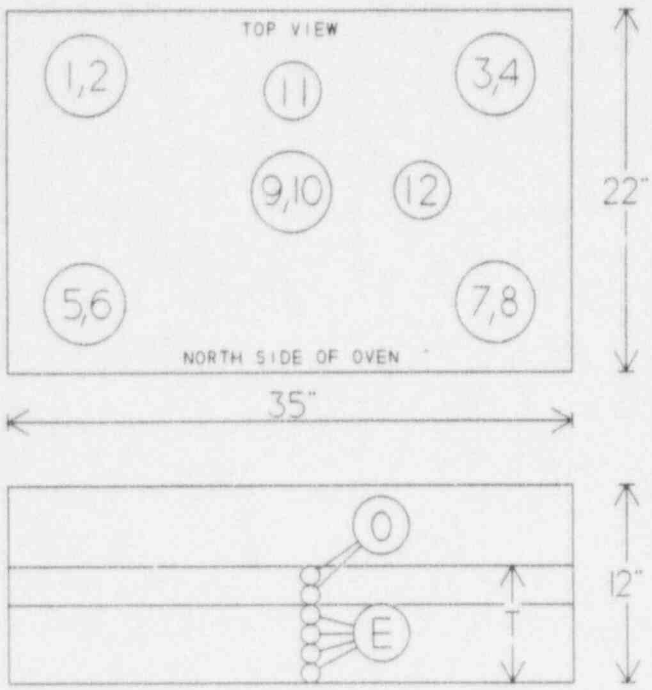
The remaining addendum contains analyses for the above 22 test charges except for charges numbered 1, 2, and 5, which were either superceded or re-performed.

NOTE: To maintain consistency throughout testing, the Rockwell C scale was used to record all hardness values since readings are valid for the entire scale. In normal practice, hardness values would be expressed using a different scale if Rockwell C readings were below 20.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-03	5/8-0 X 2½, 3 AISI 4140	550
Date	**Time @ Temperature (°F)**	**Quench**
9/8/95	1 HOUR @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **6"**

1	52	53	49	
2	41	40	4.4	49
3	52	54	50	
4	35	52	50	3.9
5	51	55	50	
6	53	42	45	54
7	53	52	48	
8	45	44	36	23
9	54	51	50	
10	48	8.2	25	5.0
11	51	17	4	3
12	50	45	25	11
13				

Comments:

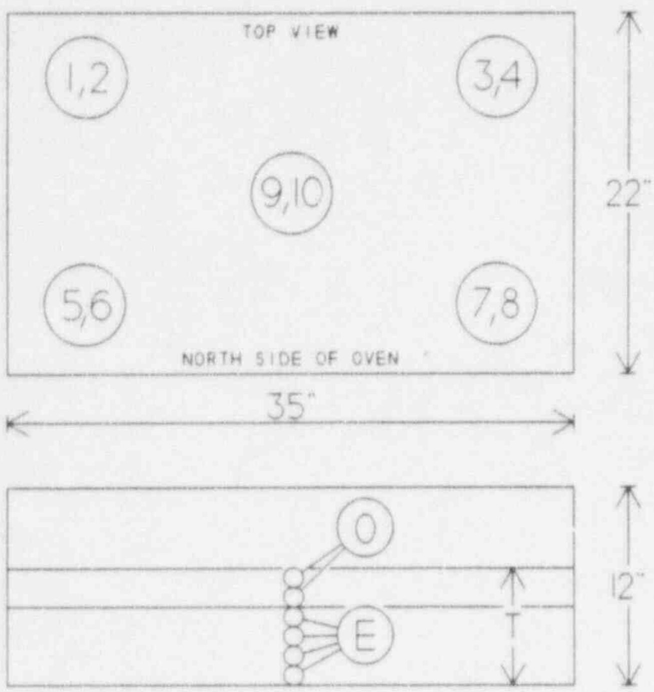
THE ENTIRE CHARGE CONSISTED OF NON-HEAT TREATED BOLTS. THE BOLTS USED FOR TEST COUPONS WERE REMOVED FROM THE LOCATIONS SHOWN ABOVE. THE COUPONS FOR ODD NUMBERED LOCATIONS (O) WERE TAKEN FROM THE TOP TWO INCH LAYER. THE COUPONS FOR EVEN NUMBERED LOCATIONS (E) WERE TAKEN FROM THE BOTTOM FOUR INCH LAYER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN *UNACCEPTABLE* COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-04	5/8-0 X 2½, 3 AISI 4140	550
Date	**Time @ Temperature (°F)**	**Quench**
9/10/95	1 1/2 HOUR @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **6"**

1	55	51		
2	52	47	46	
3	57	48		
4	54	55	40	
5	52	56		
6	54	46	48	
7	52	52		
8	43	55	31	
9	49	52		
10	18	17	57	
11				
12				
13				

Comments:

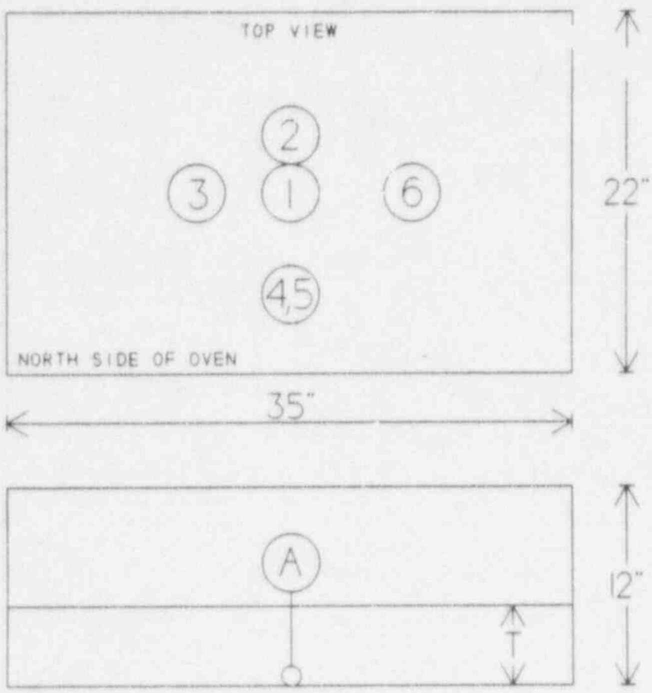
NON-HEAT TREATED BOLTS (2 1/2" LONG) WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF HEAT TREATED BOLTS OF THE SAME DIAMETER. THE COUPONS FOR ODD NUMBERED LOCATIONS (O) WERE TAKEN FROM THE TOP TWO INCH LAYER. THE COUPONS FOR EVEN NUMBFRED LOCATIONS (E) WERE TAKEN FROM THE BOTTOM FOUR INCH LAYER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN *UNACCEPTABLE* COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-06	**5/8-0 X 2½, 3 AISI 4140**	**400**
Date	Time @ Temperature (°F)	Quench
9/11/95	**1 HOUR @1575**	**POLY**

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **5"**

	A	B	C	D
1	**26**			
2	**26**			
3	**51.7**			
4	**41.4**			
5	**42.5**			
6	**36.5**			
7				
8				
9				
10				
11				
12				
13				

Comments:

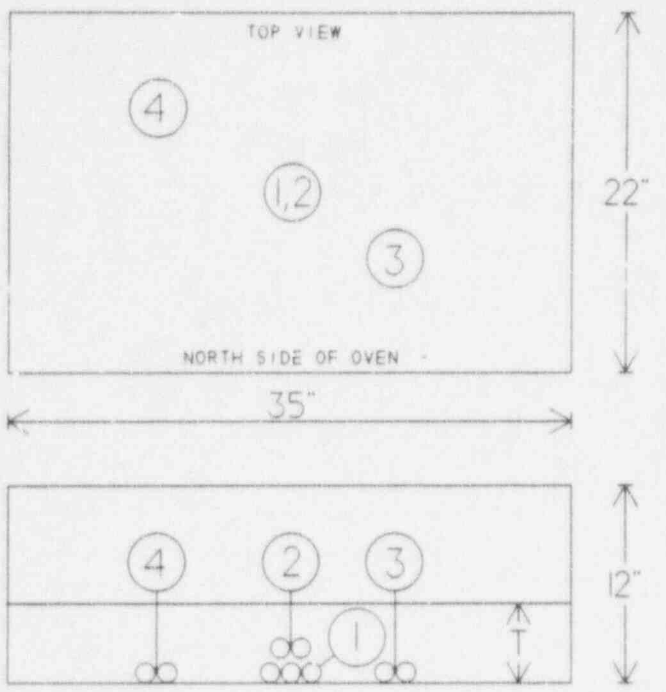
APPROXIMATELY FIFTY POUNDS OF NON-HEAT TREATED BOLTS (2 1/2" LONG) WERE PLACED IN THE BOTTOM SECTION OF THE BASKET AND ARRANGED IN A CIRCLE OF SUFFICIENT AREA TO INCLUDE THE ABOVE COUPON LOCATIONS. THE REMAINDER OF THE CHARGE CONSISTED OF PREVIOUSLY HEAT TREATED BOLTS OF THE SAME DIAMETER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN *UNACCEPTABLE* COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-07	3/4-0 X 2 ½, 3½ AISI 4140	365
Date	**Time @ Temperature (°F)**	**Quench**
9/12/95	1 HOUR @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **5"**

1	49	52	51	
2	51	53		
3	51	52		
4	48	47		
5				
6				
7				
8				
9				
10				
11				
12				
13				

Comments:

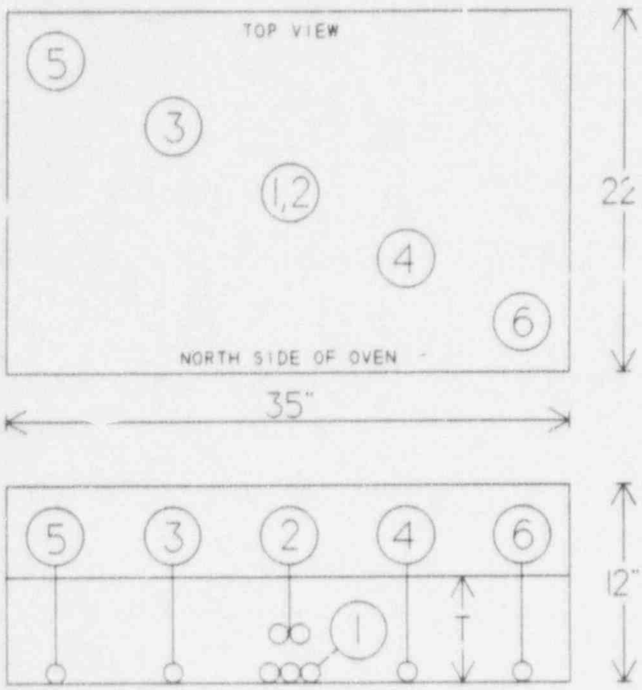
NON-HEAT TREATED BOLTS (2 1/2" LONG) WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF BOTH HEAT TREATED AND NON-HEAT TREATED BOLTS OF THE SAME DIAMETER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-08	5/8-0 X 2½, 3 AISI 4140	610
Date	**Time @ Temperature (°F)**	**Quench**
9/12/95	2 HRS 10 MIN @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): 7"

1	51	52	49	
2	55	54		
3	53			
4	52			
5	52			
6	52			
7				
8				
9				
10				
11				
12				
13				

Comments:

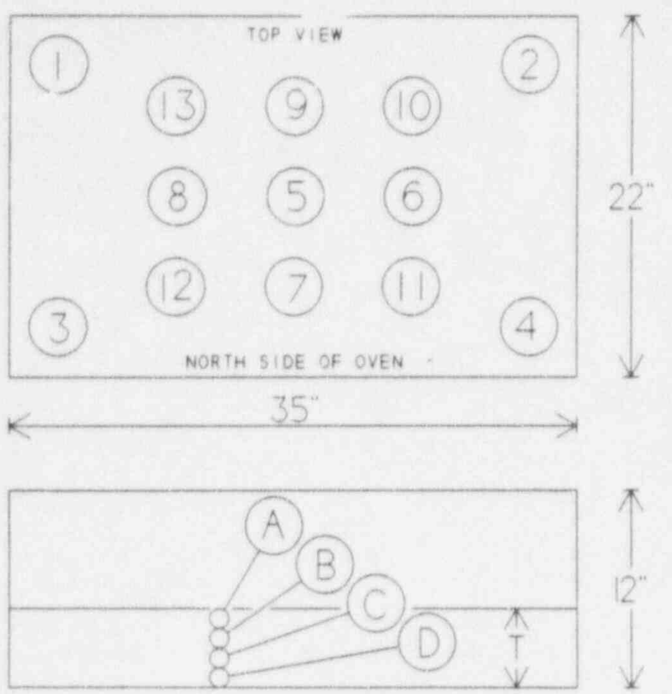
NON-HEAT TREATED BOLTS (2 1/2" LONG) WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF BOTH HEAT TREATED AND NON-HEAT TREATED BOLTS OF THE SAME DIAMETER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-09	**3/4-0 X 2 ½, 3½, 6 AISI 4140**	**400**
Date	**Time @ Temperature (°F)**	**Quench**
9/13/95	**1 HR 30 MIN @1575**	**POLY**

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **4"**

	A	B	C	D
1	54	51	55	53
2	50	52	54	52
3	55	55	51	54
4	49	53	54	54
5	53	53	50	53
6	53	54	52	52
7	53	51	53	54
8	55	53	53	53
9	54	53	55	53
10				53
11				54
12				52
13				54

Comments:

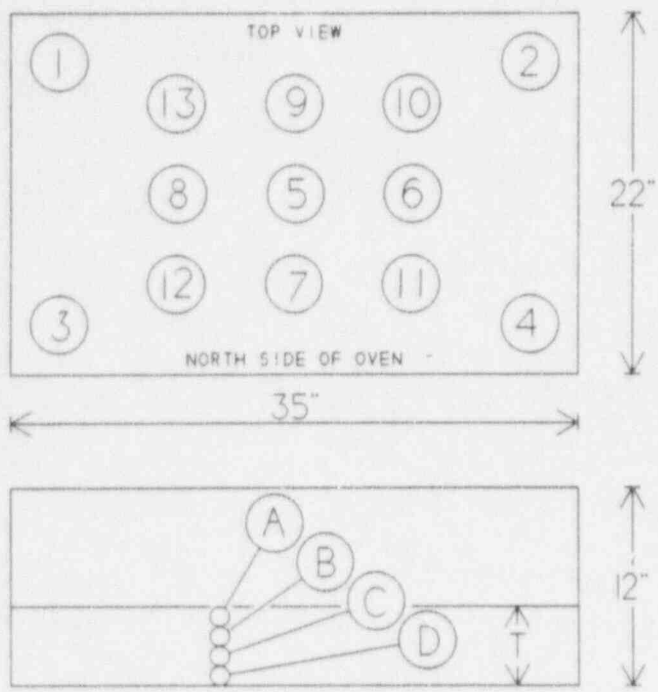
NON-HEAT TREATED BOLTS (2 1/2" LONG) WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF BOTH HEAT TREATED AND NON-HEAT TREATED BOLTS OF THE SAME DIAMETER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-10	**3/4-0 X 2 ½, 3½, 6** **AISI 4140**	**360**
Date	**Time @ Temperature (°F)**	**Quench**
9/13/95	**1 HOUR @ 1575**	**POLY**

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **4"**

	A	B	C	D
1	54	54	56	56
2	55	54	54	55
3	55	56	53	54
4	55	55	54	56
5	55	52	52	52
6	56	55	53	55
7	55	53	55	59
8	53	54	52	54
9	55	54	55	51
10				53
11				56
12				52
13				56

Comments:

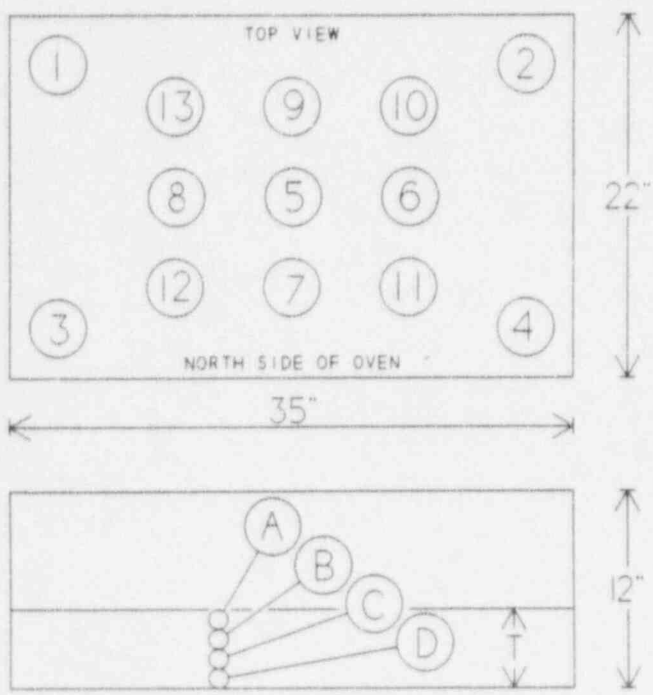
NON-HEAT TREATED BOLTS (2 1/2" LONG) WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF BOTH HEAT TREATED AND NON-HEAT TREATED BOLTS OF THE SAME DIAMETER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-11	**3/4-0 X 2 ½, 3½, 6 AISI 4140**	**485**
Date	**Time @ Temperature (°F)**	**Quench**
9/14/95	**1 HR 45 MIN @1575**	**POLY**

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **5"**

	A	B	C	D
1	54	54	52	58
2	54	54	57	57
3	54	54	54	57
4	52	57	52	53
5	55	56	53	54
6	54	55	50	57
7	50	56	53	53
8	56	52	54	49
9	56	56	54	52
10				54
11				53
12				53
13				56

Comments:

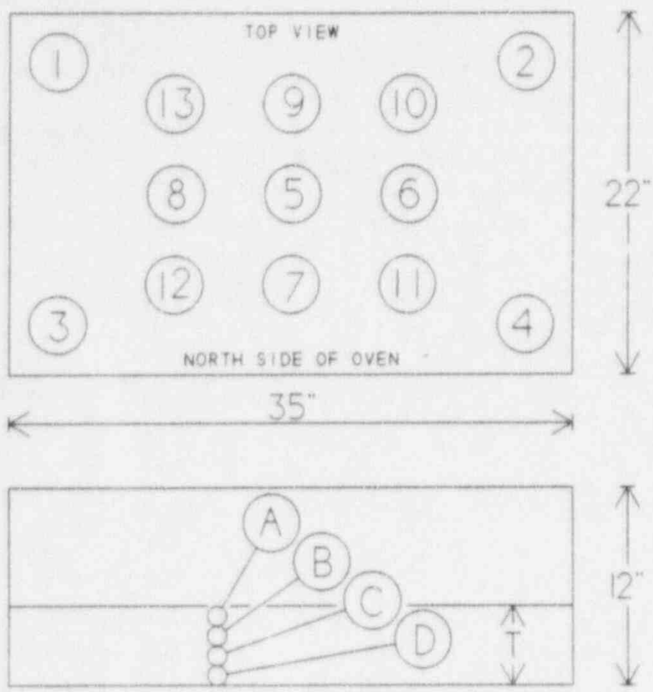
NON-HEAT TREATED BOLTS (2 1/2" LONG) WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF BOTH HEAT TREATED AND NON-HEAT TREATED BOLTS OF THE SAME DIAMETER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-12	**1/2-0 X 2 ½ AISI 4140**	**360**
Date	Time @ Temperature (°F)	Quench
9/14/95	**1 HOUR @1575**	**POLY**

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **4"**

	A	B	C	D
1	**52**	**53**	**51**	**52**
2	**53**	**52**	**53**	**52**
3	**50**	**52**	**54**	**53**
4	**50**	**53**	**53**	**52**
5	**52**	**55**	**48**	**50**
6	**50**	**51**	**51**	**51**
7	**52**	**54**	**51**	**51**
8	**51**	**52**	**50**	**50**
9	**52**	**53**	**51**	**53**
10				**51**
11				**51**
12				**51**
13				**50**

Comments:

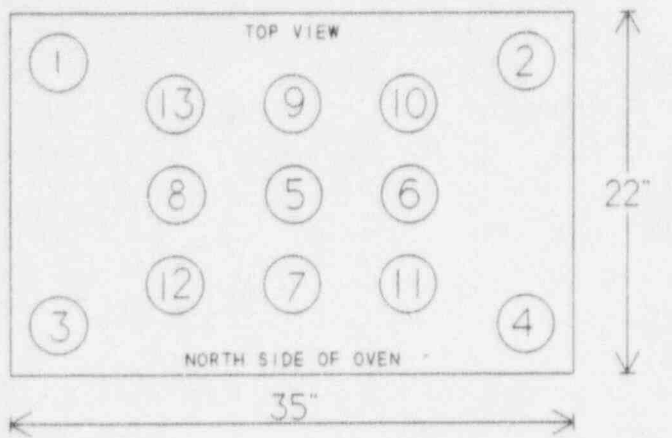
THE ENTIRE CHARGE CONSISTED OF NON-HEAT TREATED BOLTS. THE BOLTS USED FOR TEST COUPONS WERE REMOVED FROM THE LOCATIONS SHOWN ABOVE.

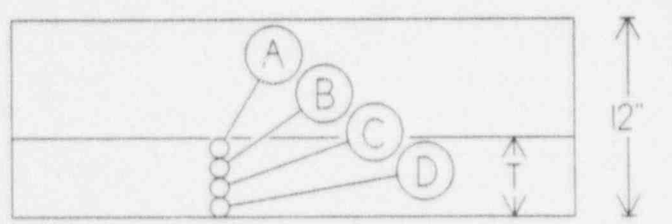
BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-13	7/8-0 X 3, 4 AISI 4140	465
Date	**Time @ Temperature (°F)**	**Quench**
9/15/95	1 1/2 HOURS @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)





Depth of Products (T): **5 1/2"**

	A	B	C	D
1	53	54	51	53
2	54	55	54	52
3	54	54	52	53
4	54	54	53	55
5	51	54	51	53
6	56	53	53	54
7	55	54	52	54
8	52	54	54	54
9	55	54	54	51
10				52
11				52
12				52
13				52

Comments:

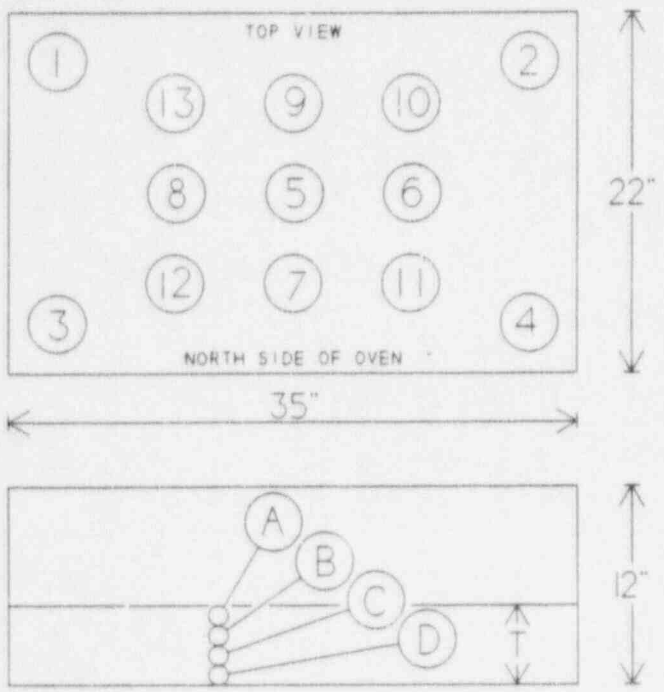
NON-HEAT TREATED BOLTS WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF HEAT TREATED BOLTS OF THE SAME DIAMETER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-14	7/8-0 X 3, 4 AISI 4140	575
Date	**Time @ Temperature (°F)**	**Quench**
9/15/95	2 1/2 HOURS @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **6 1/2"**

	A	B	C	D
1	53	54	53	53
2	55	52	54	53
3	53	53	56	55
4	55	54	55	52
5	49	54	55	55
6	55	54	53	54
7	54	52	54	53
8	54	53	52	55
9	55	54	54	55
10				54
11				54
12				55
13				54

Comments:

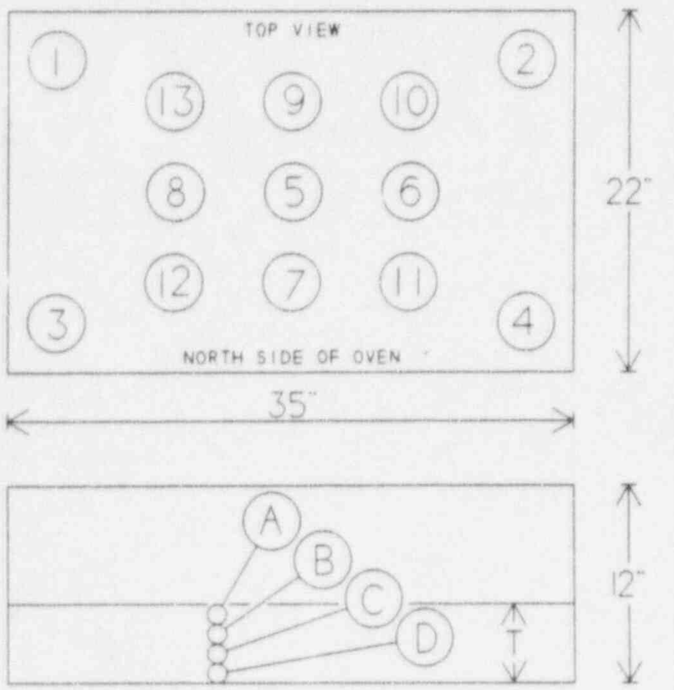
NON-HEAT TREATED BOLTS WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF HEAT TREATED BOLTS OF THE SAME DIAMETER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-15	**1-0 X VARIOUS** **AISI 4140**	**385**
Date	**Time @ Temperature (°F)**	**Quench**
9/16/95	**1 HOUR @1575**	**POLY**

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **5"**

	A	B	C	D
1	54	56	53	54
2	55	55	56	54
3	53	54	54	56
4	54	53	54	55
5	54	55	56	54
6	56	54	55	54
7	55	55	54	54
8	51	54	54	55
9	56	54	54	55
10				53
11				56
12				55
13				54

Comments:

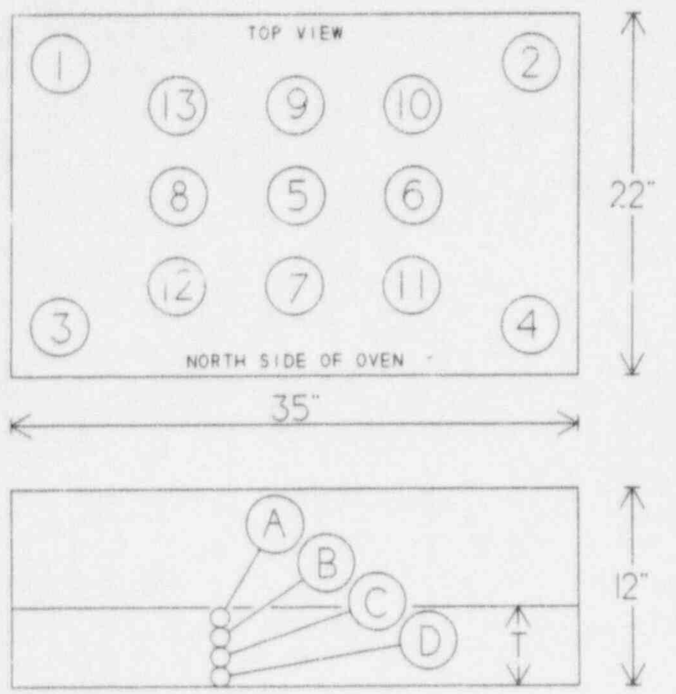
NON-HEAT TREATED BOLTS WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF HEAT TREATED BOLTS OF THE SAME DIAMETER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-16	1-0 X VARIOUS AISI 4140	578
Date	**Time @ Temperature (°F)**	**Quench**
9/16/95	2 HOURS @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): 7"

	A	B	C	D
1	58	56	54	54
2	55	54	54	55
3	55	53	54	53
4	55	55	53	57
5	55	55	56	54
6	56	54	55	56
7	51	52	51	52
8	55	58	54	57
9	52	56	53	52
10				56
11				61
12				57
13				53

Comments:

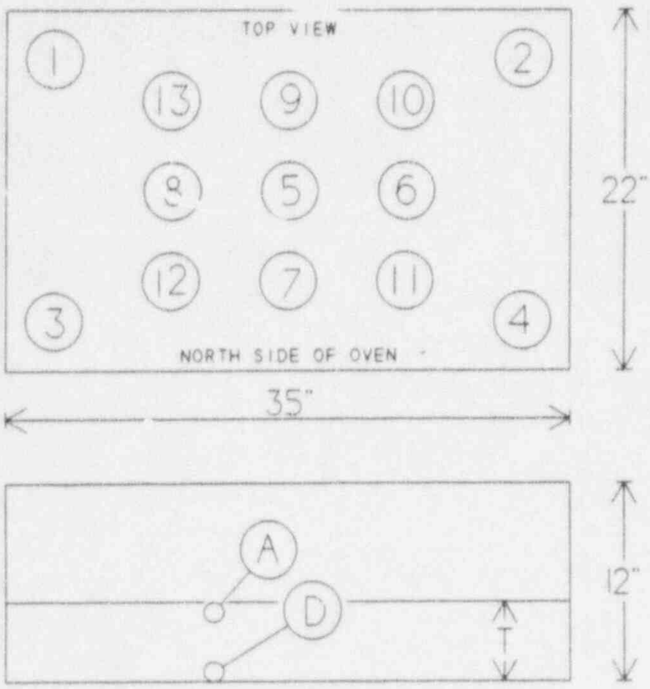
NON-HEAT TREATED BOLTS AND 1" DIAMETER X 4" COUPONS WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPONS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF HEAT TREATED BOLTS OF THE SAME DIAMETER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-17	1 1/2-0 x 5 AISI 4140	516
Date	**Time @ Temperature (°F)**	**Quench**
9/18/95	1 1/2 HOURS @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **4"**

	A	B	C	D
1	51			54
2	50			51
3	54			52
4	54			51
5	52			52
6	52			53
7	51			54
8	54			52
9	54			54
10				53
11				53
12				53
13				53

Comments:

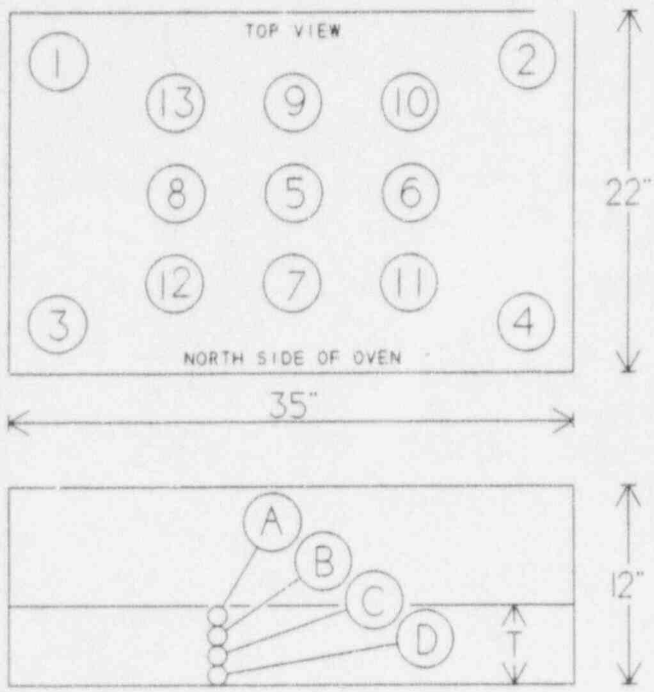
THE ENTIRE CHARGE CONSISTED OF NON-HEAT TREATED BOLTS. THE BOLTS USED FOR TEST COUPONS WERE REMOVED FROM THE LOCATIONS SHOWN ABOVE.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-18	3/8-0 x 1 AISI 4140	300
Date	**Time @ Temperature (°F)**	**Quench**
9/18/95	1/2 HOUR @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): 2 1/2"

	A	B	C	D
1	57	54	54	51
2	55	55	44	54
3	55	56	55	51
4	54	53	54	54
5	55	42	1	5
6	53	45	12	1
7	48	49	14	1
8	47	47	11	3
9	53	53	41	1
10				1
11				1
12				1
13				7

Comments:

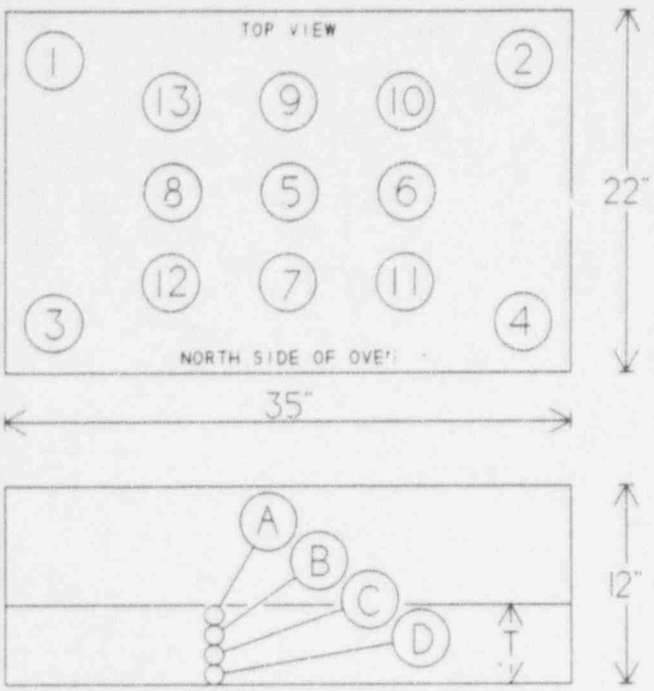
NON-HEAT TREATED BOLTS WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF HEAT TREATED BOLTS OF THE SAME SIZE.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN *UNACCEPTABLE* COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-19	3/8-C x 1 AISI 4140	300
Date	**Time @ Temperature (°F)**	**Quench**
9/18/95	1 HOUR @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): 2 1/2"

	A	B	C	D
1	55	56	56	55
2	56	56	56	55
3	55	56	56	55
4	56	55	53	56
5	55	54	54	52
6	54	56	53	50
7	55	55	52	54
8	55	54	54	50
9	56	56	55	53
10				52
11				51
12				55
13				52

Comments:

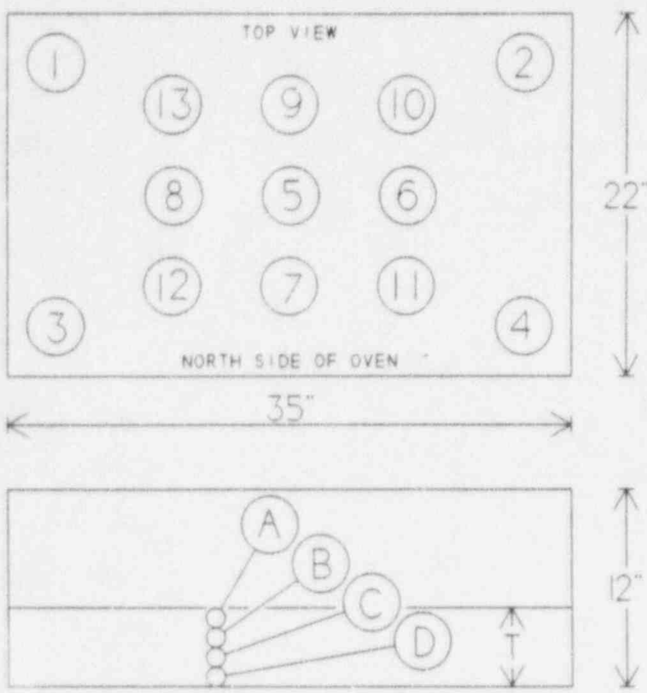
NON-HEAT TREATED BOLTS WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF HEAT TREATED BOLTS OF THE SAME SIZE. THIS LOT PURPOSEFULLY TAKEN OUT OF THE OVEN SLOWLY. OPEN OVEN TO QUENCH TIME WAS ~45 SECONDS.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-20	1-0 X VARIOUS AISI 4140	516
Date	**Time @ Temperature (°F)**	**Quench**
9/19/95	1 1/2 HOURS @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): 7"

	A	B	C	D
1	57	55	55	55
2	54	56	57	51
3	54	55	55	50
4	55	54	55	54
5	56	56	54	53
6	54	55	55	55
7	54	55	55	53
8	52	54	55	55
9	55	55	55	54
10				55
11				55
12				55
13				56

Comments:

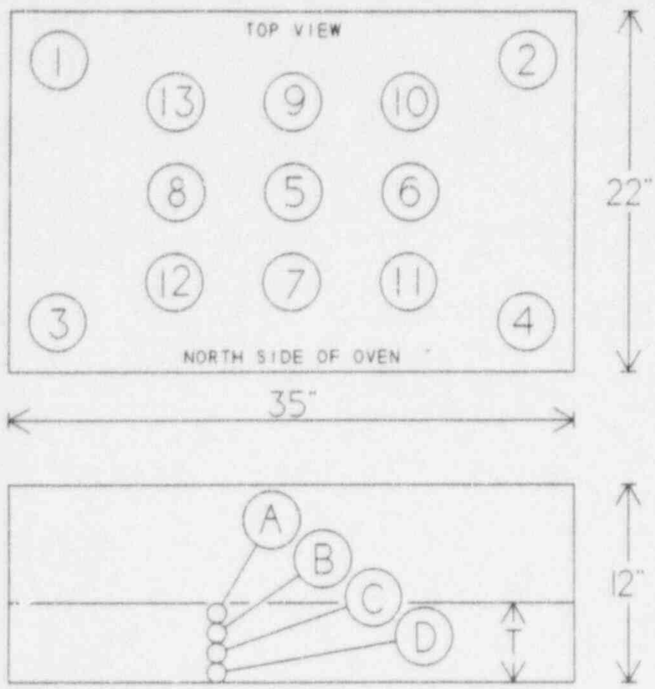
1" DIAMETER X 4" COUPONS WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE REMAINDER OF THE CHARGE CONSISTED OF HEAT TREATED BOLTS OF THE SAME DIAMETER.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN ACCEPTABLE COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-21	3/8-0 x 1 AISI 4140	331
Date	**Time @ Temperature (°F)**	**Quench**
9/20/95	1 HOUR @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): 2 1/2"

	A	B	C	D
1	55	54	55	54
2	53	56	54	53
3	49	54	54	53
4	58	56	56	56
5	50	53	23	1.3
6	54	50	47	8
7	55	54	53	34
8	56	54	45	16
9	55	54	48	29
10				40
11				38
12				26
13				46

Comments:

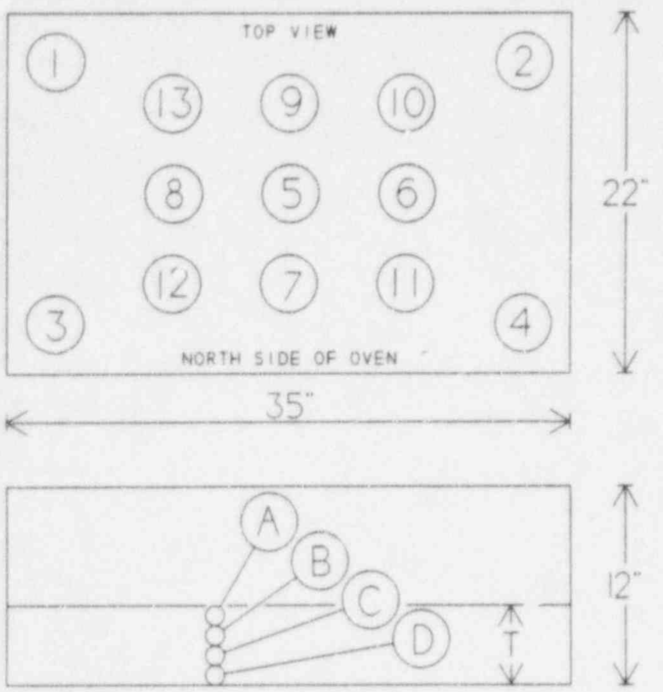
NON-HEAT TREATED BOLTS WERE PLACED IN THE LOCATIONS SHOWN ABOVE. THE TEST COUPON BOLTS WERE IDENTIFIED BY STAINLESS STEEL WIRE WRAPPED AROUND THE SHANK. THE REMAINDER OF THE CHARGE CONSISTED OF BOTH HEAT TREATED AND NON-HEAT TREATED BOLTS OF THE SAME SIZE.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN *UNACCEPTABLE* COMBINATION OF DIAMETER, WEIGHT, AND TIME.

As Quenched Heat Treat Charge Analysis

Test	Product	Weight (pounds)
ZBG-TEST-22	3/8-0 x 4 AISI 4140	273
Date	**Time @ Temperature (°F)**	**Quench**
9/20/95	1 HOUR @1575	POLY

Test Coupon Locations and Hardness Readings (HRC)



Depth of Products (T): **2"**

	A	B	C	D
1	51	51	52	47
2	52	51	52	49
3	53	51	51	51
4	52	53	49	50
5	52	50	34	17
6	53	48	47	42
7	52	49	45	42
8	51	52	50	48
9	48	45	46	44
10				49
11				46
12				46
13				43

Comments:

THE ENTIRE CHARGE CONSISTED OF NON-HEAT TREATED BOLTS. BOLTS WERE NEATLY ARRANGED IN FIVE ROWS TO SIMULATE A COMMON PRACTICE WHICH PREVENTS WARPING OF THE SHANKS.

BASED UPON THE HARDNESS VALUES, THIS CHARGE IS CONSIDERED AN *UNACCEPTABLE* COMBINATION OF DIAMETER, WEIGHT, TIME, AND BASKET LOADING.

Heat Treatment Equipment

General: The heat treatment equipment at the Cardinal facility consists of a basic electric furnace, a separate quench tank containing a polymer solution, as well as several instrumentation and control systems.

Furnace: The furnace has two main components, the base and the door. The base is supported by a steel structure at a height of 4 1/2 feet above the foundation (just lower than the top of the adjacent quench tank). The door is supported by the same structure, and moves vertically to allow for insertion and removal of the parts basket. The door operates hydraulically with a total travel of approximately 30 inches. A rack supported by bricks rests in the center of the base. The basket containing the parts being heat treated is placed on the rack. Both the rack and the basket are made from Inconel. The furnace door houses the heating elements and the thermocouple. There are eleven rows of heating elements; two on each side and three across the ceiling. Side views of the furnace door and base are shown below as Figures 1 and 2. Figure 1 is the view from the quench tank. Figure 2 is the view from the side perpendicular to the quench tank.

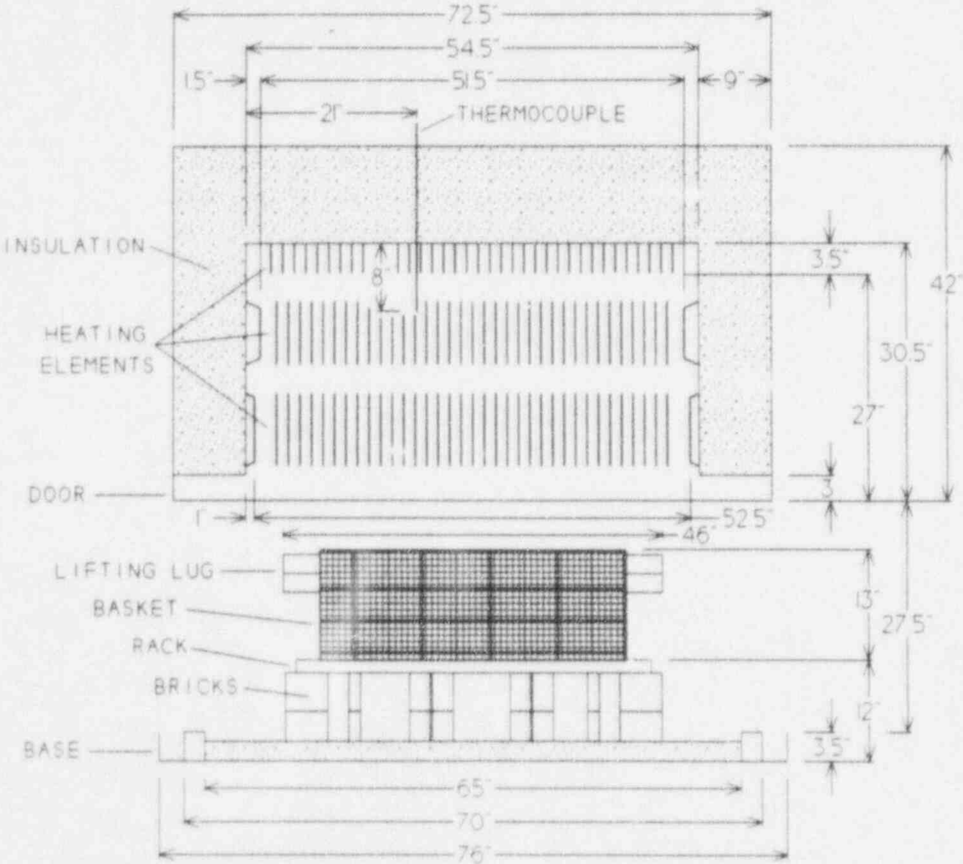


Figure 1 - Furnace Side View Facing Quench Tank

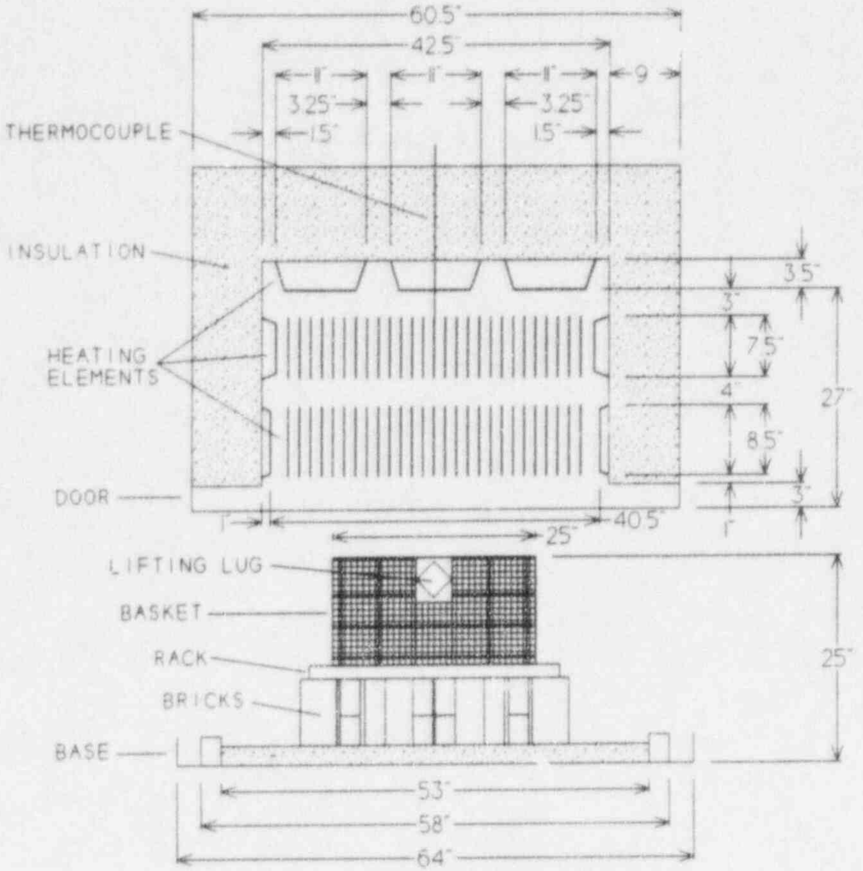


Figure 2 - Furnace Side View

Figure 3 is a side view of the furnace with the oven door in the closed position. With the oven door closed, there is approximately 2 1/2 inches of clearance between the top of the basket and the upper heating elements. The thermocouple protrudes eight inches from the ceiling and extends into the basket approximately two inches.

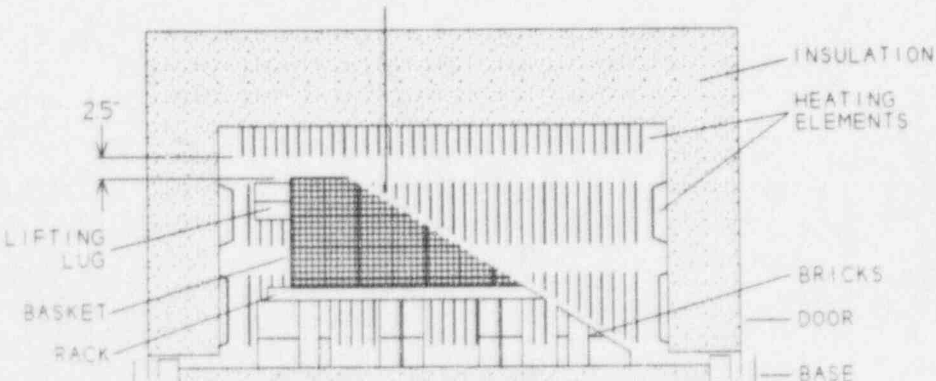


Figure 3 - Furnace Door Closed

Figure 4 is a top view (and side view) of the base with the bottom of the figure facing the quench tank. The bricks used to support the rack are arranged in a symmetrical pattern as shown.

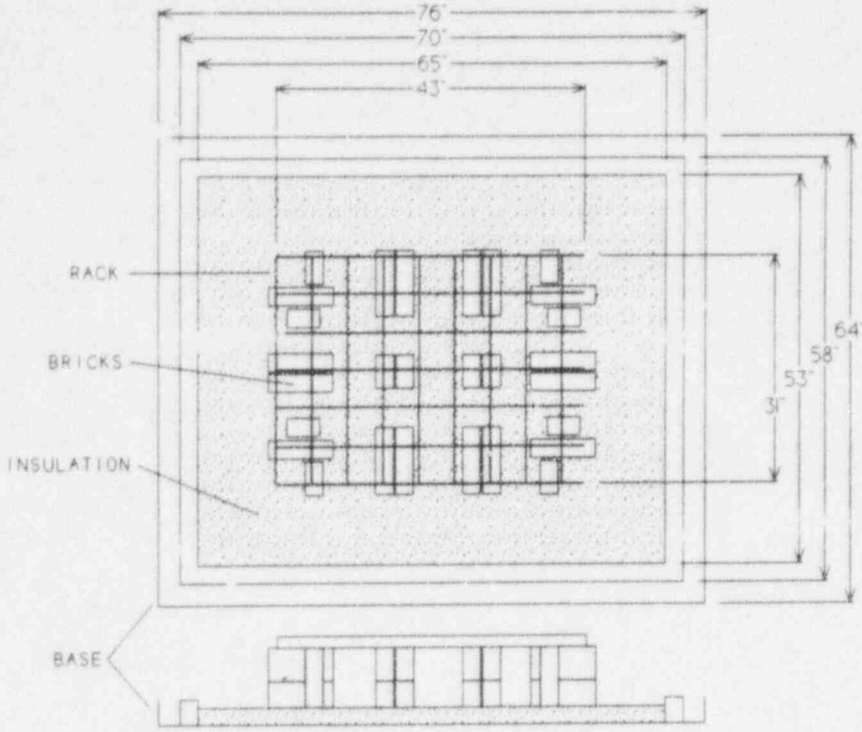


Figure 4 - Top View of Base

Figure 5 is a top view with the same perspective as Figure 4. This view shows the parts basket placed on the rack and a cutaway view of the door showing the clearance between the basket and the side heating elements.

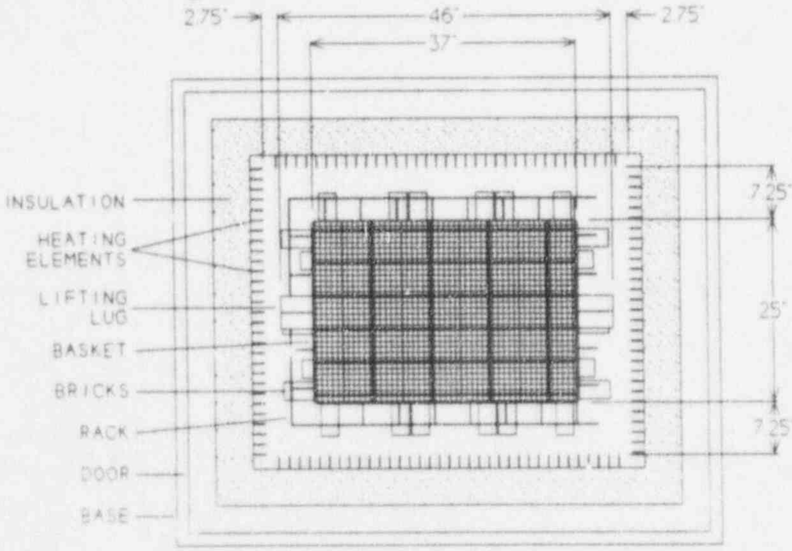


Figure 5 - Top View of Base with Basket

Figure 6 is a top view of the door as viewed from the base looking up. The right side of the drawing faced the quench tank. This view shows the upper three rows of heating elements and the location of the thermocouple.

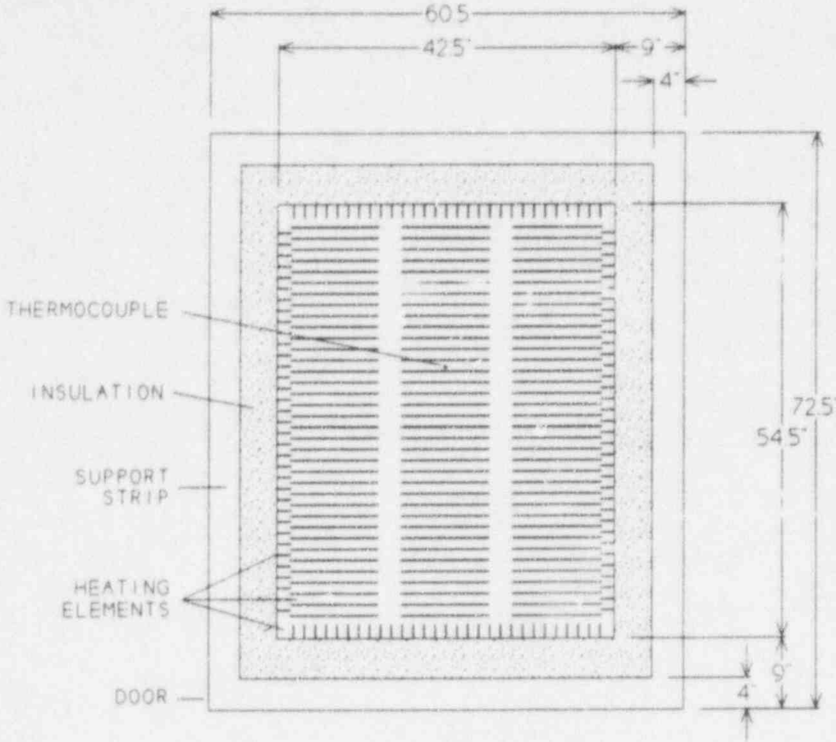


Figure 6 - Top View of Door

Quench Tank: The quench tank is located adjacent to the furnace. The tank contains 2,390 gallons of a polymer based quenchant. The polymer is suspended in water and precipitates out onto the hot parts when they are lowered into the tank. This provides an insulative layer which controls the rate of temperature drop. The polymer returns into solution as the parts cool. The polymer is a suitable replacement for oil as a quenchant, except for specifications which specifically state parts must be quenched in oil. The quenchant is circulated by an agitator assembly located at the bottom of the tank. The agitator ensures a continuous flow of quenchant through the parts basket during the quench. The polymer quenchant in maintained at approximately 125°F for quenching A/SA 193 Grade B7 products.

Instrumentation and Controls: The signal from the thermocouple is sent to a control panel which automatically maintains the furnace temperature by controlling the power to the heating elements. The temperature is maintained within a tolerance of ±15°F. The temperature signal also feeds a strip chart recorder which plots temperature against time.

Other: The oven door, basket crane, and agitators are all operated by individual hydraulic systems.