Failure Analysis of Split Roll Pins from Omaha Public Power District

August 15, 1991

File Number PH-35-91-004

Prepared by:

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MATERIAL EVALUATION REPORT

OFFICE OF DIRECTOR -- RESEARCH & DEVELOPMENT

UNION PACIFIC RAILROAD, OMAHA

WRITTEN BY: Hans C. Iwand, P.E. DATE: August 15, 1991 CASE NUMBER: PH-35-91-004

SUBJECT:

Failure analysis of two split roll pins from Omaha Public Power District

INTRODUCTION:

On July 23, 1991, three roll pins (one broken into several pieces, one cracked, the third in an as-received pin) were received at the Union Pacific Research and Development Laboratory for failure analysis. A request was made for determination of failure mode, as well as ascertaining whether the failure of the pins was incurred due to environment and or use, or whether the failure was due to manufacture.

MATERIALS SUBMITTED:

a. Three 1/4-inch outside diameter, three-inch long split roll pins.
b. Two pages of hand-written notes from Mr. Dr. Bob Lisowyj.
c. Two assembly prints, identified as: A-5617 and AC-1098A respectively.
d. A copy of the ANSI standard pertaining to taper, straight, grooved, and spring pins (number of standard illegible).
e. A hand-written note, on stationary printed for Donald G. Flegle, dated 7/18/91, stating that the machinist who installed and removed the roll pins used no lubricant.

All of the aforementioned materials are shown in Appendix 1.

CONCLUSIONS:

1. Having assessed the various mechanisms which cause embrittlement in steels, temper-embrittlement is the cause for failure of the split roll pins submitted.

2. The approximate double-shear strength of the pin shows that the pin would fail under a load of 6,916 pounds. The reported design strength of the pin is 7,700 pounds. The pins appear to be correctly hardened and are of the proper cross-sectional area for the reported mechanical properties.

3. Since subsurface cracking was found in all of the pins, and all of the cracks emanate from lines of inclusions, the pins had failed prior to installation, and not due to the operating conditions.

4. Due to the segregation found in the micro-structures, and the tempered martensitic micro-structure; the failure of the pins is attributed to either heat-treatment, or the manufacture of the steel itself during solidfication of the ingot. By reducing the amount of banding, and carefully controlling heat-treatment processes, this type of embrittlement will not occur.

EXPERIMENTAL:

Each of the pins was separated and labeled with a distinct label. The fractured was broken into at least five pieces, four of which were submitted, and was labeled as Pin #1. The cracked, but still intact pin was labeled as Pin #2. The last pin which was submitted "as-received" was labeled as Pin #3.

The dimensional characteristics of Pin #2 were measured using a Mitutoyo 12-inch dial indicator. The cracking of the pin was observed to branch slightly, with a bowing crack that had almost caused complete separation of a semic-circular portion of the pin. The length of the section was also measured. By slightly bending the pin (not enough to cause permanent deformation), the smaller portion of the pin was removed. This section was attached to an aluminum stub for scanning electron microscopical analysis of the fracture surface.

One of the four sections of Pin #1 was mounted in a clear mounting media for metallographic analysis. The mount was ground and polished in a six step method, beginning with 240 grit abrasive paper and finishing with a 1.0 micron diamond polish. The mount was cleaned using an ultrasonic bath, with a small amount of Micro detergent between grinding steps. After completion of the polishing process, the pin was observed at magnifications from 50x to 1000x in a Leitz metallovert optical metallograph. The part was then etched using a 2% Nital solution, and again observed at various magnifications. The mount was re-polished and micro-hardness measurements were conducted in random areas. A Rockwell Tukon micro-hardness tester (next calibration due January 1992) using 500 gram loading, a Knoop diamond indenter, and 40x objective was utilized for the measurements. A micro-hardness standard was used to verify the accuracy of the operator and equipment.

The chemical composition of Pin #1 was determined using an ARL optical emission spectrometer. Due to the limitations of sample size for further chemical analysis, it was necessary to section another of the four pieces using a water cooled cut off wheel, and mount the piece in a copper media. The copper media allows for not only electrical conductivity, but also acted as a flat surface to cover the opening within the spectrometer. By carefully locating the section in the machine, it was possible to obtain a chemistry of the pin without interference by the copper. An NIST 1263A standard was run after the pin analysis to verify the accuracy of the equipment (see Appendix 2).

To achieve an understanding of the fracture mechanism the section from Pin #2 was observed in the scanning electron microscope (SEM), and a photograph was made of the fracture surface. Energy dispersive x-ray analysis was also performed on the fracture surface.

In order to verify the hardness levels of all of the submitted pins, samples from Pin #2 and Pin #3 were cut using a water cooled cut off wheel, and micro-hardness measurements were performed in an identical manner as already reported.

By identifying the fracture as intergranular, several enchants were utilized to further determine the failure mechanism. Utilizing another piece of Pin #1, a metallographic mount was placed in a carbon media for metallographic analysis using the SEM. The etchant utilized was a saturated picral with the addition of sodium tridecylbenzene sulfonate as a wetting agent [1]. After observing the microstructure at various magnifications, the mount was removed and etched using Oberhoffer's reagent [2]. The mount was again removed and etched using a 2% Nital etchant. Several photographs were made of the microstructures observed.

The mount of Pin #2 and Pin #3 used previously for micro-hardness measurements was repolished using 1.0 micron diamond compound and etched using the Oberhoffer's reagent. This microstructure was observed and photographed using the Leitz metallovert.

RESULTS & DISCUSSION:

The chemical analysis confirmed the written notes from Dr. Bob Lisowyj that the pin was manufactured according to ASTM A682 in a 1070 condition. The results obtained (see Appendix 1) showed that the carbon content was slightly higher than the allowable range, however, all other concentrations were within the allowable range (see Appendix III for a copy of the ASTM A682 standard)[3]. The ASTM A682 standard does not identify a specific hardness level at which the material is to be utilized. This is fairly obvious, since the standard is specific to a type of material and not the various conditions under which the material can be utilized, for instance

when heat treated. The hardness level of all of the pins was relatively uniform. Listed below in Table 1 are the hardness values as measured with the converted Rockwell "C" hardnesses (HRc), listed in parenthesis.

Table 1 Micro-hardness Knoop scale and HRc

Pin 1	Pin 2	Pin 3
513 (48)	525 (49)	545 (50)

From the hardness level it is apparent that the steel is in a heat-treated condition. In order to determine the characteristics of the micro-structure(s) and the cause for failure, it was necessary to rely on microscopical analysis.

The fracture surface from Pin #2 as observed in the SEM is shown in Photograph 1. The "rock-candy" type appearance is a characteristic of intergranular failure. For carbon steels to fail in such a manner some type of embrittlement phenomenon must be present. In general, there are five common mechanisms which cause intergranular failure in steels The first is stress corrosion cracking (SCC). Three specific characteristics must be present for SCC to occur. The first is an applied tensile stress, secondly, a susceptible material, and thirdly, a corrosive environment. After extensive discussions with Mr. Chuck Bloyd - O.P.P.D on August 2, 1991, it appeared that the environment under which the pin operated was relatively free of corrosive agents. Based on this information SCC was rejected as the cause for failure.

Another relatively common cause of intergranular failure in heat treated steels is quench cracking. This type of failure is caused by the internal stresses which are present during rapid cooling of the steel during heat-treatment. During cooling of the structure some areas cool more quickly than others which causes uneven distortion of the part and cracks form preferentially at the grain boundaries of the material due to their lower strength during cooling. As alluded to, quench cracks are generally found in large components with relatively large changes in section. Clearly, the split pins do not conform to such a geometric condition; therefore, quench cracking was also discounted as the failure mechanism.

In certain conditions the addition of certain lubricants and anti-seize materials which contain metals can embrittle steels, known as liquid metal embrittlement. Liquid metal embrittlement requires a liquid phase to be present during the normal operation of a component. According to the information provided (and as evidenced by the material the pins are manufactured from) there is no possibility of liquid metal embrittlement being the cause for failure.

Hydrogen embrittlement is a relatively common cause for intergranular failure. Generally, if mono-atomic hydrogen can enter the micro-structure of heat-treated steel, the embrittlement mechanism will occur. In order to remove the hydrogen, it is only necessary to heat the part for a given amount of time. Since the pins were reported to have been in service for approximately 50 to 100 cycles at temperatures reaching 140°F, hydrogen embrittlement is not a likely source for failure.

The fifth method for embrittlement is referred to as temper embrittlement. In general, reference is made to either one-step or two-step embrittlement. One-step embrittlement, commonly referred to as 350°C embrittlement is found in high-strength low-alloy steels which have quenched and tempered martensitic microstructures. In general the steel must be tempered for shorter periods of time (approximately one-hour) and below 400°C A feature of one-step embrittled steels is intergranular failure along prior austenitic grain boundaries. The presence of phosphorous, nitrogen, possibly sulfur, and manganese can all influence embrittlement. Two-step embrittlement occurs in some tempered alloy steels that are isothermally aged between 375°C and 560°C, or are slowly cooled after tempering. The presence of tin, antimony, or phosphorous (in order of sensitivity) is necessary for embrittlement to occur [4]. The optical emission spectrometer used to determine the chemical analysis on the pins is not capable of detecting tin and arsenic in its current configuration. Manganese is known to act as an embrittlement "enhancer", and as can be noted from the chemistry shown in

Appendix I, there is a significant amount of not only manganese, but phosphorus as well (though both are within the allowable tolerances).

Though temper-embrittlement is not a "new" problem to the heat-treating industry, the precise explanation for the embrittlement is still being determined at this time. From a failure analysis point of view it is perhaps not necessary to establish the theory to the embrittlement, rather it is necessary to specify the most probable cause for the failure. Several characteristics are known to be present during metallographic investigation which must be present for temper-embrittlement to be the cause for failure. Some of the metallographic features necessary to conclude temper-embrittlement are: tempered martensitic micro-structure, undissolved carbides located at prior-austenitic grain boundaries, and phosphorus at prior-austenitic grain boundaries [5]. Photographs 2-5, were taken from a metallographic mount made from Pin #1. The piece was oriented so that the micro-structure could be observed along the edge of the pin that was created during manufacture (note Figure 1). As can be seen in Photograph 2, a tempered martensitic micro-structure, with segregation (cracking) at prior-austenitic grain boundaries is present. Photograph 3 shows intergranular cracking emitting from a line of inclusions. Photograph 4 is of a similar crack to that shown in Photograph 3, however, through different etching techniques undissolved carbides can be seen decorating the line of inclusions. Photograph 5 is a higher magnification view of the carbides in and around the prior-austenitic grain boundaries. Photograph 6 is from Pin #3 (see Figure 1 for the orientation), by using Oberhoffer's etchant which preferentially etches phosphorous white, it is observable that phosphorus exists in variable concentrations throughout the micro-structure [ibid.]. Photograph 7 is from Pin #3, in an un-etched condition, using Nomarski contrast. The as-recieved pin shows evidence of an intergranular crack following along a line of inclusions. Since several of the documented temper-embrittlement characteristics are present, the failure of the pin is concluded to be due to temper-embrittlement. In order to determine whether the cause for failure is one or two-step embrittlement it will be necessary to perform more costly and technically sophisticated laboratory analysis, such as Auger electron spectroscopy. A more pragmatic method and however, not necessarily available is to review the heat-treatment records that may have been recorded during production of the split-roll pins, and a determination could be made as to the most probable cause for failure.

Since the cracks were found to be subsurface and emanating from lines of inclusions, the failure of the pins is attributable to the manufacture and or heat-treatment of the steel, and not the environment or application of the pins, as other than some slight amount wear being present, no other evidence of degredation could be attributed to its application and use.

Dis-regarding the temper-embrittlement an attempt was made to determine whether in theory based on the hardness and cross-sectional area of the pin it would meet 7,700 pounds of shear according to the ANSI standard provided by O.P.P.D.. This was estimated using the average hardness values measured from the three pins to determine tensile-strength. Using the cross-sectional area of the pin (disregarding the missing area due to split in the pin), and shear-strength being one-half of tensile strength (based on Mohr's circle), it was possible to estimate the approximate shear force. The result obtained was within 10% of the reported value, therefore, from a design point of view the pin appears to be within design requirements. See Appendix III for the calculation.

REFERENCES

1. Vandervoort, G. F., Metallography - Principles and Practice, McGraw-Hill Book Company, 1976. pp. 157.

2. Vandervoort, G. F., Metallography - Principles and Practice, McGraw-Hill Book Company, 1976., pp. pp. 6, 534.

3. ASTM Standards, Volume 3.01., 692-90.

4. Smith, W., Structure and Properties of Engineering Alloys, McGraw-Hill Company, 1981., pp. 152-156.

5. Kraus, G., Steels: Heat Treatment and Processing Principles, ASM International, 1989., 205-239.

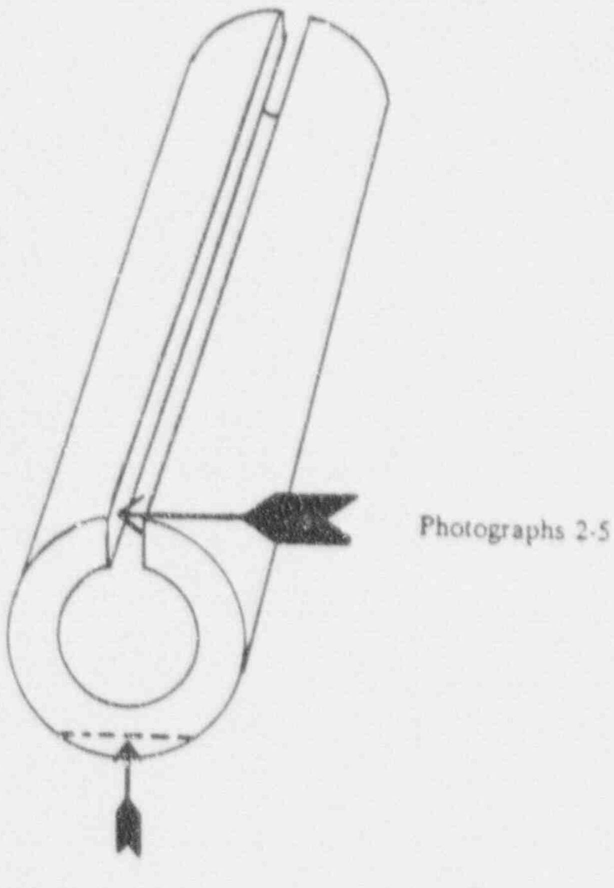
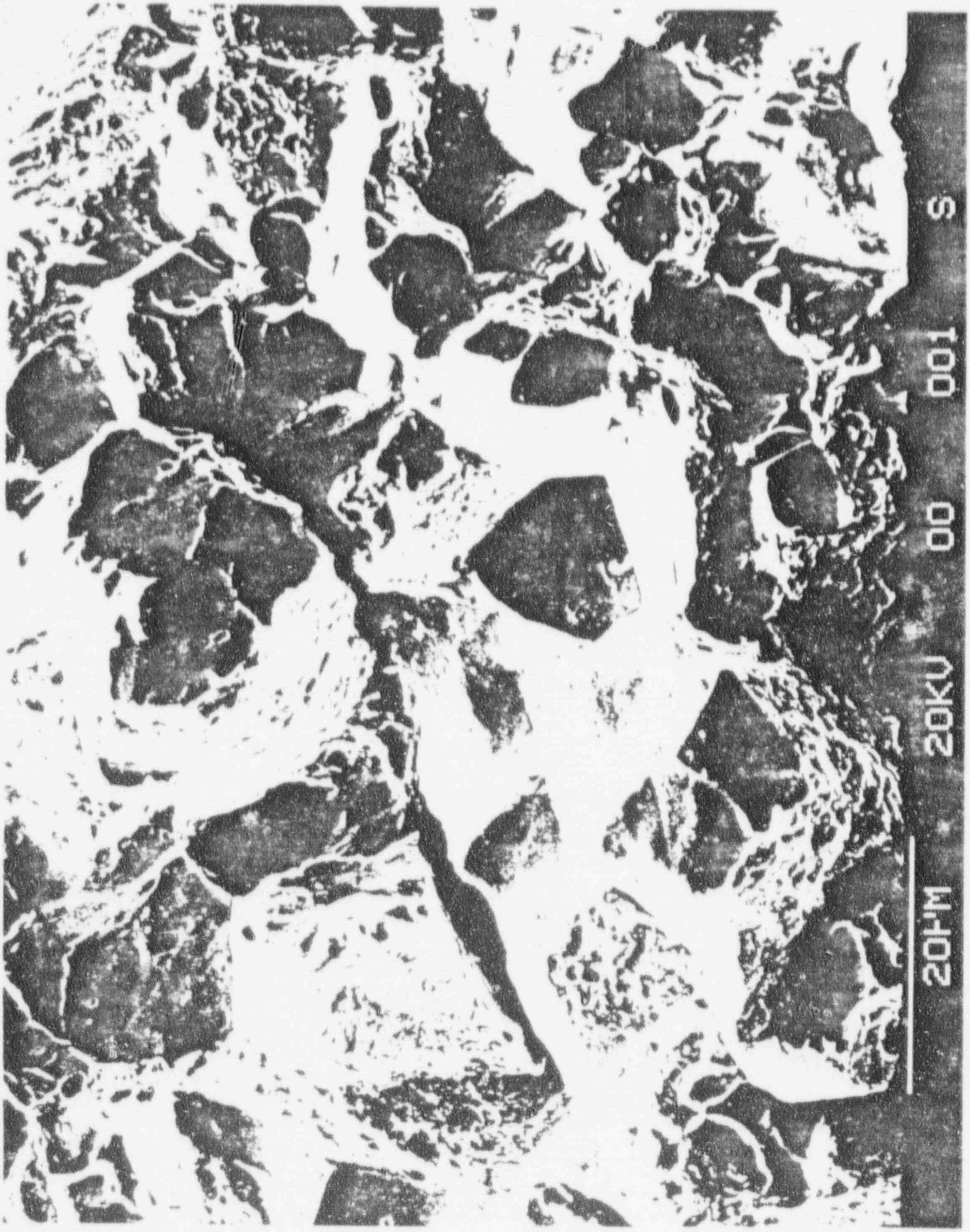
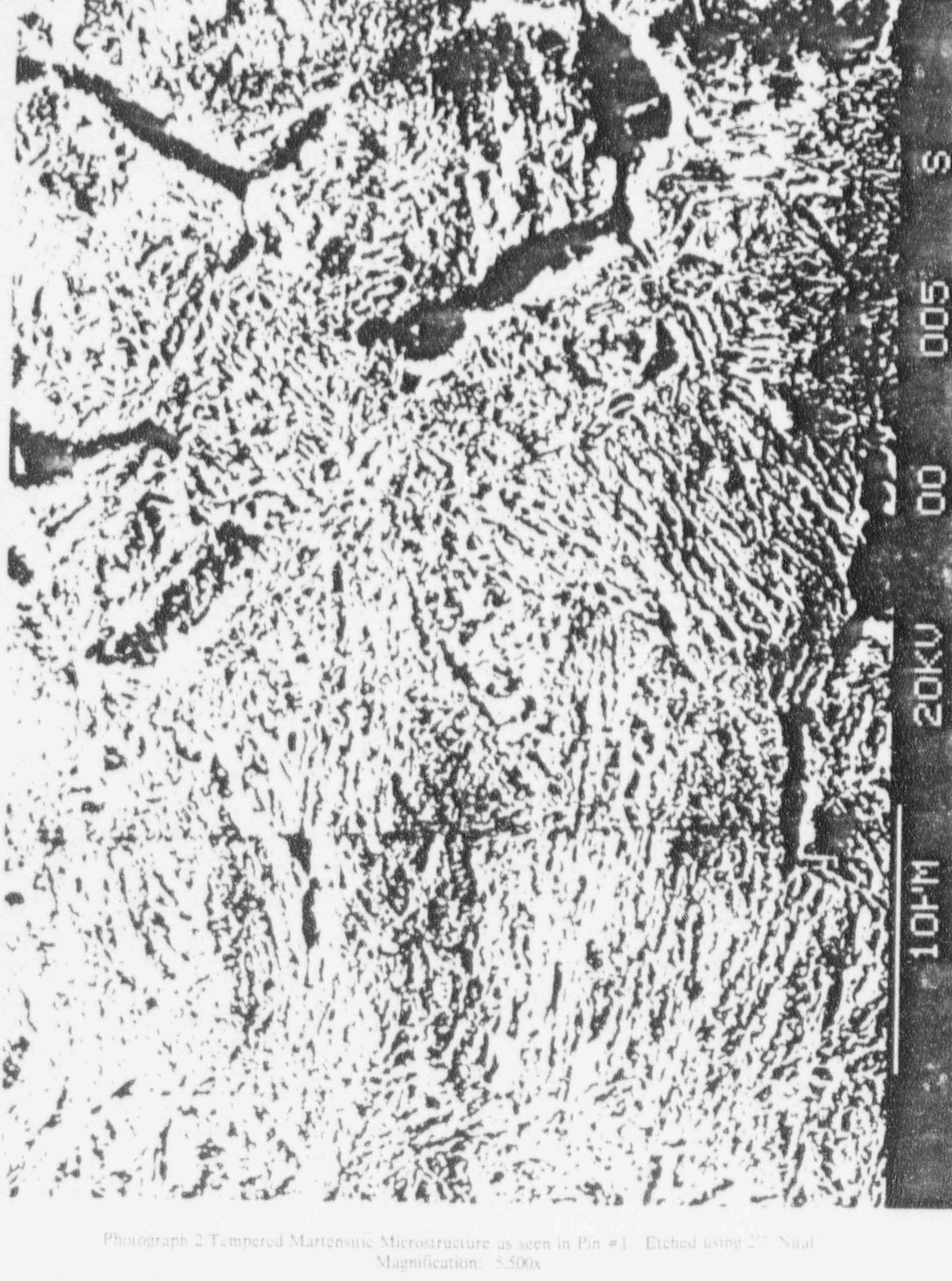


Figure 1 Graphical Depiction of Perspectives used for Metallographic Photographs

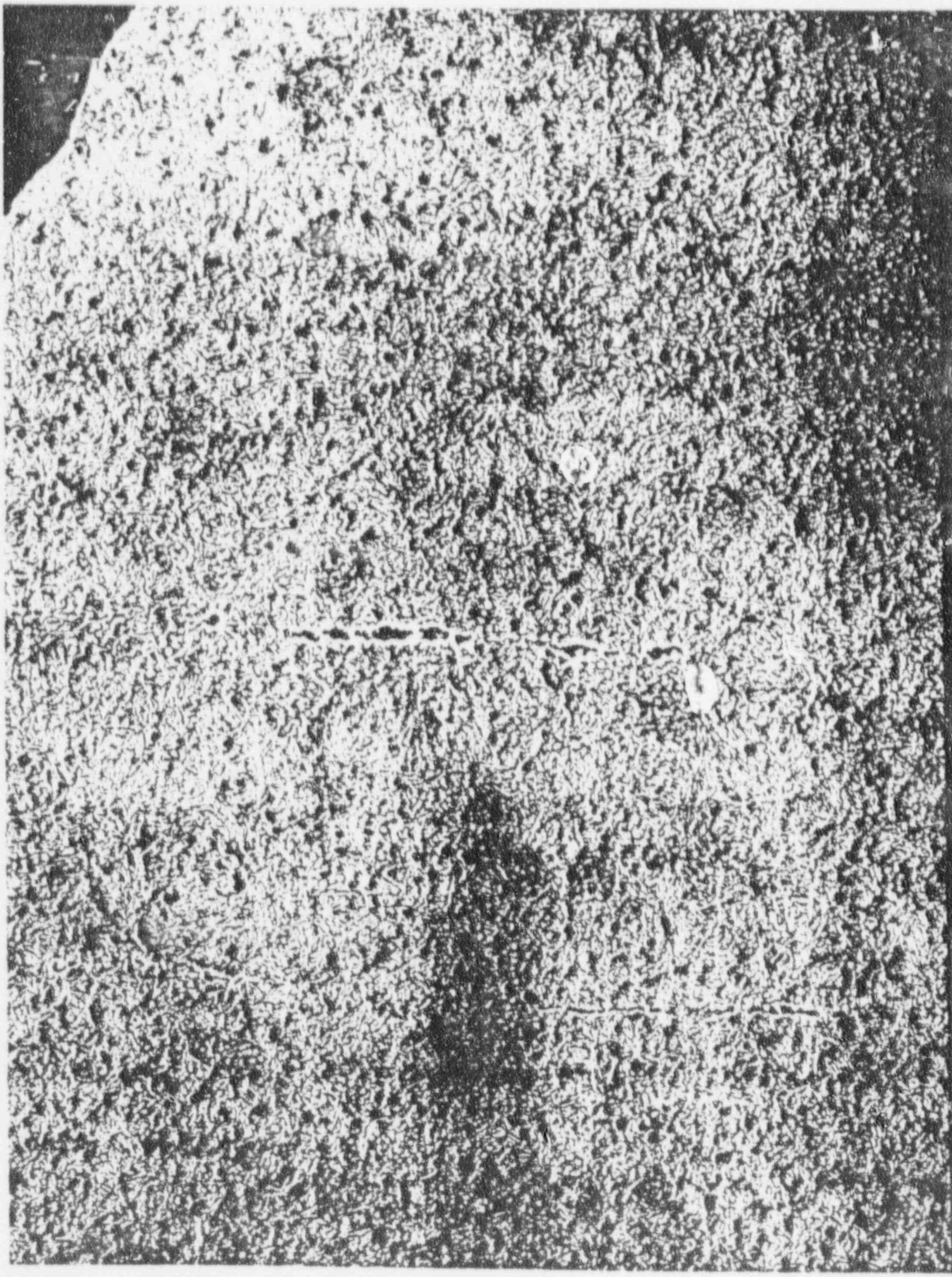


Photograph 1: Intergranular Fracture Surface from Pin #2.
Magnification: 2,000x

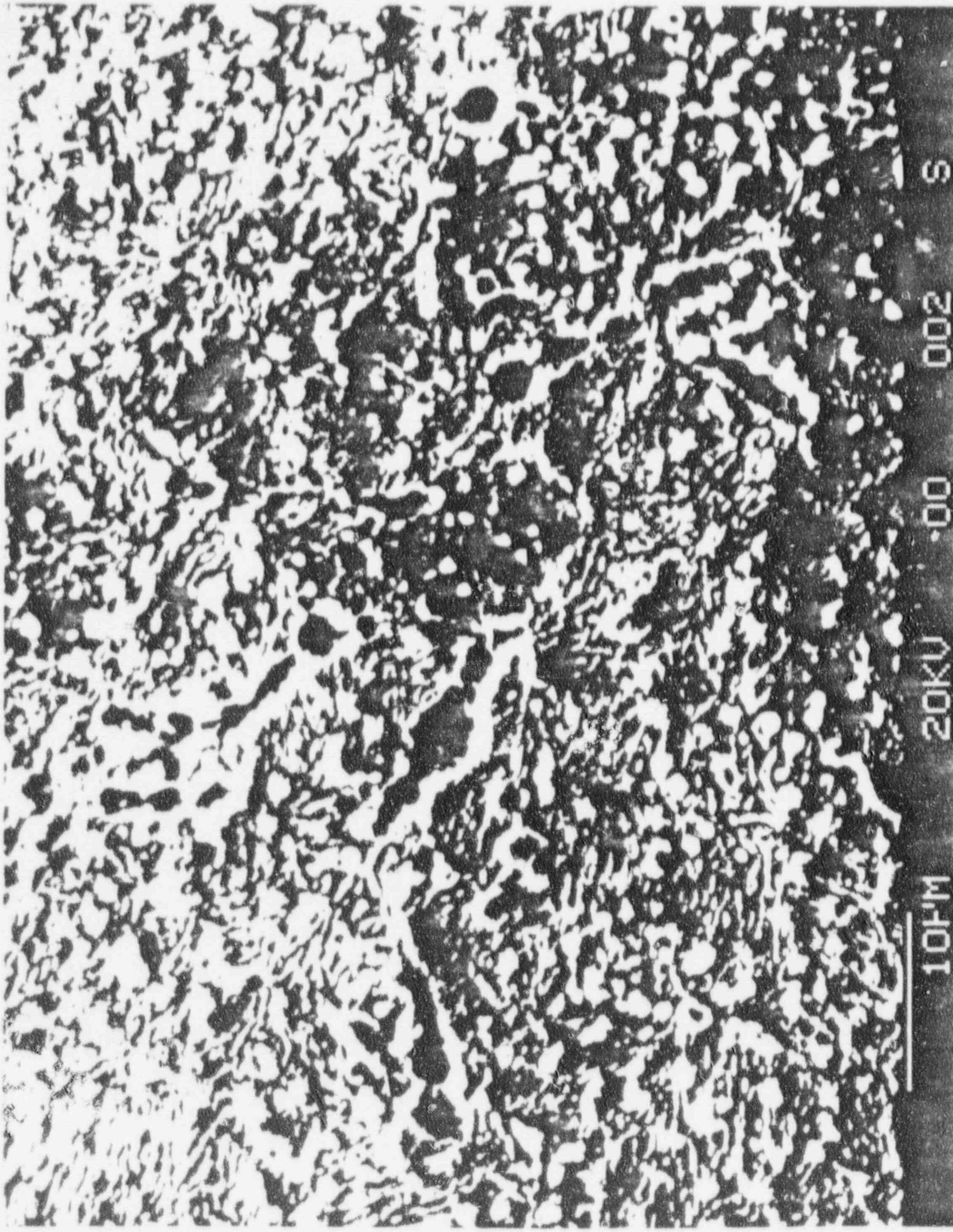


Photograph 2 Tempered Martensitic Microstructure as seen in Pin #1. Etched using 2% Nital
Magnification: 5,500x

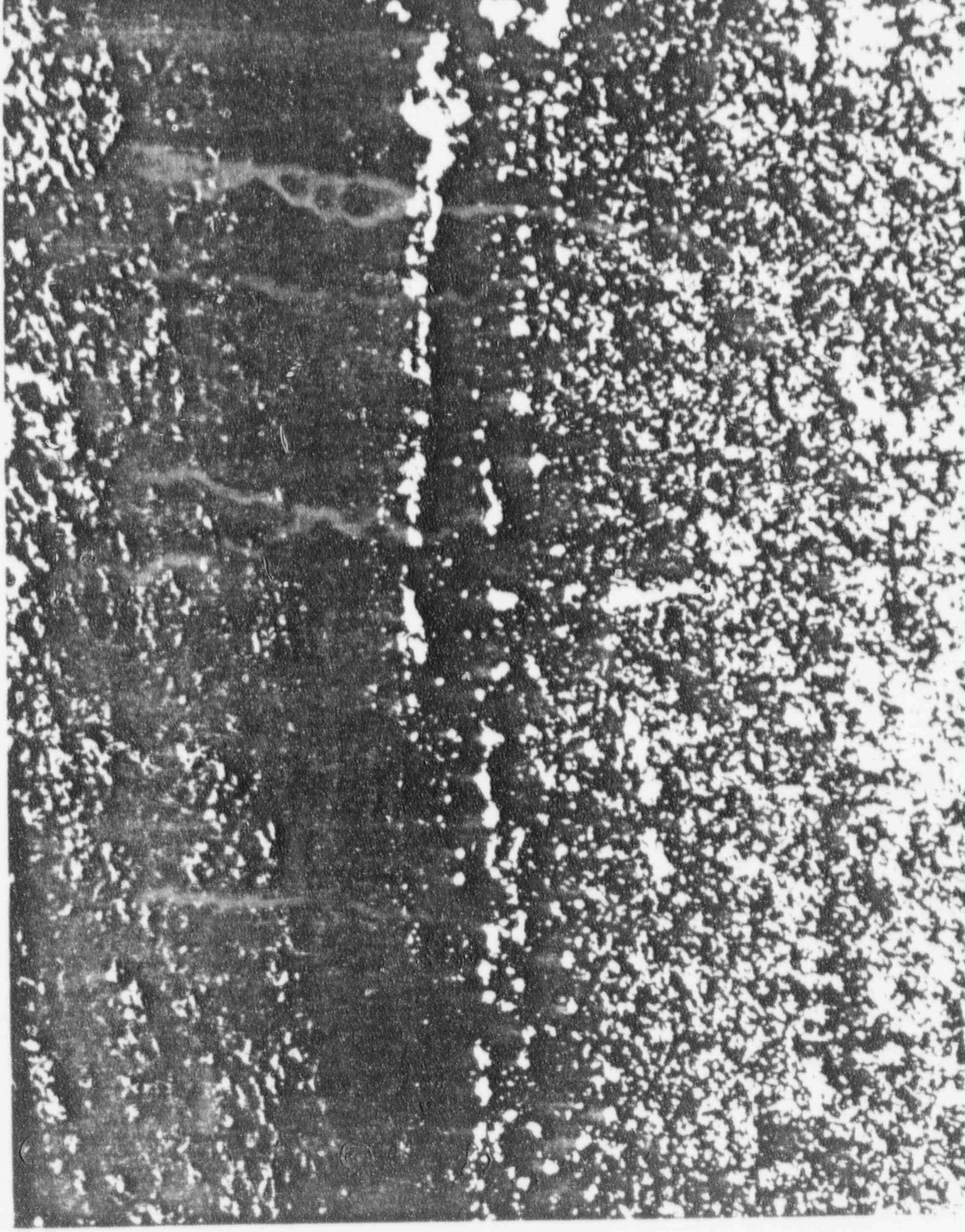
Photograph 3 Intergranular Fracture along inclusion line found sub-surface to Pin #1. Etched using 2% Nital. Magnification: 580x



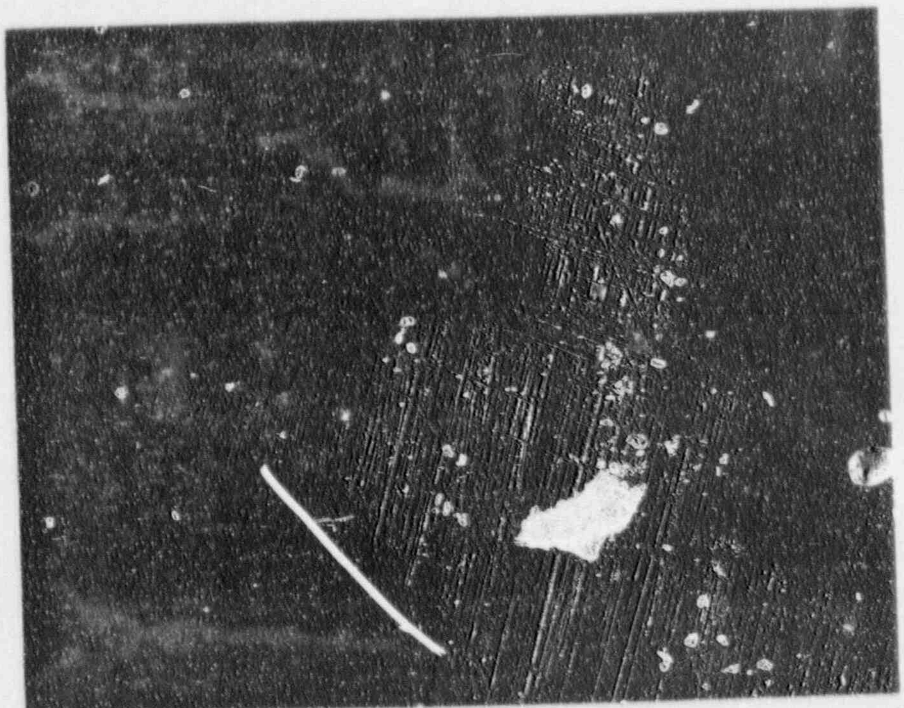
Photograph 4 Undissolved Carbides decorating a line of inclusions in Pin #1. Etched using Saturated Picral with a Wetting Agent. Magnification: 1000x



Photograph 3 Undissolved Carbides decorating Intergranular Cracks at Prior-Austenitic Grain Boundaries as seen in Pin #1. Etched using Saturated Picral and Wetting Agent. Magnification: 3,600x



Photograph 6 Phosphorus (white) Segregation in Pin #3. Etched using Oberhoffer's Reagent
Magnification: 50x



Photograph 7 Intergranular crack in Pin #3. Un-etched, using Nomarksi Constrast
Magnification: 500x

REFERENCES

1. Vandervoort, G F., Metallography - Principles and Practice, McGraw-Hill Book Company, 1976. pp. 157.

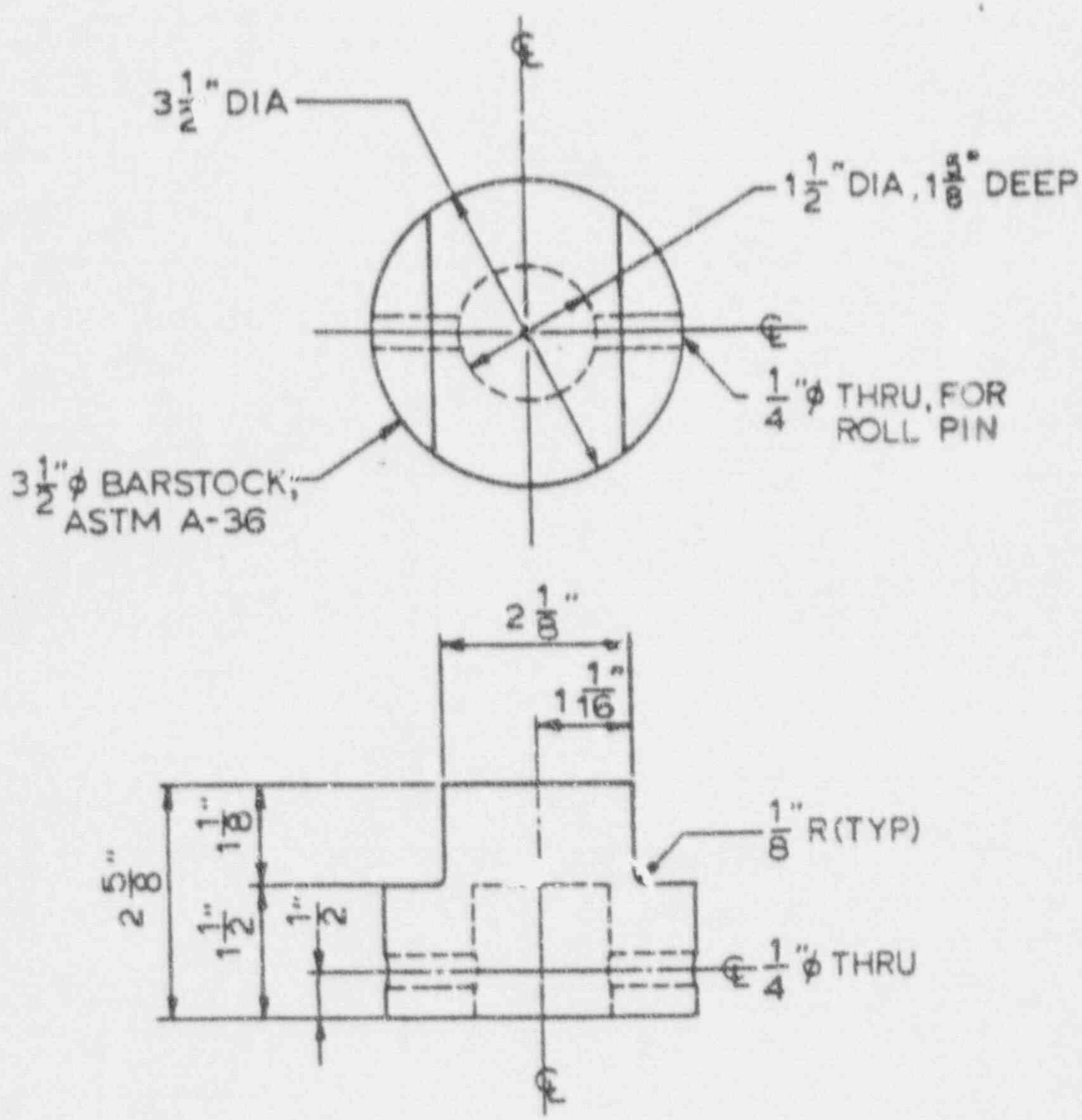
2. Vandervoort, G. F., Metallography - Principles and Practice, McGraw-Hill Book Company, 1976., pp. pp. 6, 534.

3. ASTM Standards, Volume 3.01 , 692-90.

4. Smith, W., Structure and Properties of Engineering Alloys, McGraw-Hill Company, 1981., pp. 152-156.

5. Kraus, G., Steels: Heat Treatment and Processing Principles, ASM International, 1989., 205-239.

Appendix I   Documentation Supplied by O.P.P.D.



NOTES:

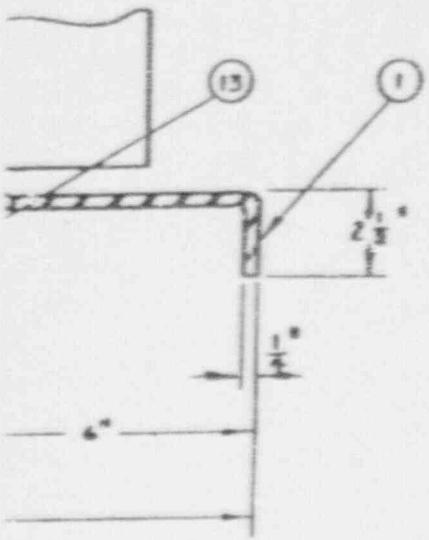
1. TOLERANCE ON HOLE DIAMETER: +0.010", -0.00"
2. TOLERANCE ON LENGTH DIMENSIONS: ± 1/16"

REV SHEET 269		
		DRAWN
	HH	CHECKED
5.5.89		ENGINEER
—	—	CIVIL
—	—	ELECTRICAL
5.5.89		MECHANICAL
—	—	NUCLEAR

FORT CALHOUN STATIC

DAMPER SHAF
COUPLING FOR
YCV-871 E&F

A 5617



ITEM	REQ'D	PART #	DESCRIPTION	MATERIAL OR VENDOR	
18	1		SOLENOID VALVE	SEE NOTE ABOVE	
17	1		AIR FILTER		
16	1		SHAFT COUPLING		
15	10		1/2 x 3/4 SHOULDER SCREW W/FLATWASHER & 3/8-16 LOC NUT		
14	10		BRONZE FLG. BRG.	1/2" I.D.	
13	10		SHAFT COLLAR	1" I.D. CRS	
12	2		CONNECT BAR	2 x 1/4" CRS	
11	1		OPERATOR ROTARY PNEUMATIC SEE NOTE ABOVE		
10	10		CRANK ARM	2 x 1/4" CRS	
9	9		BLADE STOPS	1 x 1 x 1/8 STRUCT ∠	
8	2		MULLION	12 x 2 1/2 x 1/8 FORMED U	
7	2		JAMB SEAL	22 GA. SS	
6	1		OPERATOR MOUNT	1/4 THK. MILD STEEL	
5	2		BLADE CONNECT BRKT	1/4 THK. HRS	
4	70		1/4 x 1 1/4 HEX BOLT W/LOCK WASHER & HEX NUT		
3	10		SHAFT	1" DIA. CRS	
2	20		BLADE SKIN	16 GA. HRS	
1	1		FRAME	12 x 2 1/2 x 1/8" FORMED C	

LIST OF MATERIAL

NOT SHOWN (items 17, 18)

TAG # YCV-871E & 871F
FOR DCR FC-35-73
OPPD PO # 11629
WO # 1776

NOTE: REDRAWN FROM AIR CLEAN DAMPER DWG AC-0198A REV C

RS-6MB	1	REV. NO.
4-13-89	twr	DRAWN
4-26-89	WHI	CHECK
5-5-89	AJK	ENG.
—	—	CIVIL DPT.
—	—	ELEC. DPT.
5-5-89	AJK	MECH. DPT.
-	—	Q. CONTROL
—	—	P.E.

SCALE

Fort Calhoun Station

Parallel Airfoil Blade Damper w/Pneumatic Operator

AIR CLEAN DAMPER

AC-1098A REV. 1

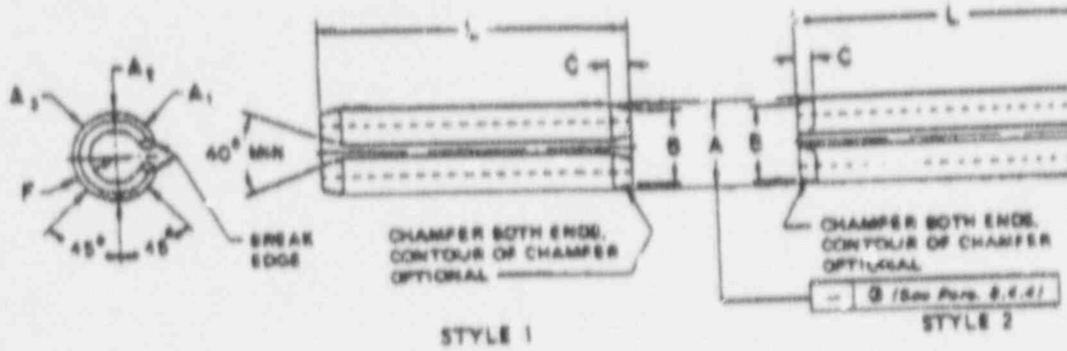
G 21464 21464

E F

4 5

A B C D

4 3 2 1



OPTIONAL CONSTRUCTIONS

Table 9 Dimensions of Slotted Type Spring Pins

Nominal Size[1] or Basic Pin Diameter		A Pin Diameter Max[2]	A Pin Diameter Min[3]	B Chamfer Diameter Max	C Chamfer Length Max	C Chamfer Length Min	F Stock Thickness Basic	Recommended Hole Size Max	Recommended Hole Size Min	Double Shear Load, Min, lb — Material: AISI 1070-1095[4] and AISI 420	AISI 302	Beryllium Copper
1/16	0.062	0.069	0.066	0.059	0.028	0.007	0.012	0.065	0.062	425	350	270
5/64	0.078	0.086	0.083	0.075	0.032	0.008	0.018	0.081	0.078	650	550	400
3/32	0.094	0.100	0.099	0.091	0.038	0.008	0.022	0.097	0.094	1,000	800	660
1/8	0.125	0.135	0.131	0.122	0.044	0.008	0.028	0.129	0.125	2,100	1,500	1,200
9/64	0.141	0.149	0.146	0.137	0.044	0.008	0.028	0.144	0.140	2,200	1,600	1,400
5/32	0.156	0.167	0.162	0.151	0.048	0.010	0.032	0.160	0.156	3,000	2,000	1,800
3/16	0.188	0.199	0.194	0.182	0.055	0.011	0.040	0.192	0.187	4,400	2,800	2,600
7/32	0.219	0.232	0.226	0.214	0.065	0.011	0.048	0.224	0.219	5,700	3,550	3,700
1/4	0.250	0.264	0.258	0.245	0.065	0.012	0.048	0.256	0.250	7,700	4,600	4,600
5/16	0.312	0.328	0.321	0.306	0.080	0.014	0.062	0.318	0.312	11,500	7,600	6,800
3/8	0.375	0.392	0.385	0.368	0.095	0.016	0.077	0.382	0.375	17,600	10,000	10,100
7/16	0.438	0.456	0.448	0.430	0.095	0.017	0.077	0.445	0.437	20,000	12,000	12,200
1/2	0.500	0.521	0.513	0.485	0.110	0.025	0.094	0.510	0.500	25,800	15,500	15,800
5/8	0.625	0.650	0.640	0.608	0.125	0.030	0.125	0.635	0.625	46,000[4]	18,800	
3/4	0.750	0.780	0.769	0.730	0.150	0.030	0.150	0.760	0.750	66,000[4]	23,200	

[1] Where specifying nominal size in decimals, zeros preceding the decimal shall be omitted.
[2] Maximum diameter shall be checked by GO ring gage.
[3] Minimum diameter shall be average of three diameters measured at points illustrated. A min = $\frac{A_1 + A_2 + A_3}{3}$
[4] Sizes 5/8 in. (0.625) and larger are produced from AISI 6150H alloy steel, not AISI 1070-1095.

For additional requirements refer to General Data for Spring Pins on Pages 25 and 26.

Characteristic	Symbol
Straightness	-
Diameter	⌀

4063

Designation: A 682 – 90

Standard Specification for Steel, Strip, High-Carbon, Cold-Rolled, Spring Quality, General Requirements For[1]

This standard is issued under the fixed designation A 682; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This specification covers the general requirements for cold-rolled carbon spring steel strip in coils or cut lengths. Strip is classified by size as a product that is 0.2499 in. or less in thickness and over ½ to 23¹⁵⁄₁₆ in. in width, inclusive.

1.2 The maximum of the specified carbon range is over 0.25 % to 1.35 %, inclusive.

1.3 The above shall apply to the cold-rolled carbon spring steel strip furnished under each of the following specifications issued by ASTM:

Title of Specification	ASTM Designation
Steel, Carbon, Strip, Cold-Rolled Hard, Untempered Spring Quality	A 680[2]
Steel, Carbon, Strip, Cold-Rolled Soft, Untempered Spring Quality	A 684[2]

NOTE—A complete metric companion to Specification A 682 has been developed—Specification A 682M; therefore, no metric equivalents are presented in this specification.

2. Referenced Documents

2.1 *ASTM Standards:*

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products[2]

A 700 Practices for Packaging, Marking, and Loading Methods for Steel Products for Domestic Shipment[3]

A 751 Test Methods, Practices and Terminology for Chemical Analysis of Steel Products[2]

E 3 Methods of Preparation of Metallographic Specimens[4]

E 44 Definitions of Terms Relating to Heat Treatment of Metals[5]

E 112 Test Methods for Determining Average Grain Size[4]

E 527 Practice for Numbering Metals and Alloys (UNS)[2]

2.2 *Federal Standards:*

Fed. Std. No. 123 Marking for Shipments (Civil Agencies)[6]

Fed. Std. No. 183 Continuous Identification Marking of Iron and Steel Products[6]

2.3 *Military Standards:*

MIL-STD-129 Marking for Shipping and Storage[6]

MIL-STD-163 Steel Mill Products Preparation for Shipment and Storage[6]

3. Terminology

3.1 *Definitions:*

3.1.1 *burr*—metal displaced beyond the plane of the surface by slitting or shearing.

3.1.2 *decarburization*—refer to Definitions E 44.

3.1.3 *lot*—the quantity of material of the same type, size, and finish produced at one time from the same cast or heat, and heat treated in the same heat-treatment cycle.

4. General Requirements for Delivery

4.1 The requirements of the purchase order, the individual material specification, and this general specification shall govern in the sequence stated.

4.2 Products covered by this specification are produced to decimal thickness only, and decimal thickness tolerances apply.

5. Manufacture

5.1 *Melting Practice*—The steel shall be made by either the open-hearth, basic-oxygen, or electric-furnace process. It is normally produced as a fully killed steel. Elements such as aluminum may be added in sufficient amounts to control the austenitic grain size.

5.2 *Cold Working Procedure:*

5.2.1 Prior to cold rolling, the hot-rolled strip shall be descaled by chemical or mechanical means.

5.2.2 The strip shall be cold rolled by reducing to thickness at room temperature (that is, below the recrystallization temperature).

6. Chemical Requirements

6.1 *Limits:*

6.1.1 When carbon steel strip is specified to chemical composition, the compositions are commonly prepared using the ranges and limits shown in Table 1. The elements

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[1] This specification is under the jurisdiction of ASTM Committee A-1 on Steel, Stainless Steel and Related Alloys, and is the direct responsibility of Subcommittee A01.19 on Sheet Steel and Steel Sheets.

Current edition approved July 27, 1990. Published September 1990. Originally published as A 682 – 73. Last previous edition A 682 – 89.

[2] *Annual Book of ASTM Standards*, Vol 01.03.

[3] *Annual Book of ASTM Standards*, Vols 01.01, 01.03, 01.04, and 01.05.

[4] *Annual Book of ASTM Standards*, Vol 03.01.

[5] *Annual Book of ASTM Standards*, Vol 01.02.

[6] Available from Standardization Documents, Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

TABLE 1 Cast or Heat (Formerly Ladle) Analysis Limits and Ranges

Element	Standard Chemical Limits and Ranges, Limit or Max of Specified Range	Range, %
Carbon[A]	over 0.25 to 0.30, incl	0.06
	over 0.30 to 0.40, incl	0.07
	over 0.40 to 0.60, incl	0.08
	over 0.60 to 0.80, incl	0.11
	over 0.80 to 1.35, incl	0.14
Manganese	to 0.50, incl	0.20
	over 0.50 to 1.15, incl	0.30
	over 1.15 to 1.65, incl	0.35
Phosphorous	to 0.08, incl	0.03
	over 0.08 to 0.15, incl	0.05
Sulfur	to 0.08, incl	0.03
	over 0.08 to 0.15, incl	0.05
	over 0.15 to 0.23, incl	0.07
	over 0.23 to 0.33, incl	0.10
Silicon	to 0.20, incl	0.10
	over 0.20 to 0.30, incl	0.15
	over 0.30 to 0.60, incl	0.30

[A] The carbon ranges shown in the column headed Range apply when the specified maximum limit for manganese does not exceed 1.00 %. When the maximum manganese limit exceeds 1.00 %, add 0.01 to the carbon ranges shown above.

comprising the desired chemical composition are specified in one of three ways:

6.1.1.1 By a maximu:n limit,

6.1.1.2 By a minimum limit, or

6.1.1.3 By minimum and maximum limits, terined the "range." By c:mmon usage, the range is the arithmetical difference between the two limits (for example, 0.60 to 0.71 is 0.11 range).

6.1.2 Steel grade numbers indicating chemical composition commonly produced to this specification are shown in Table 2 and may be used.

6.2 *Cast or Heat (Formerly Ladle) Analysis:*

6.2.1 An analysis of each cast or heat of steel shall be made by the manufacturer to determine the percentage of elements specified or restricted by the applicable specification.

6.2.2 When requested, cast or heat analysis for elements listed or required shall be reported to the purchaser or to his representative.

6.3 *Product Analysis (Formerly Check Analysis)*—Product analysis is the chemical analysis of the semi-finished product form. The strip may be subjected to product analysis by the purchaser either for the purpose of verifying that the chemical composition is within specified limits for each element, including applicable tolerance for product analysis, or to determine variations in compositions withi· · cast or heat. The results of analyses taken from different pieces within a case may differ from each other and from the cast analysis. The chemical composition thus determined shall not vary from the limits specified by more than the amounts shown in Table 3, but the several determinations of any element in any cast may not vary both above and below the specified range.

6.4 *Methods of Analysis*—Test Methods, Practices, and Terminology A 751 shall be used for referee purposes.

7. Metallurgical Structure

7.1 *Grain Size:*

7.1.1 The steel strip shall have an austenitic grain size of which a minimum of 70 % is 5 or finer.

7.1.2 One sample shall be taken from each lot.

7.1.3 The sample shall be evaluated in accordance with Test Methods E 112.

7.2 *Decarburization:*

7.2.1 When specified, the steel strip shall have a maximu.z. permissible depth of complete plus partial decarburization of 0.001 in. or 1.5 % of the thickness of the strip, whichever is greater, except that strip less than 0.011 in. thick shall show no complete decarburization.

7.2.2 At least one specimen from each lot shall be taken for microscopical examination.

7.2.3 The specimens shall be prepared for microscopical examination in accordance with Methods E 3. The prepared specimen shall not be less than ½ in. in length, representing the full thickness, and shall be perpendicular to the rolling direction. The examination of the specimen includes the periphery and therefore it must be polished in a single plane without edge rounding. The specimen shall be etched and shall be examined at 100× magnification. The depth of

TABLE 2 Cast or Heat (Formerly Ladle) Analysis Chemical Composition, %

UNS Designation[A]	Steel Grade	Carbon	Manganese	Phosphorus, max[B]	Sulfur, max[B]	Silicon[C]
G10300	1030	0.27 to 0.34	0.60 to 0.90	0.040	0.050	0.15 to 0.30
G10350	1035	0.31 to 0.38	0.60 to 0.90	0.040	0.050	0.15 to 0.30
G10400	1040	0.36 to 0.44	0.60 to 0.90	0.040	0.050	0.15 to 0.30
G10450	1045	0.42 to 0.50	0.60 to 0.90	0.040	0.050	0.15 to 0.30
G10500	1050	0.47 to 0.55	0.60 to 0.90	0.040	0.050	0.15 to 0.30
G10550	1055	0.52 to 0.60	0.60 to 0.90	0.040	0.050	0.15 to 0.30
G10600	1060	0.55 to 0.66	0.60 to 0.90	0.040	0.050	0.15 to 0.30
G10640	1064	0.59 to 0.70	0.50 to 0.80	0.040	0.050	0.15 to 0.30
G10650	1065	0.59 to 0.70	0.60 to 0.90	0.040	0.050	0.15 to 0.30
G10700	1070	0.65 to 0.75	0.60 to 0.90	0.040	0.050	0.15 to 0.30
G10740	1074	0.69 to 0.80	0.50 to 0.80	0.040	0.050	0.15 to 0.30
G10800	1080	0.74 to 0.88	0.60 to 0.90	0.040	0.050	0.15 to 0.30
G10850	1035	0.80 to 0.94	0.70 to 1.00	0.040	0.050	0.15 to 0.30
G10860	1086	0.80 to 0.94	0.30 to 0.50	0.040	0.050	0.15 to 0.30
G10950	1095	0.90 to 1.04	0.30 to 0.50	0.040	0.050	0.15 to 0.30

[A] New designation established in accordance with Practice E 527 and SAE J1086, Recommended Practice for Numbering Metals and Alloys (UNS).

[B] Ordinarily produced to 0.025 % max phosphorus and 0.035 % max sulfur by cast or heat analysis.

[C] When specified, silicon may be ordered at 0.10 to 0.20 %.

TABLE 3 Permissible Variations from Specified Cast or Heat (Formerly Ladle) Analysis Ranges and Limits

Element	Limit or Max of Specification, %	Variations Over Max Limit or Under Min Limit	
		Under Min Limit	Over Max Limit
Carbon	over 0.25 to 0.40, incl	0.03	0.04
	over 0.40 to 0.80, incl	0.03	0.05
	over 0.80	0.03	0.06
Manganese	to 0.60, incl	0.03	0.03
	over 0.60 to 1.15, incl	0.04	0.04
	over 1.15 to 1.65, incl	0.05	0.05
Phosphorus			0.01
Sulfur			0.01
Silicon	to 0.30 incl	0.02	0.03
	over 0.30 to 0.60	0.05	0.05

decarburization reported should be the average depth in both the amount of free ferrite (complete decarburization) and the affected depth to the point where carbon content appears to be the same as the carbon content of the strip (partial decarburization) under investigation. In some instances, it is necessary to resort to heat treatment of the specimens to reveal decarburized areas more accurately.

8. Mechanical Requirements

8.1 The mechanical property requirements, number of specimens, and test locations and specimen orientation shall be in accordance with the applicable product specification.

8.2 Unless otherwise specified in the applicable product specification, test specimens must be prepared in accordance with Test Methods and Definitions A 370.

8.3 Mechanical tests shall be conducted in accordance with Test Methods and Definitions A 370.

9. Dimensions, Weights, and Tolerances

9.1 The thickness, width, camber, and length tolerances shall conform to the requirements specified in Tables 4, 5, 6, 7, 8, and 9.

9.2 *Flatness*—It is not practical to formulate flatness tolerances for cold-rolled carbon spring steel strip to represent the range of widths and thicknesses in coils and cut lengths.

10. Finish and Edges

10.1 *Surface*—The surface requirements shall be as specified in the product specifications.

10.2 *Edges*—Cold-rolled carbon spring steel strip shall be supplied with one of the following edges as specified:

TABLE 4 Thickness Tolerances (Plus or Minus), Cold-Rolled Carbon Strip Steel Including High Carbon Strip Steel

Nominal Gage (in.)	Over ½ in. to Less than 12 in wide	12 in. to less than 18 in.	18 in. to 23 15/16 in.
.160–.250	.0025	.0032	.0036
.125–.1599	.0022	.0028	.0032
.070–.1249	.0018	.0022	.0028
.040–.0699	.0014	.0018	.0024
.030–.0399	.0012	.0015	.0020
.020–.0299	.0010	.0013	.0015
.015–.0199	.0008	.0010	.0012
.010–.0149	.0005	.0008	.0010
<.010	.0003	.0006	.0008

[A] Measured ⅜ in. or more in from edge; and on narrower than 1 in., at any place between edges.

TABLE 5 Width Tolerances for Edges Nos. 1, 4, 5, and 6, Cold-Rolled Carbon Spring Steel Strip

Width Tolerances, in			
Edge No	Specified Width	Specified Thickness	Width Tolerance Over and Under
1	Over ½ to ¾, incl	0.0938 and thinner	0.005
1	Over ¾ to 7, incl	0.125 and thinner	0.005
4	Over ½ to 1, incl	0.1875 to 0.025, incl	0.015
4	Over 1 to 2, incl	0.2499 to 0.025, incl	0.025
4	Over 2 to 4, incl	0.2499 to 0.035, incl	0.047
4	Over 4 to 6, incl	0.2499 to 0.047, incl	0.047
5	Over ½ to ¾, incl	0.0938 and thinner	0.005
5	Over ¾ to 5, incl	0.125 and thinner	0.005
5	Over 5 to 9, incl	0.125 to 0.008, incl	0.010
5	Over 9 to 20, incl	0.105 to 0.015, incl	0.010
5	Over 20 to 23 15/16, incl	0.080 to 0.023, incl	0.015
6	Over ½ to 1, incl	0.1875 to 0.025, incl	0.015
6	Over 1 to 2, incl	0.2499 to 0.025, incl	0.025
6	Over 2 to 4, incl	0.2499 to 0.035, incl	0.047
6	Over 4 to 6, incl	0.2499 to 0.047, incl	0.047

TABLE 6 Width Tolerances for Edge No. 2 (Mill) Cold-Rolled Carbon Spring Steel Strip

Width Tolerances, in	
Specified Width	Tolerances, Over and Under
Over ½ to 2 incl	1/32
Over 2 to 5, incl	3/64
Over 5 to 10, incl	5/64
Over 10 to 15, incl	3/32
Over 15 to 20, incl	⅛
Over 20 to 23 15/16	5/32

10.2.1 *No. 1*—A prepared edge of a specified contour (round or square) that is produced when a very accurate width is required or when an edge condition suitable for electroplating is required, or both.

10.2.2 *No. 2*—A natural mill edge carried through the cold rolling from the hot-rolled strip without additional processing of the edge.

10.2.3 *No. 3*—An approximately square edge produced by slitting on which the burr is not eliminated. This is produced when the edge condition is not a critical requirement for the finished part. Normal coiling or piling does not provide a definite positioning of the slitting burr.

10.2.4 *No. 4*—An approximately rounded edge. This edge is produced when the width tolerance and edge condition are not as exacting as for No. 1 edges.

10.2.5 *No. 5*—An approximately square edge produced from slit edge material on which the burr is eliminated.

10.2.6 *No. 6*—An approximately square edge. This edge is produced when the width tolerance and edge condition are not as exacting as for No. 1 edges.

11. Workmanship

11.1 The steel shall have a workmanlike appearance and shall not have defects of a nature or degree for the grade and quality ordered that will be detrimental to the fabrication of the finished part.

11.2 Coils may contain some abnormalities that render a portion of the coil unusable since the inspection of coils does

TABLE 7 Width Tolerances for Edge No. 3 (Slit) Cold-Rolled Carbon Spring Steel Strip

Width Tolerances, in.		
Specified Width	Thickness	Tolerances for Specified Width, Over and Under
Over 1/2 to 6, incl	over 0.160 to 0.2499, incl	0.016
Over 6 to 12, incl	over 0.160 to 0.2499, incl	0.020
Over 12 to 23 15/16, incl	over 0.160 to 0.2499, incl	0.031
Over 1/2 to 6, incl	over 0.099 to 0.160, incl	0.010
Over 6 to 12, incl	over 0.099 to 0.160, incl	0.016
Over 12 to 23 15/16, incl	over 0.099 to 0.160, incl	0.020
Over 1/2 to 6, incl	over 0.068 to 0.099, incl	0.008
Over 6 to 12, incl	over 0.068 to 0.099, incl	0.010
Over 12 to 20, incl	over 0.068 to 0.099, incl	0.016
Over 20 to 23 15/16, incl	over 0.0[illegible]8 to 0.099, incl	0.020
Over 1/2 to 9, incl	over 0.0[illegible] to 0.068, incl	0.005
Over 9 to 12, incl	over 0.015 [illegible]	0.010
Over 12 to 20, incl	over 0.016 to 0.068, incl	0.016
Over 20 to 23 15/16, incl	over 0.01[illegible] to 0.068, incl	0.020
Over 1/2 to 9, incl	up [illegible]	0.005
Over 9 to 12, incl	up to 0.016, incl	0.010
Over 12 to 20, incl	up to 0.01[illegible], incl	0.016
Over 20 to 23 15/16, incl	up to 0.[illegible]5, incl	0.020

TABLE 8 Camber Tolerances, Cold-Rolled Carbon Spring Steel Strip

NOTE—Camber is the deviation of a side edge from a straight line. The standard for measuring this deviation is based on any 8-ft length. It is obtained by placing an 8-ft straightedge on the concave side and measuring the maximum distance between the strip edge and the straightedge.

Width, in.	Camber Tolerances, max
Over 1/2 to 1 1/2, incl	1/2 in. in any 8 ft
Over 1 1/2 to 23 15/16, incl	1/4 in. in any 8 ft

not afford the same opportunity to remove portions containing imperfections as is the case with cut lengths.

12. Retests

12.1 The difficulties in obtaining truly representative samples of strip without destroying the usefulness of the coil account for the generally accepted practice of allowing retests for mechanical properties and surface examination. Two additional samples are secured from each end of the coil from which the original sample was taken. A portion of the coil may be discarded prior to cutting the samples for retest. If any of the retests fail to comply with the requirements, the coil shall be rejected.

13. Rework and Retreatment

13.1 Lots rejected for failure to meet the specified requirements may be resubmitted for test provided the manufacturer has reworked the lots as necessary to correct the deficiency or has removed the nonconforming material.

14. Inspection

14.1 The manufacturer shall afford the purchaser's inspector all reasonable facilities necessary to satisfy him that the material is being produced and furnished in accordance with this specification. Mill inspection by the purchaser shall not interfere unnecessarily with the manufacturer's operations. Unless otherwise agreed to, all tests and inspections,

TABLE 9 Length Tolerances, Cold-Rolled Carbon Spring Steel Strip

Specified Width, in.	Specified Length, in.[A]		
	24 to 60, incl	Over 60 to 120, incl	Over 120 to 240, incl
Over 1/2 to 12, incl	1/4	1/2	3/4
Over 12 to 23 15/16, incl	1/2	3/4	1

[A] Tolerance over specified length. No tolerances under.

except product analysis, shall be made at the place of production.

15. Rejection and Rehearing

15.1 Unless otherwise specified, any rejection based on tests made in accordance with this specification shall be reported to the purchaser within a reasonable time.

15.2 Material that shows injurious defects subsequent to its acceptance at the purchaser's works shall be rejected and the manufacturer shall be notified. The material must be adequately protected and correctly identified in order that the manufacturer may make a proper investigation. In case of dissatisfaction with the results of the test, the manufacturer may make claims for a rehearing.

16. Certification and Reports

16.1 Upon request of the purchaser in the contract or order, a manufacturer's certification that the material was produced and tested in accordance with this specification shall be furnished. A report of the test results may be included if required.

17. Marking

17.1 Unless otherwise specified, the material shall be identified by having the manufacturer's name or mark, ASTM designation, weight, purchase order number, and material identification legibly stenciled on top of each lift or shown on a tag attached to each coil or shipping unit.

17.2 When specified in the contract or order, and for direct procurement by or direct shipment to the Government, marking for shipment, in addition to requirements specified in the contract or order, shall be in accordance with MIL-STD-129 for military agencies and in accordance with Fed. Std. No. 123 for civil agencies.

17.3 For Government procurement by the Defense Supply Agency, strip material shall be continuously marked for identification in accordance with Fed. Std. No. 183.

18. Packaging

18.1 Unless otherwise specified, the strip shall be packaged and loaded in accordance with Practices A 700.

18.2 When Level A is specified in the contract or order, and for direct procurement by or direct shipment to the Government, preservation, packaging, and packing shall be in accordance with the Level A requirements of MIL-STD-163.

18.3 When coils are ordered it is customary to specify a minimum or range of inside diameter, maximum outside diameter, and a maximum coil weight, if required. The ability of manufacturers to meet the maximum coil weights depends upon individual mill equipment. When required, minimum coil weights are subject to negotiation.

Appendix II Chemical Results as Obtained by Optical Emission

[illegible] 11-Aug-1991 08:3[illegible]

[illegible] standard 1263A

.62	0.02	0.005	1.50	0.74	1.31	0.03	0.32	0.09

.31	0.24	0.046	0.048

…ed & Understood by me. | Date | Invented by | Date

Recorded by

Appendix III Calculation

As a first order approximation:

Determine shear strength of split roll pin.

Assumptions:

1) Orientation of pin in joint does not influence shear strength.
2) Tensile & shear strength based on hardness conversion to obtain mechanical properties
3) No effects of coldworking or work hardening will be included.
4) Missing area due to split does not affect cross-sectional area.
5) Applied load uniform and low strain rate

Area of pin: O.D = 0.250 in. $A_O = \pi r^2 \Rightarrow \pi\left(\frac{0.250}{2}\right)^2$

I.D = 0.160 in. $A_I = \pi r^2 \quad \pi\left(\frac{0.160}{2}\right)^2$

$A_O - A_I = 0.029$ in.

Hardness (avg.) of all pins: 49 HRc ≈ 477 HB

Tensile Strength ≈ 500 · 477 ⇒ 238,500 psi

Shear Strength ≈ ½ Tensile Strength ⇒ 119,250 psi

Pin is oriented in double shear ∴ $\sigma = \frac{F}{2A}$

$$F = 2A(\sigma)$$

$$F = 2(0.029) \cdot 119{,}250$$

F = 6,916 LBS. ←

Note ANSI Std. provided by O.P.P.D. states 7,700 lbs. Estimate within 10%.