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LOW TEMPERATURE MECHANICAL PROPERTIES, FRACTOGRAPHIC AND METALLOGRAPHIC EVALUATION OF SEVERAL ALLOY STEELS

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16. ABSTRACT

This report presents the mechanical properties of alloy steels, 4130, 4140, 4340, 6150, and 8740. Test specimens were manufactured from approximately 1.00 inch (2.54 cm) diameter bar stock which had been heat treated to two different hardness levels, (Rockwell C-30 and Rockwell C-40).

The following mechanical tests were performed at temperatures of 80°F (+26.7°C), 0°F (-17.8°C), -100°F (-73°C), and -200°F (-129°C):

1. Tensile test (Ultimate, yield, modulus, elongation, and reduction of area)
2. Notched Tensile Test
3. Charpy V-Notched Impact Test (Impact Energy)
4. Double Shear Strength Test (Ultimate and Yield).

The test data indicate excellent tensile strength, notched/unnotched tensile ratios, ductility, impact, and shear properties at all test temperatures, except at -200°F (-129°C) where the impact strength of the higher strength group of alloy steels, 4130 (Rc-37) and 4140 (Rc-44) decreased to approximately 9 ft. lbs. (12 joules) and 6 ft. lbs. (8 joules), respectively.

Chemical, metallographic, and fractographic analyses were also performed to evaluate microstructure, microhardness and the effect of decrease in temperature on the ductile to brittle failure transition.

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SUMMARY

This report presents the chemical and mechanical properties and the metallographic and fractographic characteristics of alloy steels 4130, 4140, 4340, 6150, and 8740 in two different heat treated conditions for each alloy. All test specimens were manufactured from an approximately 1.00-inch (2.54 cm) diameter bar which had been heat treated to two different hardness levels: (Rockwell C-30 and Rockwell C-40).

Mechanical tests (smooth tensile, notched tensile, Charpy impact and shear) were performed at temperatures of 80°F (+26.7°C), 0°F (-17.8°C), -100°F (-73°C) and -200°F (-129°C). The test data indicated excellent smooth and notched tensile strengths, ductility, shear, and impact properties at all test temperatures; except at -200°F (-129°C), where the impact strength of alloys 4130 (Rockwell C-37 hardness) and 4140 (Rockwell C-44 hardness) decreased to approximately 9 ft. lbs. (12 joules) and 6 ft. lbs. (8 joules), respectively.

The metallographic examination of microstructure and microhardness indicated banding and non-metallic inclusions in alloy 4340 and decarburization and non-metallic inclusions in alloy 6150.

Fractographic analysis indicated a tendency toward brittleness with increasing strength and decreasing temperature for the smooth and the notched tensile specimen fractures, and the charpy V-notched impact specimen fractures. However, fractographs of the double shear specimen fractures indicated ductility for all of the specimens tested over the temperature range.

INTRODUCTION

Wide use is made of alloy steels called out in specifications MIL-B-6812 and MIL-B-8831, which specifies aircraft bolts of approximately 130 Ksi (0.896 GN/m^2) strength level and 12-point External Wrenching Bolts of 180 Ksi (1.241 GN/m^2) respectively. The Materials Division of MSFC is often required to select the types of steel fasteners used in cryogenic application. Therefore, several of the alloy steels listed in these specifications were chosen by MSFC for evaluation at cryogenic conditions.

It is generally believed that alloy steels are susceptible to brittle failure at cryogenic temperatures due to a ductile-to-brittle transition occurring at a temperature somewhere near -100°F (-73°C). Several specifications for aircraft fasteners limit the use of alloy steels to a minimum temperature of -65°F (-54°C). For this reason it was decided to evaluate alloy steels 4130, 4140, 4340, 6150, and 8740 at temperatures from ambient to -200°F (-129°C).

Two different strength levels were chosen which would closely approximate the strengths found in specifications MIL-B-6812 (Rockwell C-26-32 hardness) and MIL-B-8831 (Rockwell C-39-43 hardness). The heat treating procedures found in specification MIL-H-6875B were used as a guide.

Our investigation, utilizing the two different strength levels, was centered on the effects of decreasing temperature on the ductility, toughness, and shear properties of the various alloy steels.

MATERIAL PROCESSING

The chemical composition of the as-received materials used in this investigation are shown in Table I and the heat treatments are listed in Table II. These thermal treatments were designed to produce two different strength levels comparable to those strengths found in specifications MIL-B-6812 and MIL-B-8831. As illustrated in Table II, one group of material was in the Rockwell hardness range of C-28 to 33 and the other group of material was in the hardness range of Rockwell C-37 to 44.

EQUIPMENT AND MECHANICAL TEST SPECIMENS

The equipment, except for the shear die, used in the mechanical properties evaluation is described in a report by the author (Ref. 1). The tensile test specimens are illustrated in Figures 1 and 2. Impact specimens were machined from bar stock to the Federal Standard No. 151 configuration. Shear specimens were 2.00 inches (5.08 cm) in length by 0.3125 inches (0.8967 cm) in diameter.

The double shear die is made of nickel plated 8740 alloy steel of Rockwell C-40 hardness and the shear die inserts are made of MP-35N multiphase alloy of Rockwell C-53 hardness. The die is designed so that the center insert thickness is 1.0 diameter and the outer insert is 1/2 diameter thickness. The particular design used for this evaluation was decided upon after examination of considerable amounts of data generated by the "Fastener Testing Development Group (FTDG)," a committee established under the Department of Defense, Project No. 5300-001, under the direction of the Navy Bureau of Weapons and the Aeronautical Materials Laboratory.

The double shear die inserts were rotated after each test so that at least three tests could be made on one set of inserts. At the lower cryogenic temperatures, occasionally, only one test could be accomplished per set of inserts; however, most of these inserts could be refaced and used again.

RESULTS AND DISCUSSION

(1) Mechanical Properties

The results of the ambient through cryogenic temperature mechanical property tests are tabulated in Tables III through VII and these properties are plotted in Figures 3 through 7.

Tables III through VII contain test data on the alloy steels in two different hardened and tempered conditions. These tables, containing property data on specimens machined from 1.0 inch (2.54 cm) diameter bars, represent test data from round longitudinal smooth and V-notched tensile specimens

[0.3125 inch (0.8967 cm) diameter], and Charpy V-notched impact specimens per Federal Standard No. 151.

In general, the data found in Tables III through VII indicate increasing ultimate tensile and 0.2 percent yield strengths with decreasing temperatures. The elongations (in 4D) and the reductions of area indicate excellent ductility over the test temperature range. The notched-to-unnotched tensile ratios decreased slightly with decreasing test temperature and remained above 1.0 for all alloys except 4140 alloy steel of Rc-44 hardness. Charpy V-notched impact strength decreased progressively with decreasing test temperature yet remained above 10.0 ft. lbs. (13.6 joules), except for the -200^{O}F (-129^{O}C) values for 4130 (Rc-37) and 4140 (Rc-44) alloy steels. The double shear ultimate and shear yield (approximated by deflectometer measurement) strengths increased consistently with decreasing temperature. The double shear test data combined with ductility, impact, and tensile (smooth and notched) test data define a group of properties which are invaluable for design consideration. Double shear, as a preferred method, was included in our testing because of the large number of fasteners used in shear applications.

(a) 4130 Alloy Steel

In Table III, which shows the low temperature mechanical properties of 4130 alloy steel, there are no smooth or V-notched tensile data for -200^{O}F (-129^{O}C) in the Rockwell C-30 hardness group. This alloy was the first to be evaluated in our test program and tests were made at -320^{O}F (1196^{O}C) before the cut-off temperature of -200^{O}F (-129^{O}C) was decided upon. Even at liquid nitrogen temperature, however, the notched-to-unnotched ratio for the Rc-30 hardness group of 4130 alloy steel remained above 1.0. Charpy V-notched impact tests were also made at random temperatures before we decided upon -200^{O}F (-129^{O}C) for the lower limit.

(b) 4140 Alloy Steel

Table IV contains the mechanical property test data for 4140 alloy steel indicating the alloy's excellent ductility (elongation and reduction of area), and shear and smooth tensile properties, over the test temperature range. However, at -200^{O}F (-129^{O}C) the material specimens of Rc-44 hardness indicated a decrease in impact strength below 10.0 ft. lbs. (13.6 joules) and a decrease in notched-to-unnotched tensile ratio below 1.0.

(c) 4340 Alloy Steel

Table V presents the mechanical test data for 4340 alloy steel indicating that the elongation and ductility remained unchanged with decreasing temperature and that the notched-to-unnotched tensile ratio remained above 1.0 for all test temperatures. Impact strength decreased with decreasing test temperature, yet a high degree of ductility was retained at -200^{O}F (-129^{O}C).

(d) 6150 Alloy Steel

Table VI shows the mechanical test data for 6150 alloy steel. The elongation remained virtually unchanged over the test temperature range; however, there was a slight decrease in reduction in area for both hardened conditions of this alloy at -200°F (-129°C). The notched-to-unnotched tensile ratio remained well above 1.0 and the impact strength remained above 10.0 ft. lbs. (13.6 joules) for both hardened conditions at all testing temperatures.

(e) 8740 Alloy Steel

Table VII contains the mechanical test data for 8740 alloy steel indicating excellent elongation, reduction of area, notched-to-unnotched tensile ratios, shear and impact strengths over the test temperature range.

Figures 3 through 7 illustrate the cryogenic mechanical properties, as tabulated in Tables III through VII, for alloy steels 4130, 4140, 4340, 6150, and 8740. Each figure has been prepared in such a manner as to show the complete graphic presentation of the mechanical properties for each alloy in their respective hardened and tempered conditions:

(2) Metallographic Characteristics

Figures 8A through 12D illustrate the longitudinal and transverse microstructures, as revealed by Nital and Picric-Hydrochloric Acid Etchants, for the as-received, and hardened and tempered conditions of the alloy steels evaluated.

(a) 4130 Alloy Steel

Figure 8A illustrates the longitudinal and transverse microstructure of alloy steel 4130 in the as-received and in the normalized conditions. Figure 8B illustrates the two hardened and tempered conditions (Rc-30 and Rc-37 hardnesses) of the 4130 alloy steel.

(b) 4140 Alloy Steel

Figures 9A, B, and C illustrate the longitudinal and transverse microstructure of alloy steel 4140 in the as-received, and in the two hardened and tempered conditions (Rc-33 and Rc-44 hardenesses).

(c) 4340 Alloy Steel

Figures 10A, B, and C illustrate the longitudinal and transverse microstructure of alloy steel 4340 in the as-received, and in the two hardened and tempered conditions (Rc-28 and Rc-43 hardenesses). The microstructure indicates banding and non-metallic inclusions which are more prevalent in the as-received material.

(d) 6150 Alloy Steel

Figures 11A, B, C, and D illustrate the longitudinal and transverse microstructure of alloy steel 6150 in the as-received (cold drawn-annealed), and in the two hardened and tempered conditions (Rc-30 and Rc-41 hardness). Figure 11A indicates surface decarburization for all three conditions of the material.

(e) 8740 Alloy Steel

Figures 12A, B, C, and D illustrate the longitudinal and transverse microstructure of alloy steel 8740 in the as-recieved (hot rolled-annealed), normalized, and hardened and tempered conditions (Rc-29 and Rc-40 hardenesses). The as-received (hot-rolled-annealed) microstructure in Figure 12A indicates a structure very similar to the normalized structure found in Figure 12B except the normalized microstructure is more homogeneous. Figure 12C and D illustrate the hardened and tempered microstructures of Rc-40 and Rc-28 material, respectively. Both structures reveal fine martensite, the Rc-28 material having the more coarse martensite.

(3) Fractographic Characteristics

Figures 13A - 22D are fractographs taken by Scanning Electron Microscopy (SEM) and by Transmission Electron Microscopy (TEM) at magnifications from 2300X to 3150X. These fractographs were made on fractured smooth and V-notched round tensile specimens, smooth round shear specimens, and on Charpy V-notched impact specimens tested at temperatures from ambient to -200^{o}F (-129^{o}C) for all the test materials except the 4130 alloy steel. Since the alloy steel 4140 closely resembles the 4130 alloy steel in chemistry and in mechanical properties, several fractographs were omitted to avoid redundancy; however, the Charpy V-notched and the shear fractures of 4130 alloy steel have been included for comparison purposes.

In general, the susceptibility toward brittleness is increased with increasing strength and decreasing temperature. The smooth bar tensile strengths (ultimate and yield) increased with decreasing temperature, averaging, at -200^{o}F (-129^{o}C), an approximate increase of 12% over the ambient temperature strengths.

The following examples will illustrate some specific examples of smooth tensile failure modes:

(a) The alloy steel attaining the greatest smooth tensile strength of the alloy steels tested at -200°F (-129°C), was 4140 of Rc-44 hardness. The fractographs (Figure 15A) of the -200°F (-129°C) smooth tensile fracture, of this alloy steel, indicated a mixed mode of failure, showing some ductility.

(b) Fractographs indicating the least ductility in the smooth tensile fractures at -200°F (-129°C) were those of alloy steel 4140 of Rc-33 hardness (Figure 16A).

(c) The fractographs showing smooth tensile fractures for alloy steel 4340 of Rc-43 hardness (Figure 17A) indicated the best ductility at all testing temperatures for the higher Rockwell hardnesses.

The notched tensile strengths of most of the alloy steels tested at -200°F (-129°C) were greater than their corresponding ambient temperature strengths, except for the 4140 alloy steel of Rc-44 hardness which decreased considerably in notched tensile strength at the -200°F (-129°C) temperature. This brittle fracture characteristic is reflected in the fractographs (Figure 15B) of 4140 alloy steel. Of all the alloy steels evaluated in this program, the 8740 of Rc-40 hardness indicated a steady increase in notched tensile strength with decreasing temperature, reaching a maximum strength of 290 ksi (1.999 GN/m^2) at -200°F (-129°C). This ductile fracture is reflected in the fractographs of Figure 21B.

The Charpy V-notched impact strengths of all the alloy steels, tested in this program, decreased with decreasing temperature. This loss in strength is reflected in the fractographs. Specific examples of the impact specimen failures are illustrated as follows:

(a) The more brittle impact fractures are indicated in the fractographs of alloy steel 4130 of Rc-37 hardness (Figure 14A) tested at -200°F (-129°C); and alloy steel 4140 of Rc-44 hardness (Figure 15C) tested at -100°F (-73°C) and -200°F (-129°C).

(b) The fractographs indicating the most ductile impact fractures over the test temperature range are found in alloy steel 4340 of Rc-28 hardness (Figure 18C) followed by 8740 alloy steel of Rc-29 hardness (Figure 22C). These extremely ductile appearances correlate well with the actual impact strengths which exceeded 50.0 ft. lbs. (67.8 joules) at -200°F (-129°C) for these two alloys.

The double shear strengths of all the alloy steels tested in this program increased with decreasing temperature. The fractographs of the shear fractures indicate ductility and a smeared appearance for all of the specimens tested over the temperature range.

CONCLUSIONS

Based upon the results of this evaluation of hardened and tempered alloy steels 4130, 4140, 4340, 6150, and 8740, the following conclusions are drawn:

(1) The ultimate tensile and 0.2 percent yield strengths of the longitudinal test specimens increased with decreasing temperature.

(2) The elongation measured over a 2.00-inch (5.08 cm) gage length (4D) remained fairly constant over the test temperature range, while the reduction of area decreased slightly with decreasing temperatures.

(3) The notched-to-unnotched tensile ratio (K_t=10) decreased slightly with decreasing test temperatures, yet it indicated good ductility at -200°F (-129°C).

(4) Charpy V-notched impact strength decreased with decreasing temperature yet remained above 10.0 ft. lbs. (13.6 joules) at -200°F (-129°C) for all of the alloy steels evaluated in the program, except for the alloy steels 4130 (Rc-37) and 4140 (Rc-44) which decreased to approximately 9 ft. lbs. (12 joules) and 6 ft. lbs. (8 joules), respectively.

(5) The double shear ultimate and shear yield (approximated by deflectometer measurement) increased consistantly with decreasing test temperatures.

(6) Considering the overall mechanical properties and the metallographic and fractographic characteristics of the alloy steels tested in this program, it would be reasonable to consider bar material, hardened and tempered, as indicated in this evaluation, for applications to -200°F (-129°C) in aerospace uses such as fastening devices. The two exceptions to this recommendation would be alloy steels 4130 of Rc-37 hardness and 4140 of Rc-44 hardness, which would not be recommended for use below -100°F (-73°C) due to low impact strengths.

(7) Fractographic analysis can be a valuable tool in determining the ductile or brittle failure characteristic of an alloy.

REFERENCES

1. Montano, J. W. : A Mechanical Property and Stress Corrosion Evaluation of Custom 455 Stainless Steel Alloy," TMX-64682, August 2, 1972.

TABLE I
CHEMICAL COMPOSITION OF ALLOY STEEL BAR STOCK

Alloy	Specification	Heat No.	Analysis	Fe	Cr	Mn	Mo	Ni	Si	V	C	S	P
4130*	MIL-S-6758	8090692	MSFC	Main	1.01	0.60	0.23	T	0.25	0	0.30	0.013	0.004
4130	"	"	Republic Steel	"	1.01	0.57	0.21	0.04	0.25	-	0.30	0.013	0.006
4140**	QQ-S-624	137M186	MSFC	Main	0.84	0.83	0.19	0.14	0.27	-	0.39	0.017	0.011
4140	"	"	Bethlehem Steel	"	0.82	0.81	0.20	-	0.24	-	0.39	0.016	0.014
4340	MIL-S-5000	124W536	MSFC	Main	0.84	0.88	0.23	1.74	0.28	-	0.40	0.008	0.008
4340	"	"	Bethlehem Steel	"	0.81	0.80	0.25	1.80	0.28	-	0.40	0.010	0.013
6150***	MIL-S-8503	62185	MSFC	Main	1.00	0.84	0	T	0.28	0.17	0.50	0.021	0.018
6150	"	"	Copperweld Steel	"	0.96	0.82	-	-	0.26	0.19	0.51	0.022	0.012
8740*	MIL-S-6049	11929	MSFC	Main	0.47	0.81	0.25	0.45	0.30	0	0.39	0.014	0.007
8740*	"	"	Timken Steel	"	0.50	0.87	0.25	0.49	0.30	-	0.38	0.011	0.009

* Hot Rolled As Rolled Aircraft Quality-Vacuum Degassed
** Hot Rolled As Rolled Commercial Quality
*** Cold Drawn Annealed Aircraft Quality-Vacuum Degassed

TABLE II
HEAT TREATMENT OF ALLOY STEEL BAR STOCK

Alloy	Normalized	Hardened	Quench	Tempered	Hardness Rockwell C	Tempered	Hardness Rockwell C
4130	1650°F (899°C)	1590°F (866°C)	Oil	1050°F (566°C)	30	725°F (385°C)	37
4140	1650°F (899°C)	1565°F (851°C)	Oil	1050°F (566°C)	33	725°F (385°C)	44
4340	1600°F (871°C)	1500°F (816°C)	Oil	1200°F (649°C)	28	825°F (440°C)	43
6150	1600°F (871°C)	1550°F (843°C)	Oil	1200°F (649°C)	30	950°F (510°C)	41
8740	1650°F (899°C)	1550°F (843°C)	Oil	1175°F (635°C)	28	850°F (454°C)	40

TABLE III
Low Temperature Mechanical Properties of 4130 Alloy Steel
Longitudinal Round Tensile and Shear Specimens and MIL-STD 151
Charpy V-Notched Impact Specimens
Machined From 1.0-Inch (2.54cm) Diameter Bar

Hardness Rockwell C	Test Temperature °F	°C	Ultimate Tensile Strength Ksi	(GN/m^2)	0.2% Offset Yield Strength Ksi	(GN/m^2)	Elongation 2.0-Inch (5.08cm)	RA %	Avg. K_t	N/U* Tensile Ratio	Average Impact-Energy Ft-Lb.	(Joules)	No. of Impact Tests	Shear Strength** FSu Ksi	(GN/m^2)	FSy Ksi	(GN/m^2)
30	80	(+26.7)	131.4	(0.906)	112.2	(0.774)	22.1	69.4	10.9	1.45	111.7	(151.4)	5	77.3	(0.53)	64.4	(0.44)
	0	(-17.8)	136.2	(0.939)	116.2	(0.801)	22.4	67.4	10.9	1.44	109.0	(147.8)	1	80.5	(0.56)	66.7	(0.46)
	-100	(-73.0)	145.9	(1.006)	124.4	(0.858)	22.6	63.8	10.9	1.40	65.0	(88.1)	1	86.6	(0.60)	71.7	(0.49)
	-200	(-129.0)	-	-	-	-	-	-	-	-	29.8	(40.4)	4	98.4	(0.68)	74.9	(0.52)
	-320	(-196.0)	195.1	(1.345)	189.5	(1.306)	21.8	53.6	9.8	1.04	5.8	(7.9)	5				
37	80	(+26.7)	164.4	(1.133)	136.3	(0.940)	16.8	63.2	9.4	1.46	27.3	(37.0)	5	91.5	(0.63)	81.4	(0.56)
	0	(-17.8)	167.7	(1.156)	137.8	(0.950)	17.5	64.2	9.4	1.54	26.8	(36.3)	3	95.6	(0.66)	82.5	(0.57)
	-100	(-73.0)	177.1	(1.221)	146.8	(1.012)	17.7	61.6	9.4	1.44	15.8	(21.4)	3	99.7	(0.69)	85.9	(0.59)
	-200	(-129.0)	184.6	(1.273)	154.5	(1.065)	17.9	60.6	9.7	1.32	8.6	(11.6)	2	111.6	(0.77)	96.5	(0.66)
	-320	(-196.0)	-	-	-	-	-	-	-	-	3.4	(4.6)	5				

* Values represent an average of 5 smooth and 5 notched tensile specimens for each hardened condition and each test temperature.
** Values represent an average of 4 shear specimens for each condition and each temperature.

TABLE IV
Low Temperature Mechanical Properties of 4140 Alloy Steel
Longitudinal Round Tensile and Shear Specimens and MIL-STD-151
Charpy V-Notched Impact Specimens
Machined From 1.0-Inch (2.54cm) Diameter Bar

Hardness Rockwell C	Test Temperature °F	°C	Ultimate Tensile Strength Ksi	(GN/m^2)	0.2% Offset Yield Strength Ksi	(GN/m^2)	Elongation 2.0-Inch (5.08cm)	RA %	Avg. K_t	N/U* Tensile Ratio	Average Impact-Energy Ft-Lb.	(Joules)	No. of Impact Tests	Shear Strength** FS_u Ksi	(GN/m^2)	FS_y Ksi	(GN/m^2)
33	80	(+26.7)	155.8	(1.074)	142.9	(0.985)	19.4	62.5	12.4	1.50	70.2	(95.2)	4	95.6	(0.66)	81.0	(0.56)
	0	(-17.8)	161.0	(1.110)	147.8	(1.019)	19.3	61.5	12.3	1.43	73.8	(100.0)	4	99.4	(0.68)	80.0	(0.55)
	-100	(-73.0)	168.0	(1.158)	153.7	(1.060)	20.0	61.0	12.3	1.44	62.4	(84.6)	4	105.8	(0.73)	87.6	(0.60)
	-200	(-129.0)	177.9	(1.226)	166.3	(1.146)	20.2	59.8	12.5	1.44	22.8	(30.9)	4	117.8	(0.81)	95.8	(0.66)
44	80	(+26.7)	218.9	(1.509)	199.0	(1.372)	12.6	49.9	9.9	1.24	13.2	(17.9)	4	120.8	(0.83)	110.0	(0.76)
	0	(-17.8)	222.2	(1.532)	204.5	(1.410)	13.2	51.8	10.3	1.23	12.6	(17.1)	3	119.9	(0.83)	110.0	(0.76)
	-100	(-73.0)	236.4	(1.630)	220.5	(1.520)	12.9	50.6	10.6	1.08	9.1	(12.3)	4	127.1	(0.88)	113.6	(0.78)
	-200	(-129.0)	244.8	(1.688)	229.6	(1.583)	13.2	49.1	10.2	0.87	5.7	(7.7)	4	139.2	(0.96)	124.6	(0.86)

* Values represent an average of 5 smooth and 5 notched tensile specimens for each hardened condition and each test temperature.
** Values represent an average of 4 shear specimens for each condition and each temperature.

TABLE V
Low Temperature Mechanical Properties of 4340 Alloy Steel
Longitudinal Round Tensile and Shear Specimens and MIL-STD-151
Charpy V-Notched Impact Specimens
Machined from 1.0-Inch (2.54cm) Diameter Bar

Hardness Rockwell C	Test Temperature °F	°C	Ultimate Tensile Strength Ksi	(GN/m^2)	0.2% Offset Yield Strength Ksi	(GN/m^2)	Elongation 2.0-Inch (5.08cm)	RA %	Avg. Kt	N/U* Tensile Ratio	Average Impact-Energy Ft-Lb.	(Joules)	No. of Impact Tests	Shear Strength** FSu Ksi	FSu (GN/m^2)	FSy Ksi	FSy (GN/m^2)
28	80	(+26.7)	134.4	(0.927)	120.4	(0.830)	22.4	62.0	9.6	1.52	94.2	(127.7)	3	88.1	(0.61)	70.3	(0.48)
	0	(-17.8)	139.5	(0.962)	124.2	(0.856)	23.5	60.5	10.2	1.52	90.1	(122.2)	2	89.9	(0.62)	68.6	(0.47)
	-100	(-73.0)	147.9	(1.020)	131.2	(0.904)	21.2	57.7	10.2	1.49	84.8	(115.0)	3	94.5	(0.65)	72.0	(0.50)
	-200	(-129.0)	157.1	(1.083)	141.5	(0.976)	22.8	56.0	9.6	1.51	62.8	(85.1)	3	101.2	(0.70)	80.3	(0.55)
43	80	(+26.7)	201.9	(1.392)	192.6	(1.328)	14.6	51.3	11.3	1.34	26.4	(35.8)	3	118.8	(0.82)	106.0	(0.73)
	0	(-17.8)	207.7	(1.432)	198.8	(1.371)	14.7	50.4	12.2	1.33	22.1	(30.0)	2	120.6	(0.83)	111.1	(0.77)
	-100	(-73.0)	213.9	(1.475)	204.9	(1.413)	14.6	48.0	12.2	1.30	17.6	(23.9)	2	123.8	(0.85)	111.2	(0.77)
	-200	(-129.0)	222.9	(1.537)	214.3	(1.477)	14.6	46.1	12.5	1.19	16.2	(22.0)	2	134.7	(0.93)	119.6	(0.82)

* Values represent an average of 5 smooth and 5 notched tensile specimens for each hardened condition and each test temperature.
** Values represent an average of 4 shear specimens for each condition and each temperature.

TABLE VI
Low Temperature Mechanical Properties of 6150 Alloy Steel
Longitudinal Round Tensile and Shear Specimens and MIL-STD-151
Charpy V-Notched Impact Specimens
Machined from 1.0-Inch (2.54cm) Diameter Bar

Hardness Rockwell C	Test Temperature °F	Test Temperature °C	Ultimate Tensile Strength Ksi	Ultimate Tensile Strength (GN/m²)	0.2% Offset Yield Strength Ksi	0.2% Offset Yield Strength (GN/m²)	Elongation 2.0-Inch (5.08cm)	RA %	Avg. K_t	N/U* Tensile Ratio	Average Impact-Energy Ft-Lb.	Average Impact-Energy (Joules)	No. of Impact Test	Shear Strength** FS_u Ksi	Shear Strength** FS_u (GN/m²)	Shear Strength** FS_y Ksi	Shear Strength** FS_y (GN/m²)
30	80	(+26.7)	151.6	(1.045)	141.9	(0.978)	17.9	53.1	9.8	1.46	90.2	(122.3)	4	91.0	(0.63)	74.2	(0.51)
	0	(-17.8)	155.9	(1.075)	147.1	(1.014)	18.0	51.7	10.1	1.48	77.8	(105.5)	3	93.3	(0.64)	76.5	(0.53)
	-100	(-73.0)	158.8	(1.095)	147.9	(1.020)	18.3	51.0	10.7	1.45	27.7	(37.6)	3	97.4	(0.67)	77.4	(0.53)
	-200	(-129.0)	174.8	(1.205)	166.1	(1.145)	18.2	48.2	9.2	1.37	18.0	(24.4)	5	109.4	(0.75)	87.8	(0.60)
41	80	(+26.7)	189.2	(1.304)	181.3	(1.250)	13.0	44.4	10.4	1.37	21.1	(28.6)	3	111.8	(0.77)	99.3	(0.68)
	0	(-17.8)	194.4	(1.340)	187.5	(1.293)	12.6	43.0	9.7	1.35	16.4	(22.2)	3	113.4	(0.78)	98.2	(0.68)
	-100	(-73.0)	201.2	(1.387)	193.6	(1.335)	13.1	42.3	9.8	1.29	13.6	(18.4)	3	118.6	(0.82)	102.3	(0.70)
	-200	(-129.0)	211.8	(1.460)	205.2	(1.415)	13.2	40.0	9.3	1.21	12.7	(17.2)	3	133.7	(0.92)	117.7	(0.81)

* Values represent an average of 5 smooth and 5 notched tensile specimens for each hardened condition and each test temperature.
** Values represent an average of 4 shear specimens for each condition and each temperature.

TABLE VII
Low Temperature Mechanical Properties of 8740 Alloy Steel
Longitudinal Round Tensile and Shear Specimens and MIL-STD-151
Charpy V-Notched Impact Specimens
Machined from 1.0-Inch (2.54cm) Diameter Bar

Hardness Rockwell C	Test Temperature °F	°C	Ultimate Tensile Strength Ksi	(GN/m^2)	0.2% Offset Yield Strength Ksi	(GN/m^2)	Elongation 2.0-Inch (5.08cm)	RA %	Avg. K_t	N/U* Tensile Ratio	Average Impact-Energy Ft-Lb.	(Joules)	No. of Impact Test	Shear Strength** FS_u Ksi	(GN/m^2)	FS_y Ksi	(GN/m^2)
28	80	(+26.7)	131.4	(0.906)	119.2	(0.822)	23.0	65.1	8.3	1.54	98.8	(133.9)	3	85.3	(0.59)	66.5	(0.46)
	0	(-17.8)	135.9	(0.937)	122.0	(0.841)	23.8	64.5	9.6	1.55	94.5	(128.1)	2	87.7	(0.60)	65.6	(0.45)
	-100	(-73.0)	143.5	(0.989)	129.0	(0.889)	23.9	61.8	9.6	1.54	87.6	(118.8)	3	94.9	(0.65)	74.0	(0.51)
	-200	(-129.0)	153.3	(1.057)	141.0	(0.972)	24.2	59.8	9.6	1.57	50.7	(68.7)	3	106.2	(0.73)	82.8	(0.57)
40	80	(+26.7)	184.3	(1.271)	174.8	(1.205)	16.7	57.5	8.7	1.51	51.8	(70.2)	3	110.8	(0.76)	98.3	(0.68)
	0	(-17.8)	189.3	(1.305)	179.6	(1.238)	16.7	56.6	9.5	1.49	48.5	(65.8)	2	113.0	(0.78)	96.4	(0.66)
	-100	(-73.0)	200.4	(1.382)	191.2	(1.318)	16.4	54.8	9.0	1.43	29.8	(40.4)	2	121.2	(0.83)	102.5	(0.71)
	-200	(-129.0)	203.2	(1.401)	195.0	(1.344)	17.0	54.4	8.6	1.43	24.4	(33.1)	2	129.1	(0.89)	111.5	(0.77)

* Values represent an average of 5 smooth and 5 notched tensile specimens for each hardened condition and each test temperature.
** Values represent an average of 4 shear specimens for each condition and each temperature.

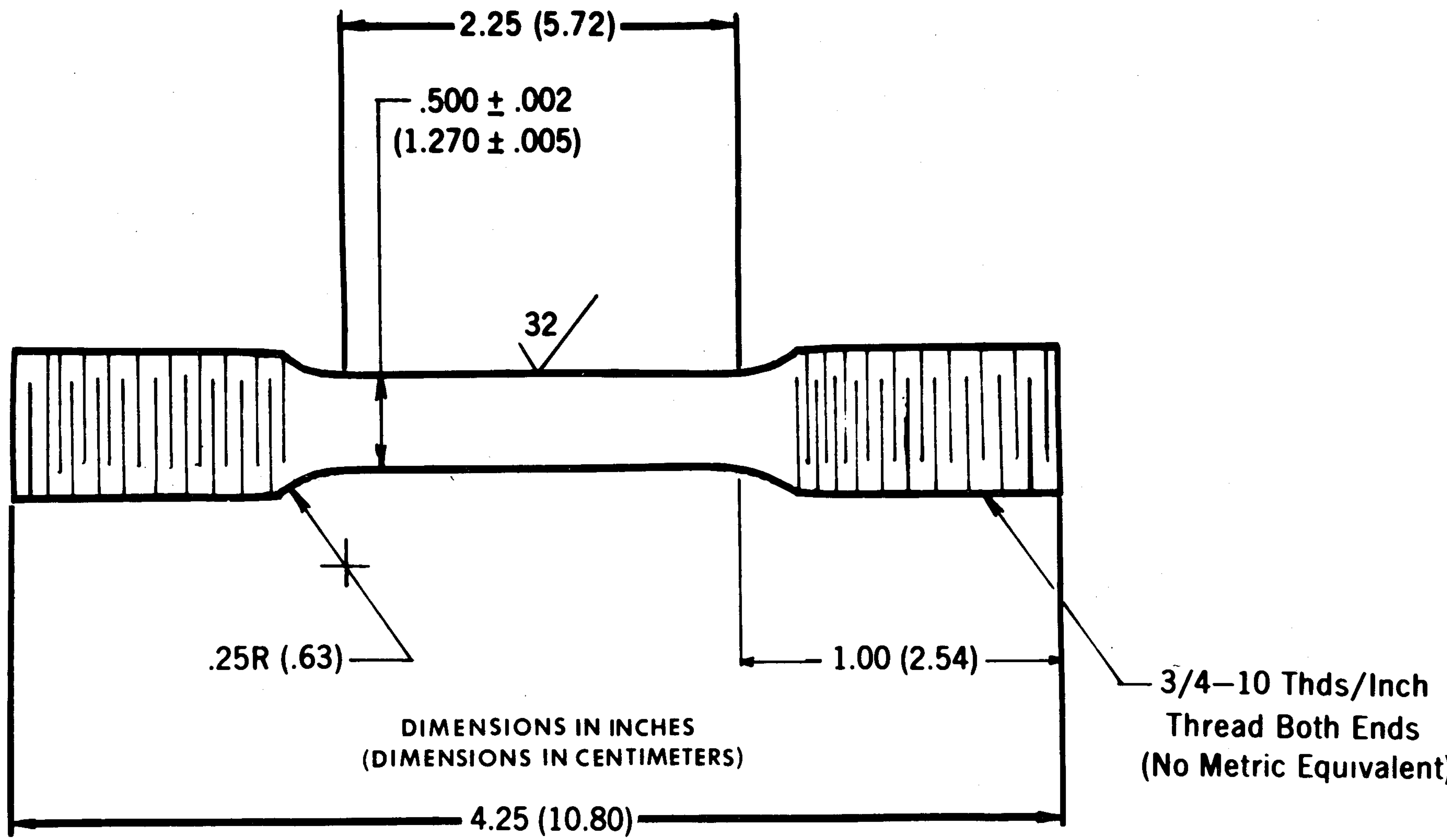


FIGURE 1 - ROUND SMOOTH TENSILE SPECIMEN CONFIGURATION

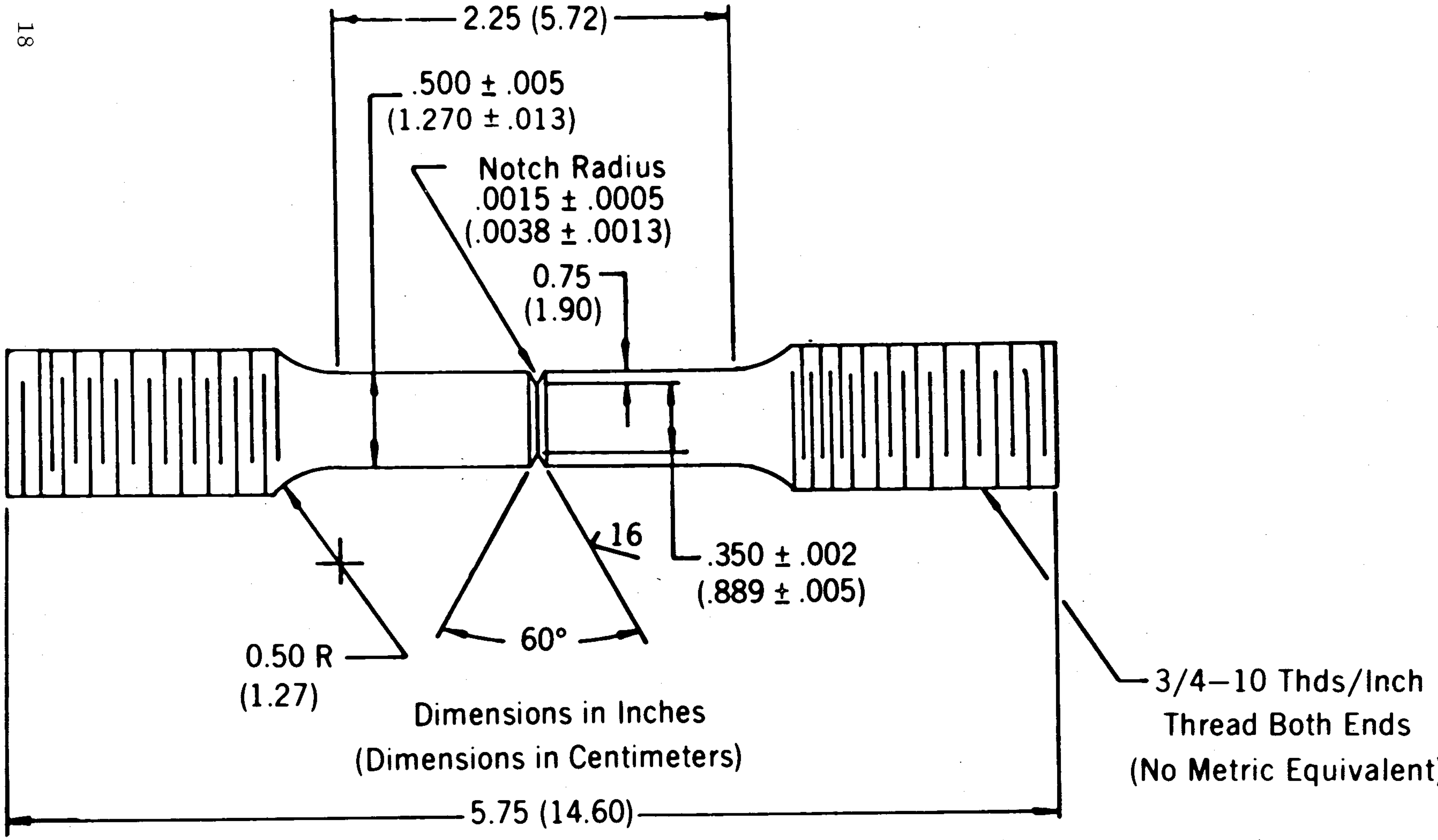


FIGURE 2 - ROUND V—NOTCH TENSILE SPECIMEN CONFIGURATION

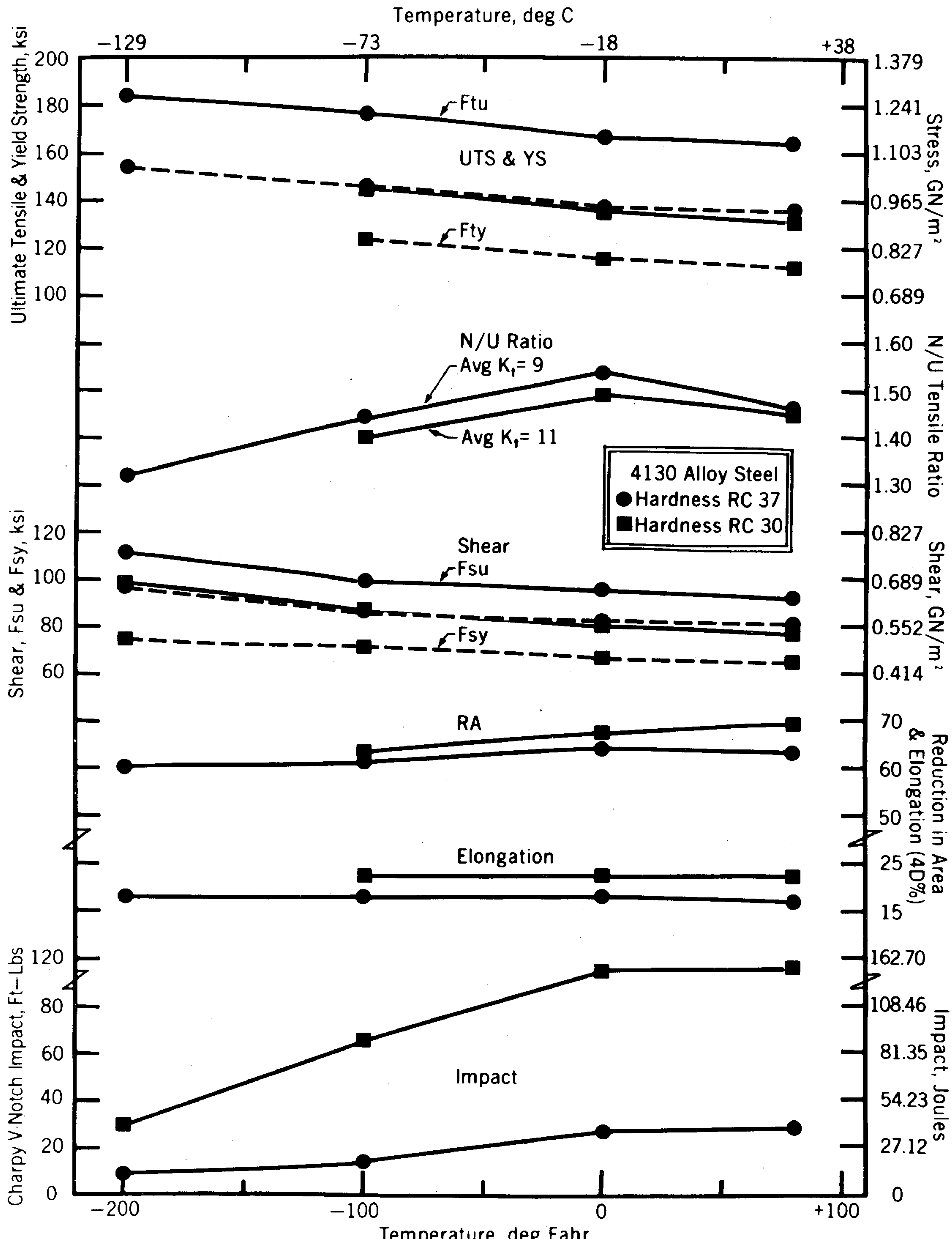


FIGURE 3 · LOW TEMPERATURE MECHANICAL PROPERTIES OF 4130 ALLOY STEEL BAR

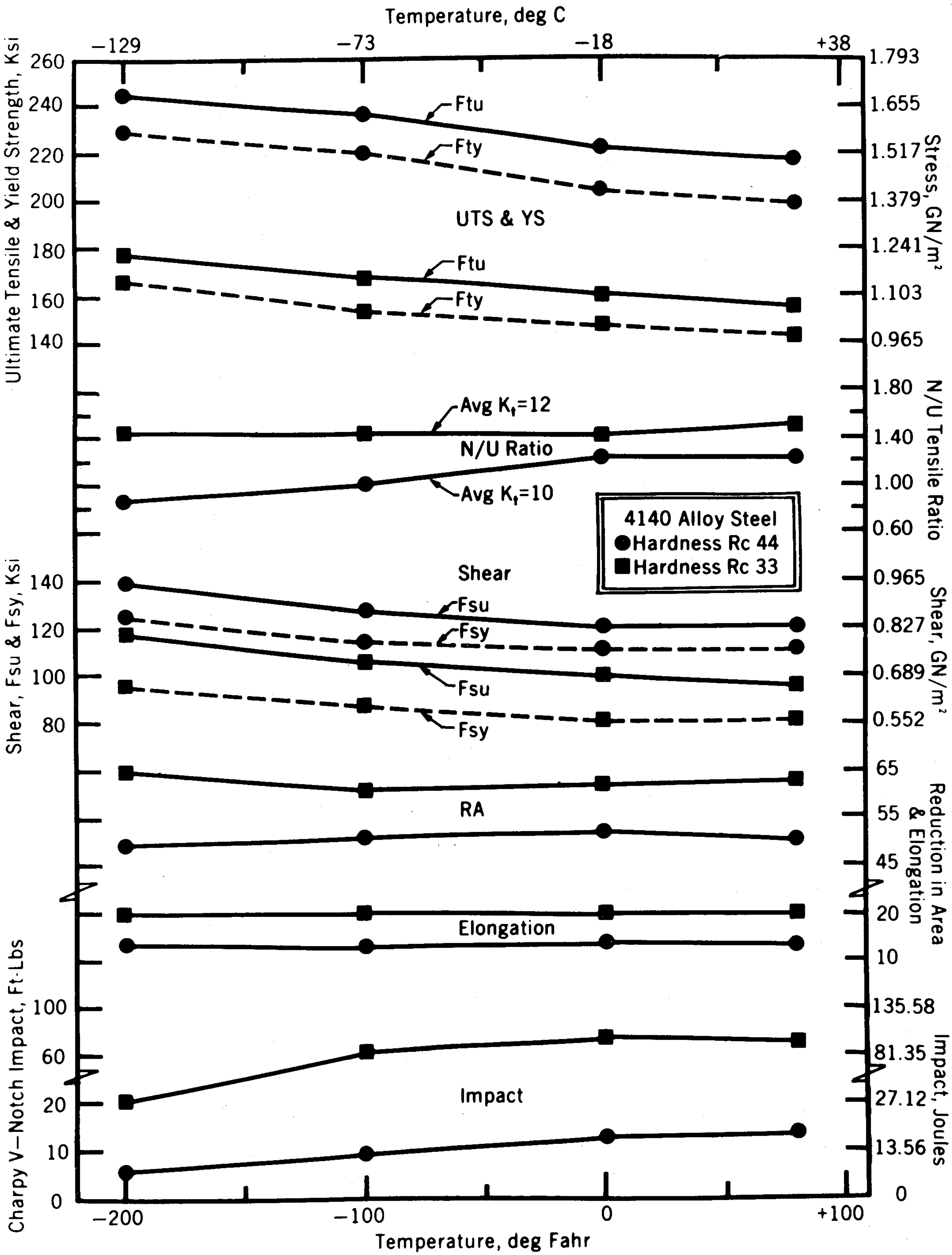


FIGURE 4 - LOW TEMPERATURE MECHANICAL PROPERTIES OF 4140 ALLOY STEEL BAR

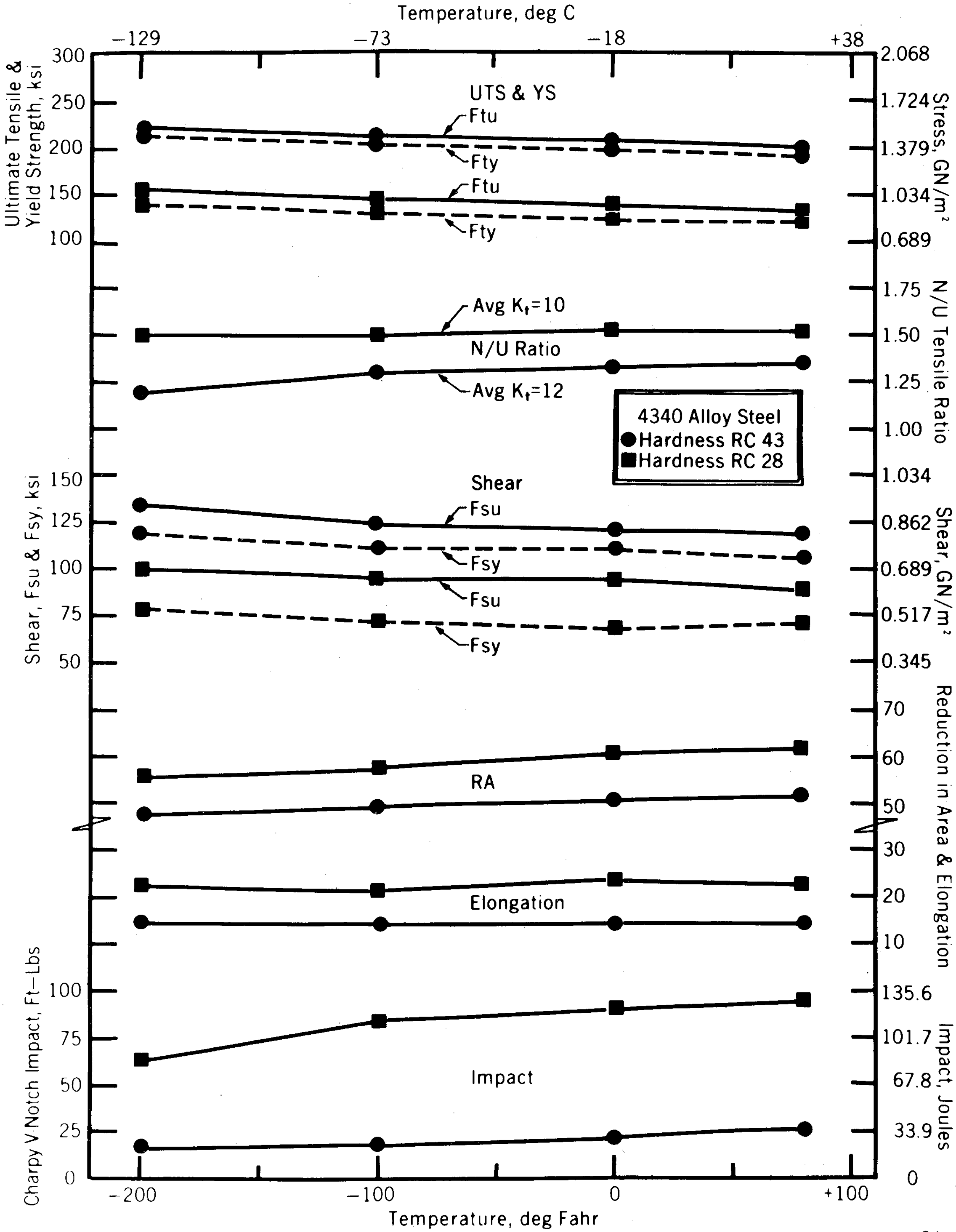


FIGURE 5 · LOW TEMPERATURE MECHANICAL PROPERTIES OF 4340 ALLOY STEEL BAR

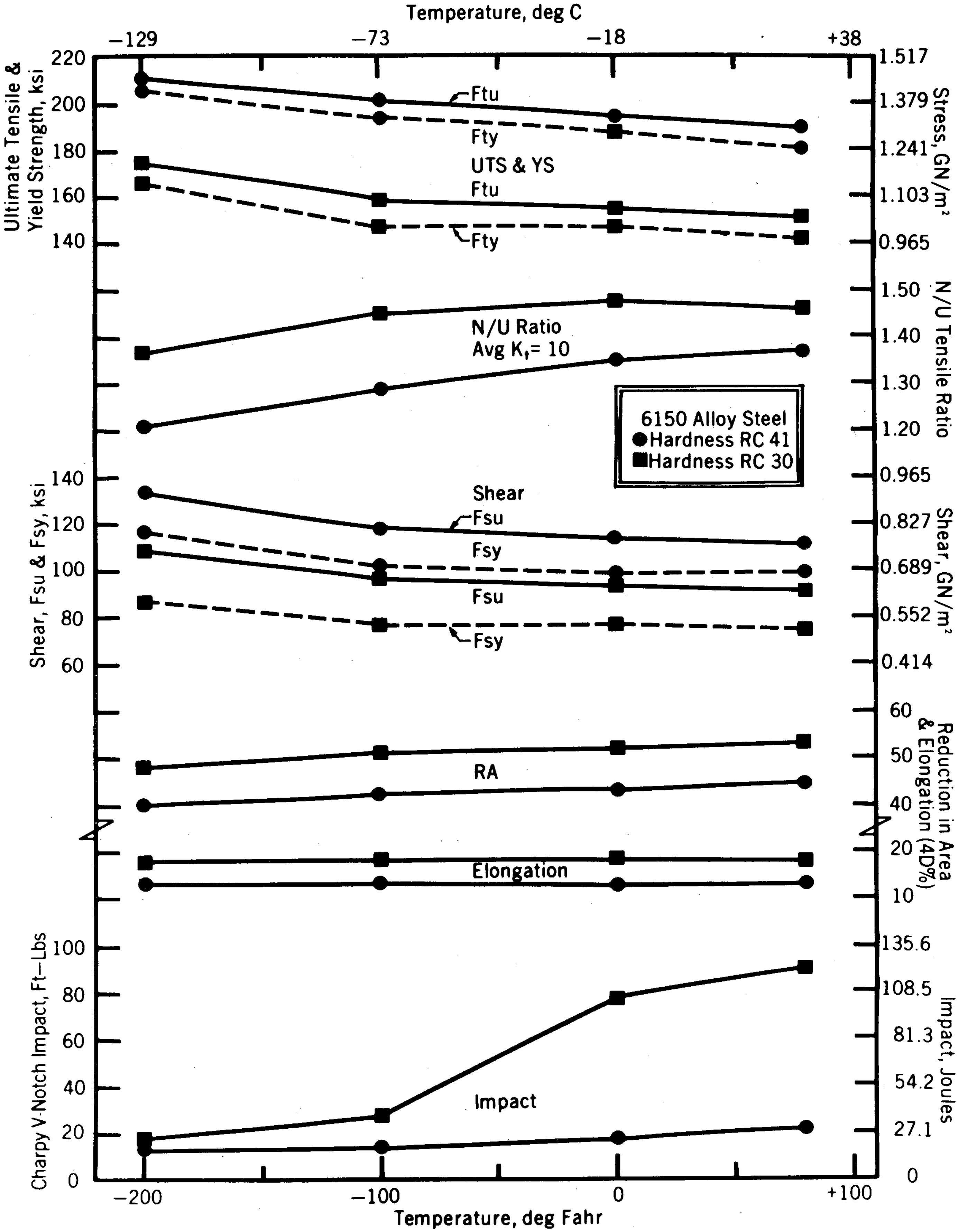


FIGURE 6 · LOW TEMPERATURE MECHANICAL PROPERTIES OF 6150 ALLOY STEEL BAR

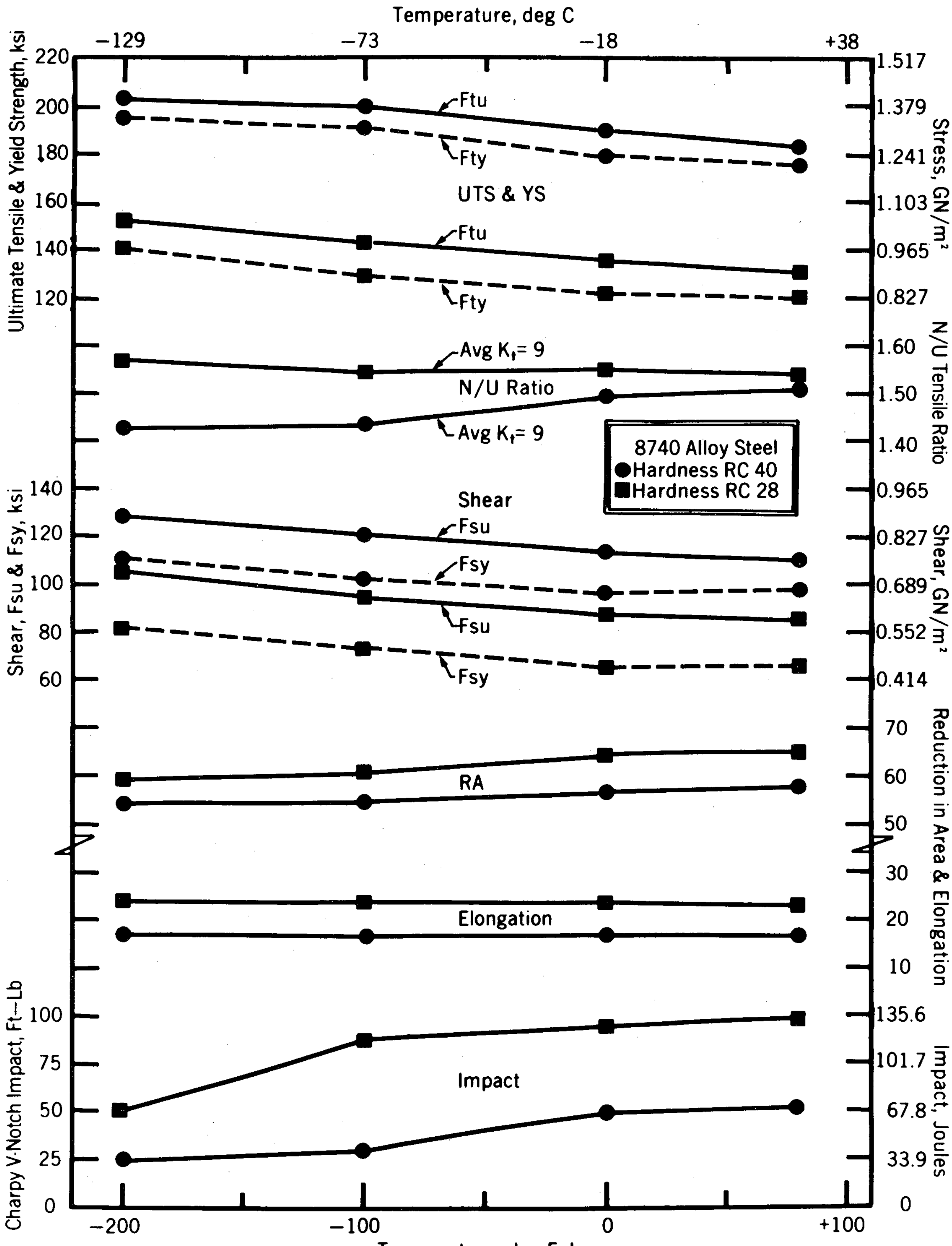


FIGURE 7 - LOW TEMPERATURE MECHANICAL PROPERTIES OF 8740 ALLOY STEEL BAR

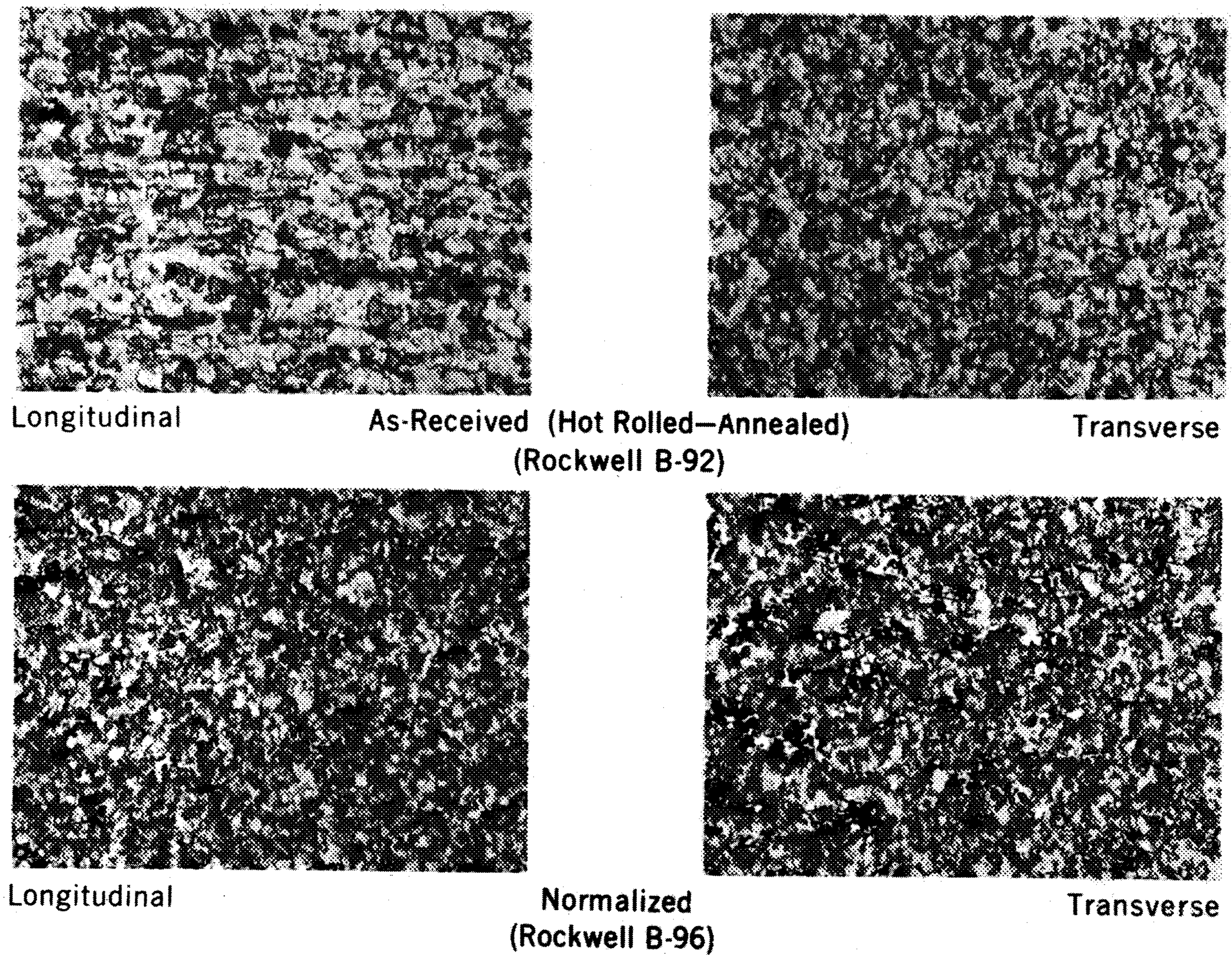
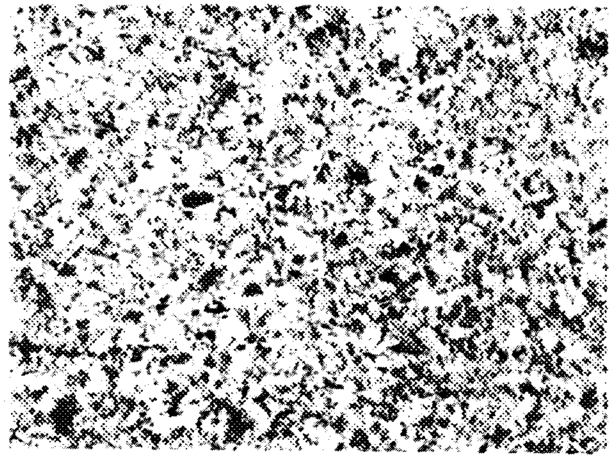
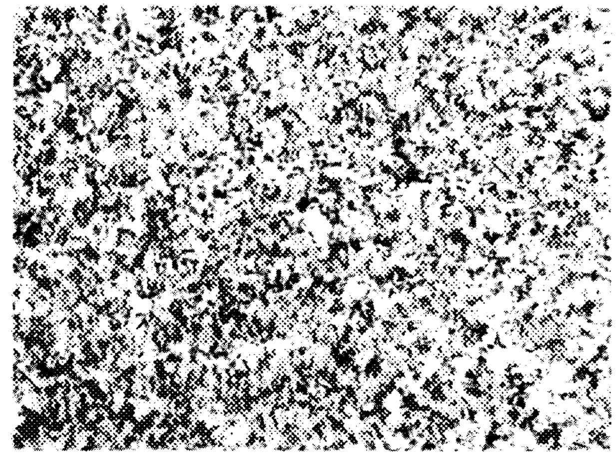


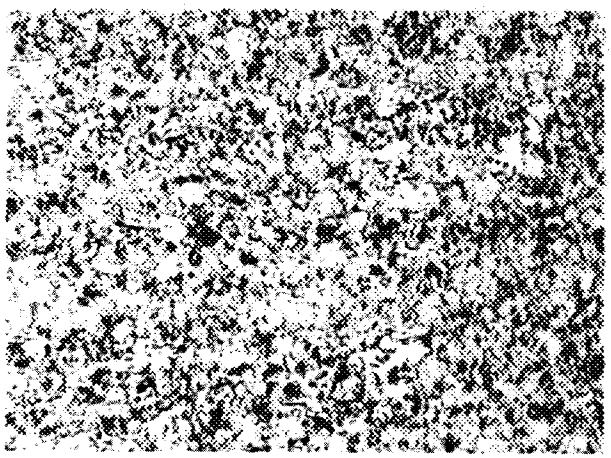
FIGURE 8A - MICROSTRUCTURE OF 4130 ALLOY STEEL IN THE AS-RECEIVED AND NORMALIZED CONDITIONS

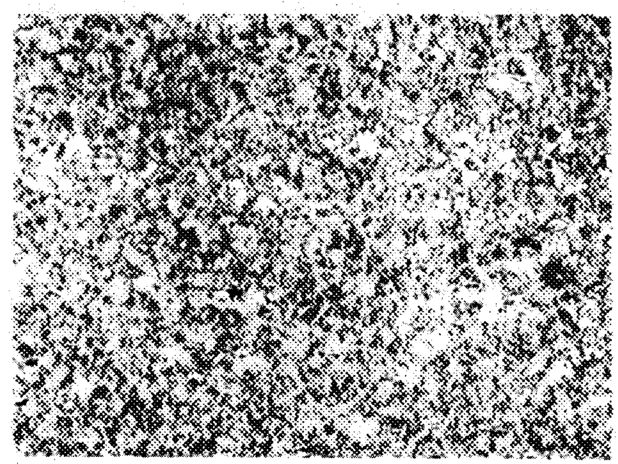
Etchant : Picric - Hydrochloric Mag 100X





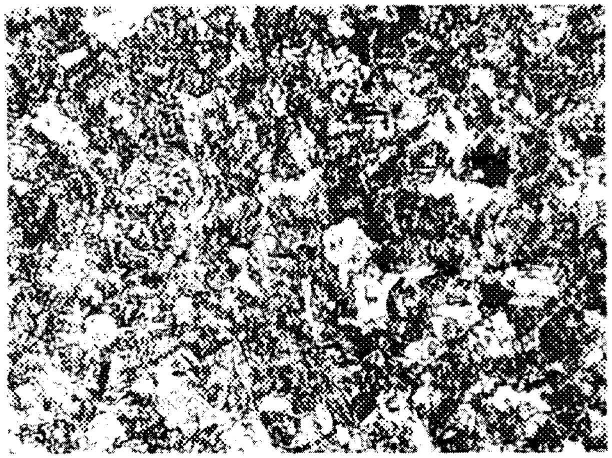
Longitudinal Tempered At 1050°F (566°C) Transverse
(Rockwell C-30)

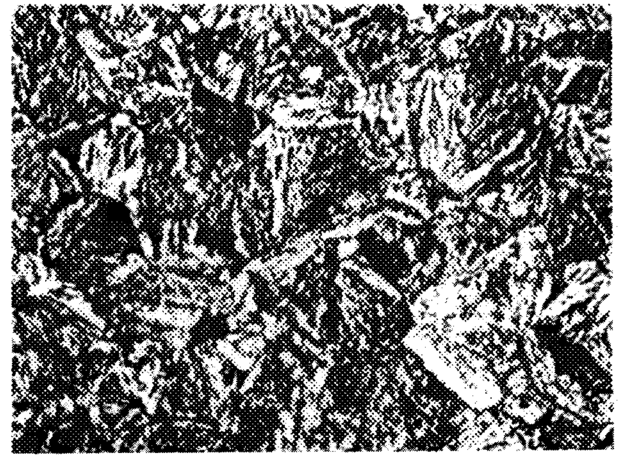




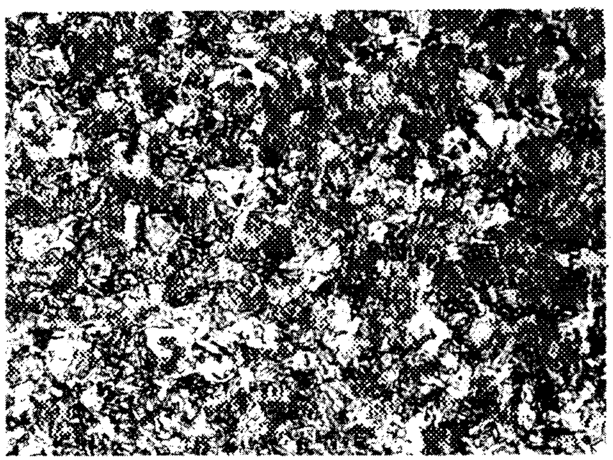
Longitional Tempered At 725°F (385°C) Transverse
(Rockwell C-37)

FIGURE 8B - MICROSTRUCTURE OF 4130 ALLOY STEEL TEMPERED AT 725°F (385°C) AND 1050°F (566°C)
Etchant : Picric - Hydrochloric Mag 100X



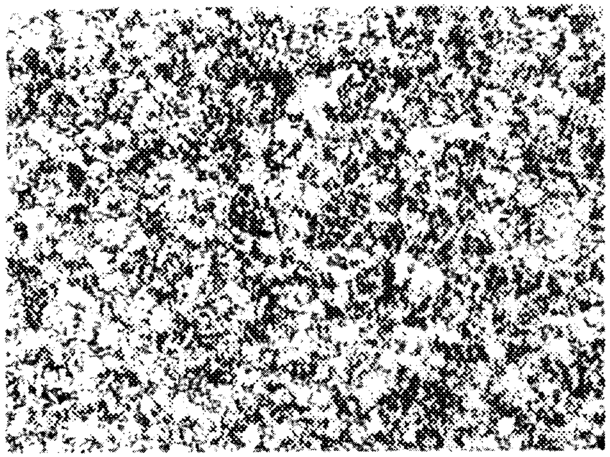


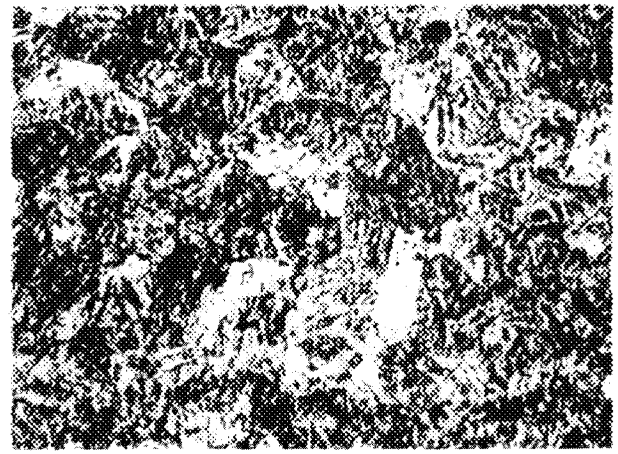
Mag 100X Longitudinal Mag 500X



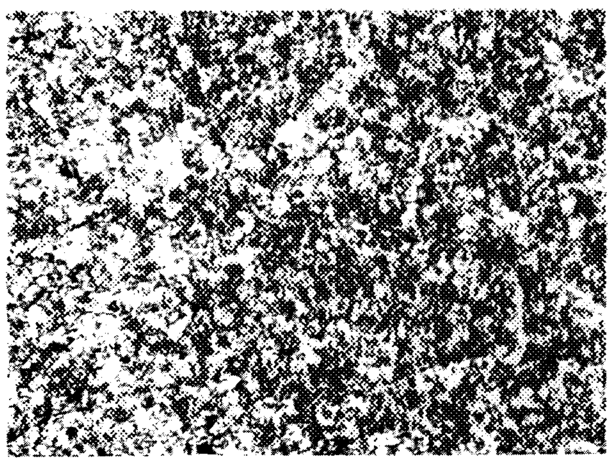
Mag 100X Transverse Mag 500X

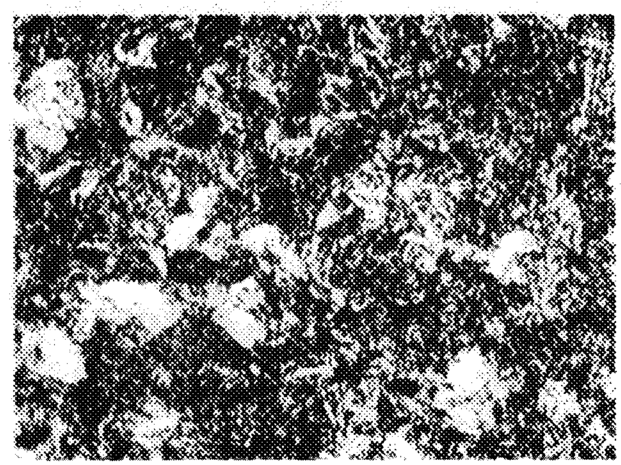
FIGURE 9A - MICROSTRUCTURE OF 4140 ALLOY STEEL IN THE AS-RECEIVED CONDITION
Etchant : Picric - Hydrochloric (Rockwell C-28.5)





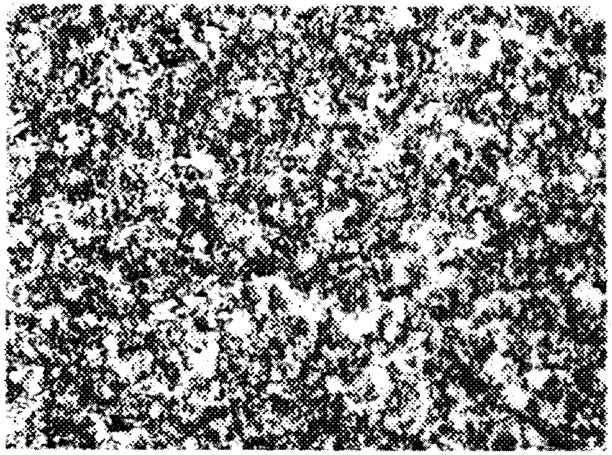
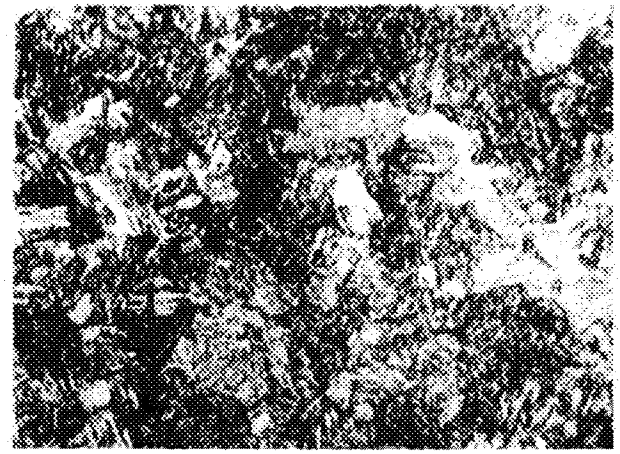
Mag 100X Longitudinal Mag 500X



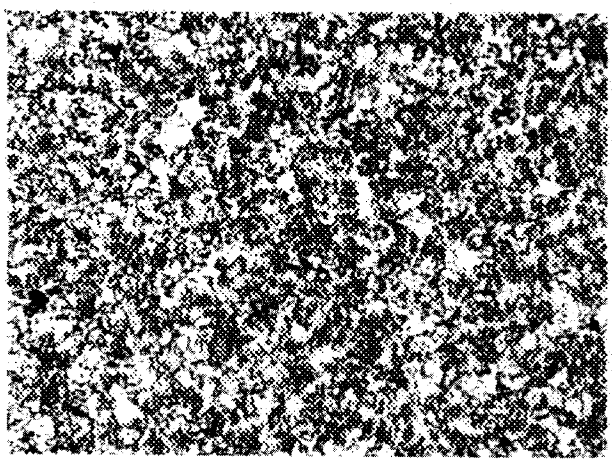
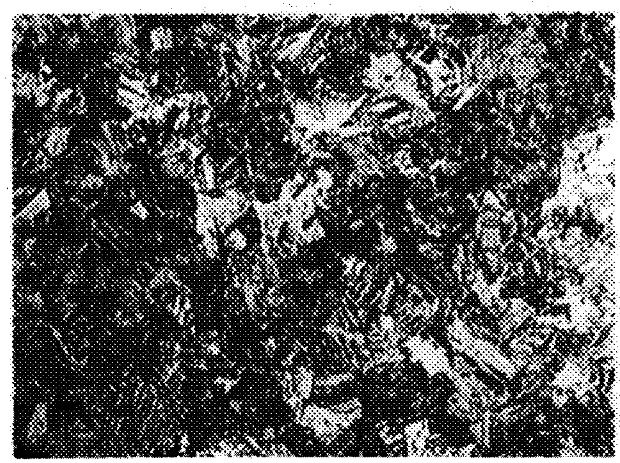


Mag 100X Transverse Mag 500X

FIGURE 9B - MICROSTRUCTURE OF 4140 ALLOY STEEL TEMPERED AT 725°F (385°C)
Etchant : Picric - Hydrochloric (Rockwell C-44)

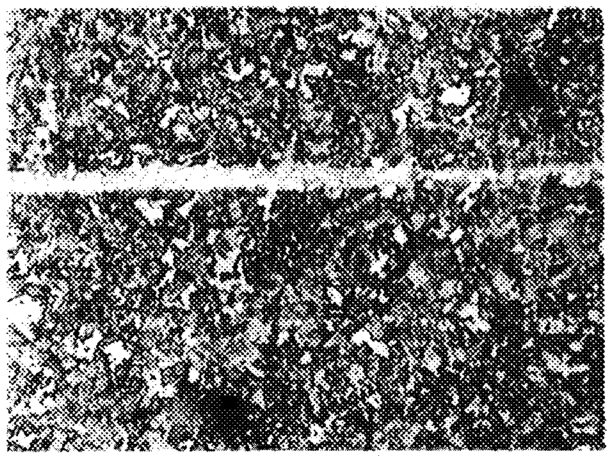



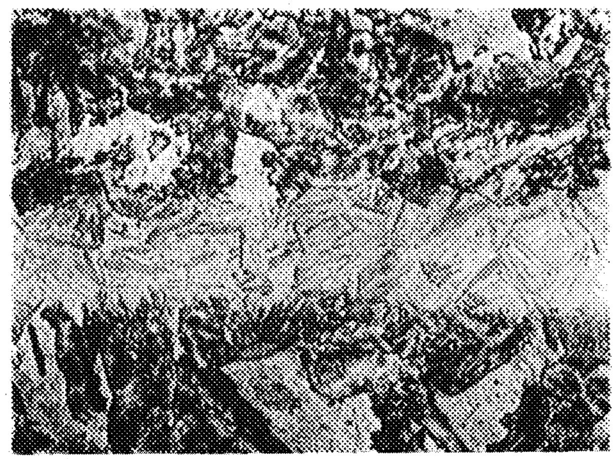
Mag 100X Longitudinal Mag 500X

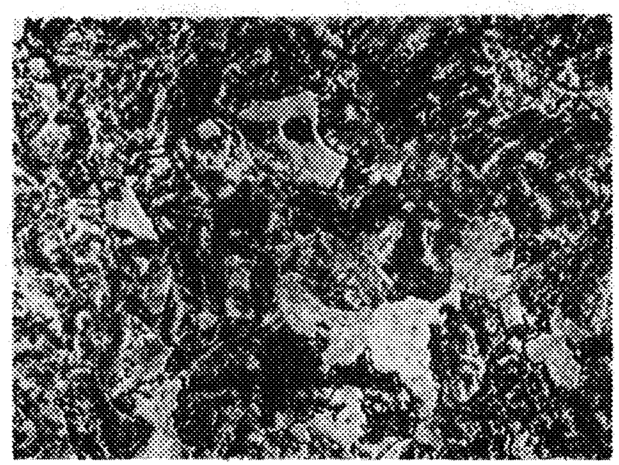
Mag 100X Transverse Mag 500X

FIGURE 9C - MICROSTRUCTURE OF 4140 ALLOY STEEL TEMPERED AT 1050°F (566°C)
Etchant : Picric - Hydrochloric (Rockwell C-33)



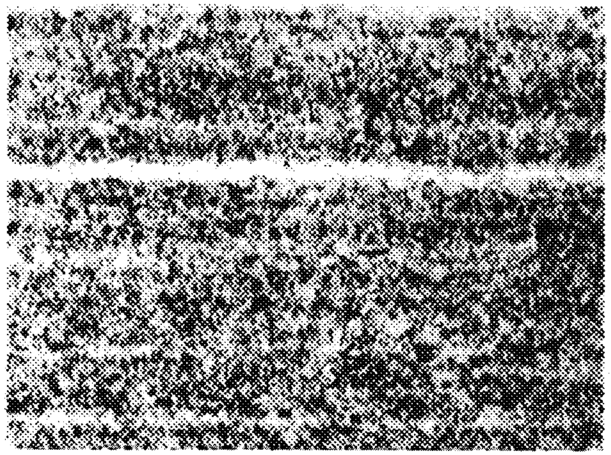
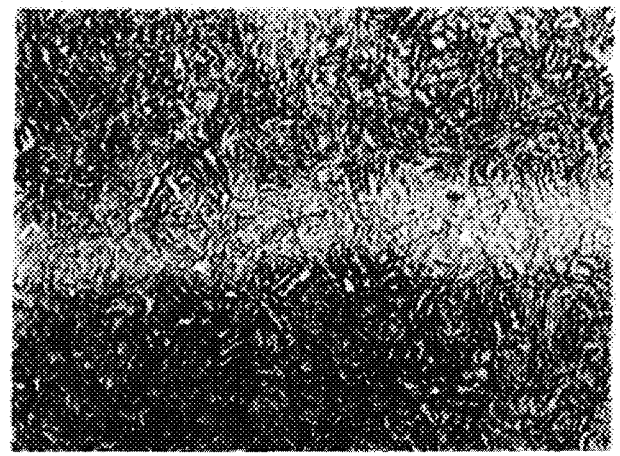


Mag 100X Longitudinal Mag 500X

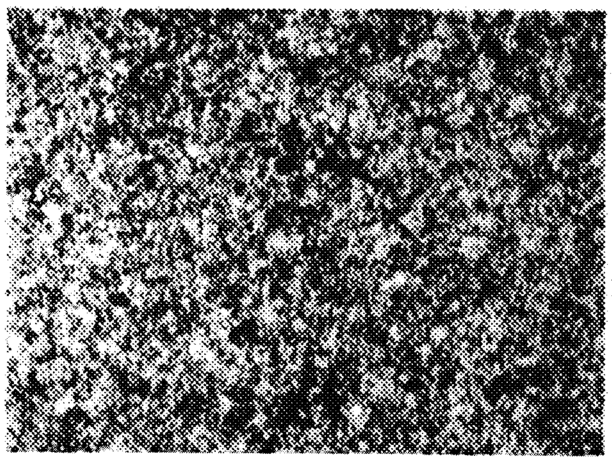
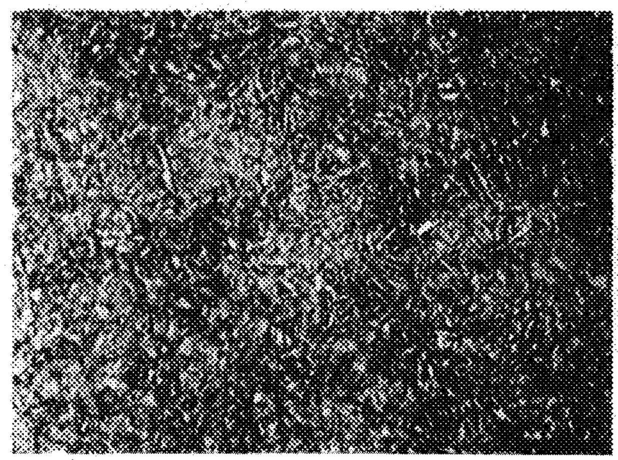


Mag 100X Transverse Mag 500X

FIGURE 10A - MICROSTRUCTURE OF 4340 ALLOY STEEL IN THE AS-RECEIVED CONDITION
Etchant : Nital (Rockwell C-32)

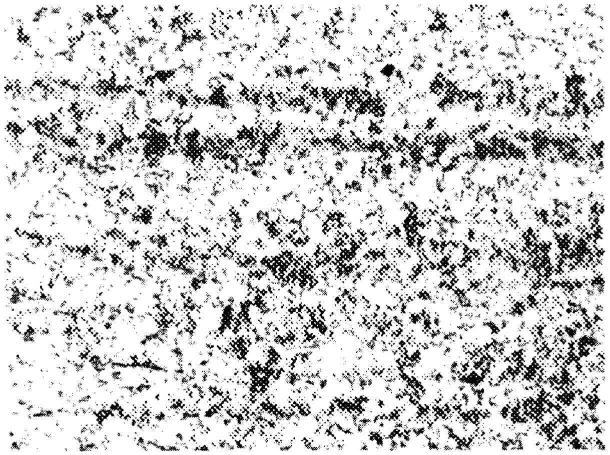



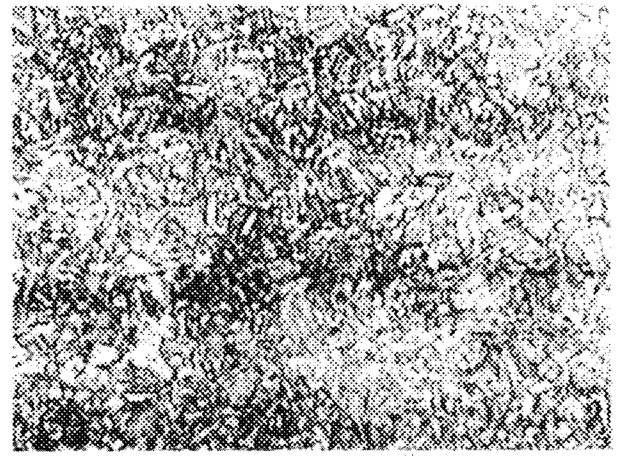
Mag 100X Longitudinal Mag 500X

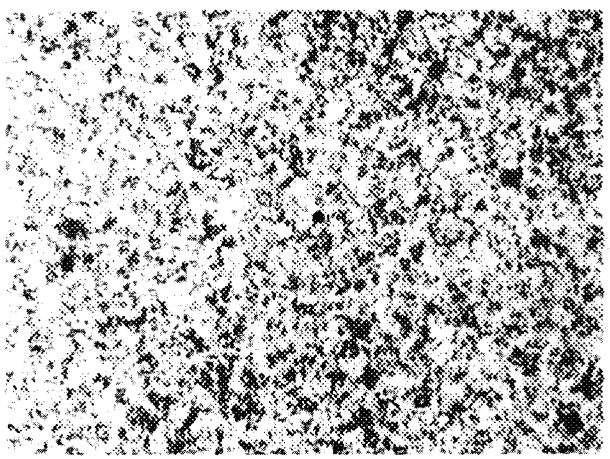
Mag 100X Transverse Mag 500X

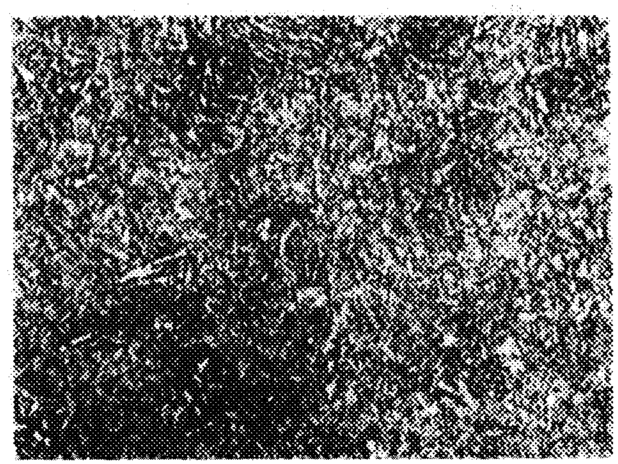
FIGURE 10B - MICROSTRUCTURE OF 4340 ALLOY STEEL TEMPERED AT 825°F (440°C)
Etchant: Nital (Rockwell C-43)





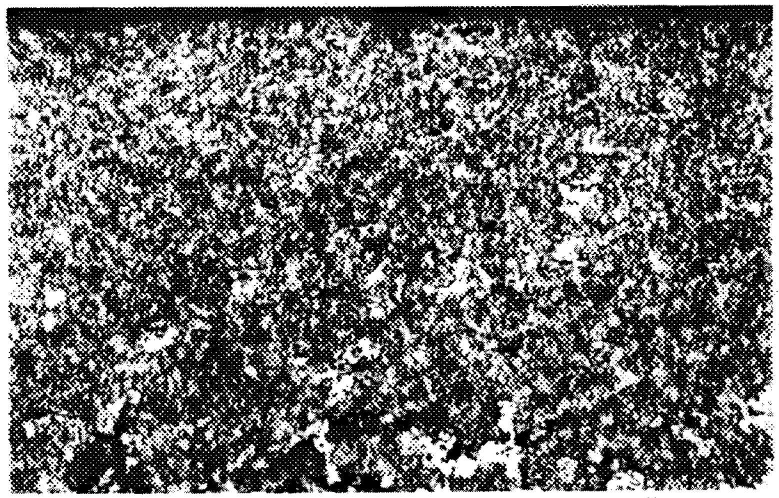
Mag 100X Longitudinal Mag 500X



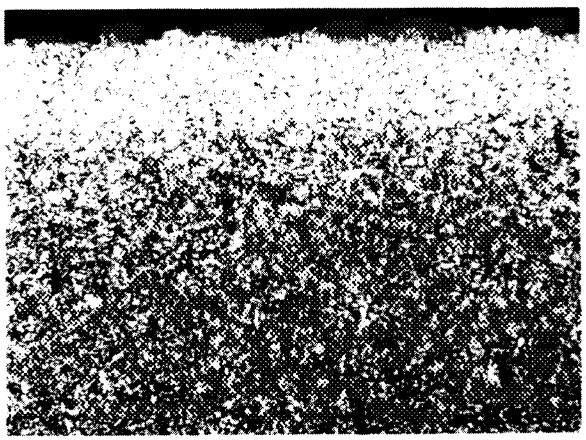


Mag 100X Transverse Mag 500X

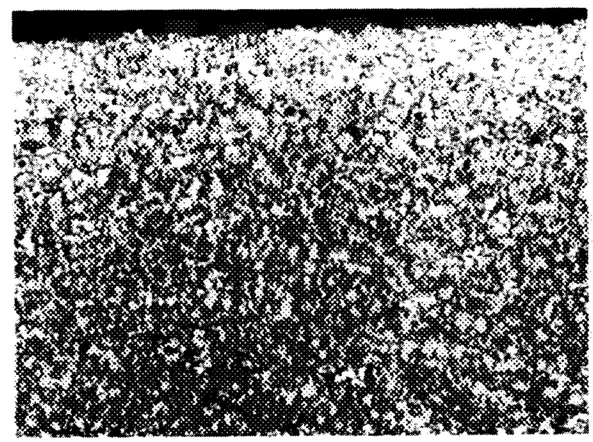
FIGURE 10C - MICROSTRUCTURE OF 4340 ALLOY STEEL TEMPERED AT 1200°F (649°C)
Etchant : Nital (Rockwell C-28)



As-Received (Cold Drawn Annealed)
(Rockwell C-20.5)



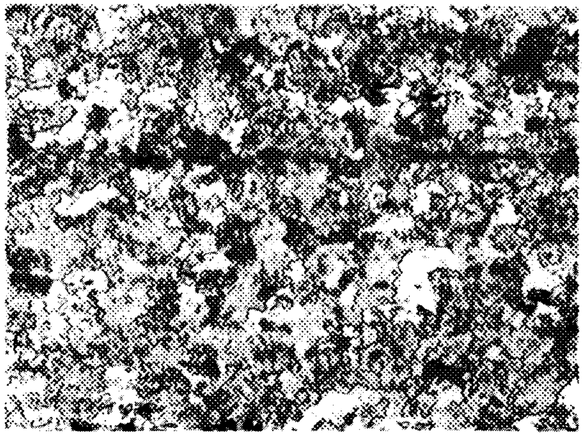
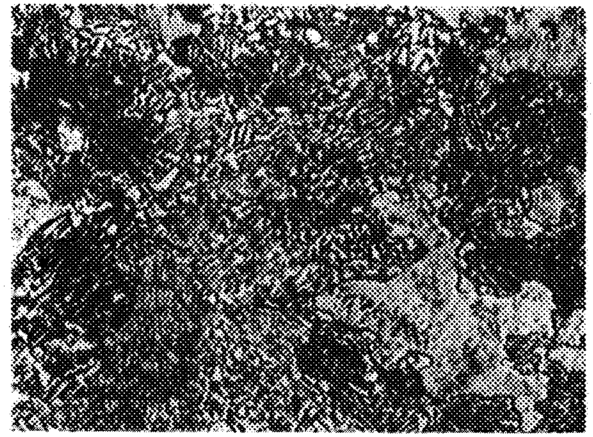
Tempered At 1200°F (649°C)
(Rockwell C-26)



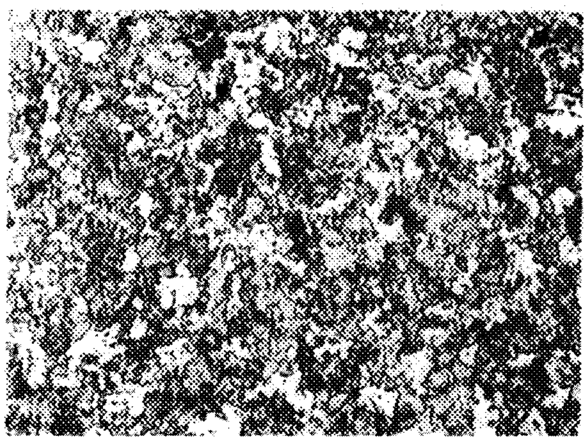
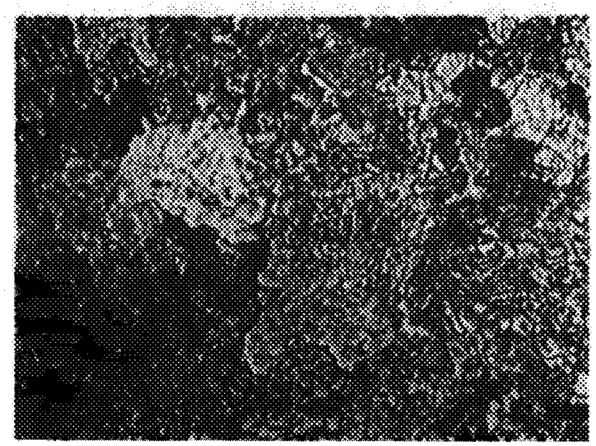
Tempered At 950°F (510°C)
(Rockwell C-41)

FIGURE 11A - MICROSTRUCTURE OF 6150 ALLOY STEEL INDICATING SURFACE DECARBURIZATION

Etchant : Nital — Transverse Mag 100X

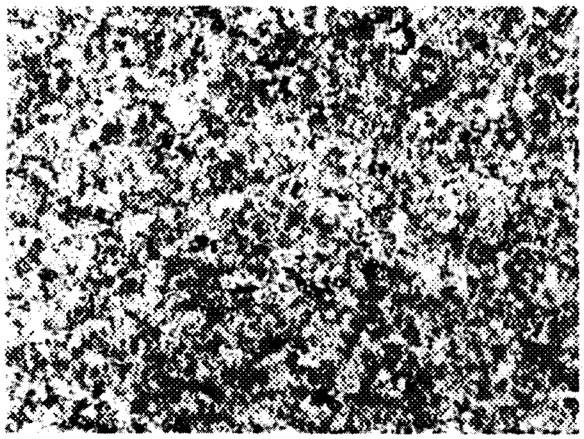



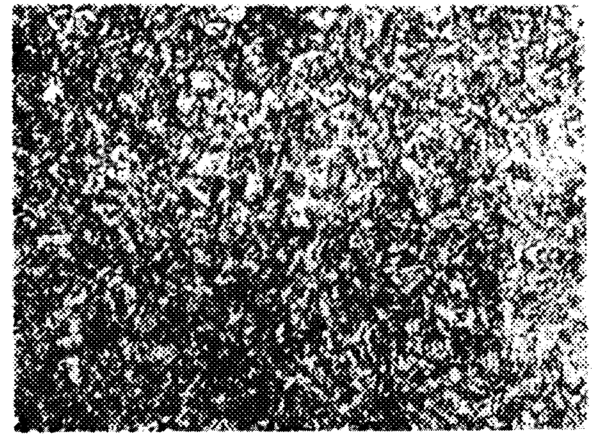
Mag 100X Longitudinal Mag 500X

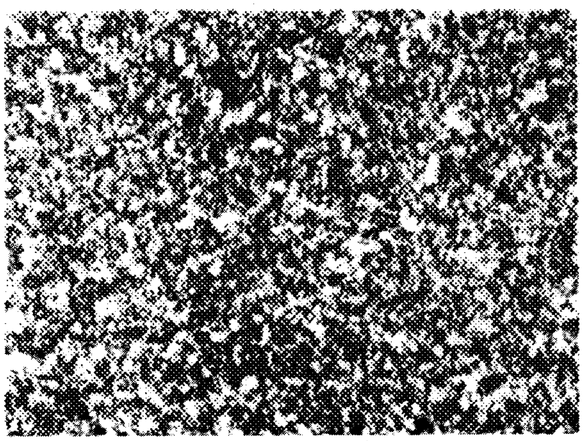
Mag 100X Transverse Mag 500X

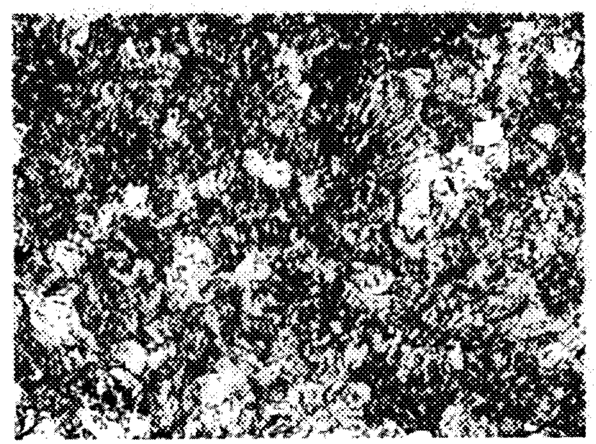
FIGURE 11B - MICROSTRUCTURE OF 6150 ALLOY STEEL IN THE AS-RECEIVED CONDITION
(COLD DRAWN-ANNEALED) (Rockwell C-20.5)
Etchant : Picric - Hydrochloric





Mag 100X Longitudinal Mag 500X

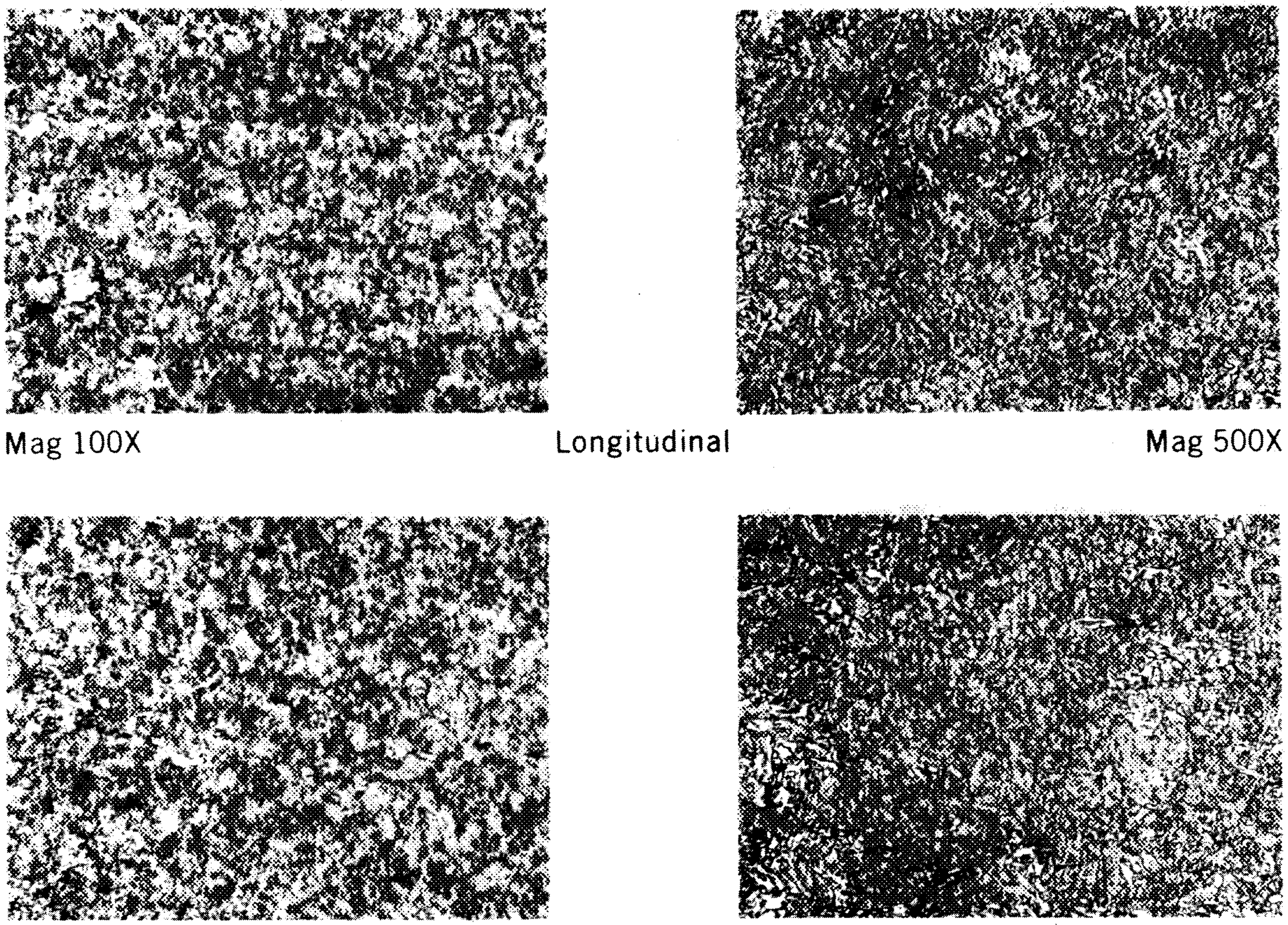




Mag 100X Transverse Mag 500X

FIGURE 11C - MICROSTRUCTURE OF 6150 ALLOY STEEL TEMPERED AT 950°F (510°C)

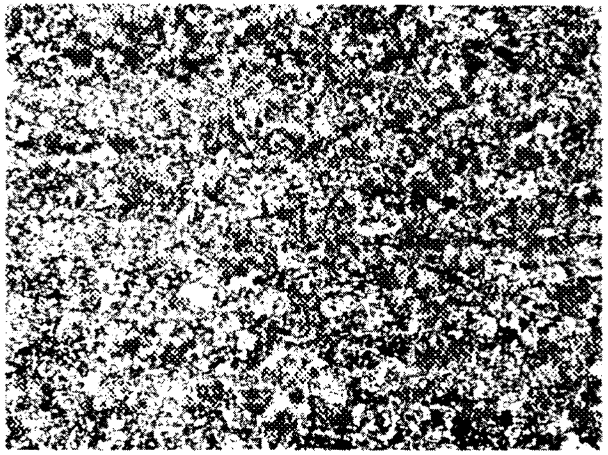
Etchant : Nital (Rockwell C-41)



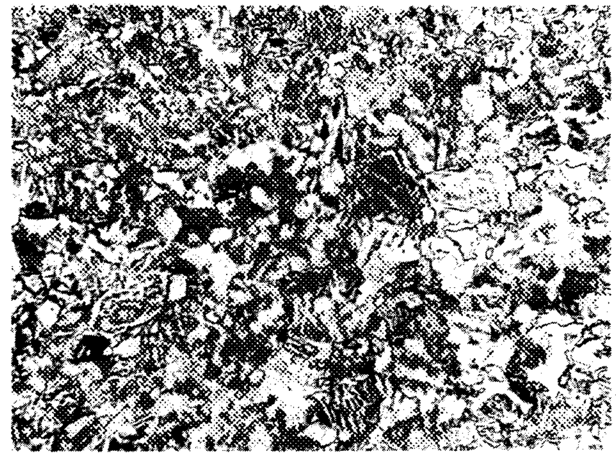
Mag 100X Longitudinal Mag 500X

Mag 100X Transverse Mag 500X

FIGURE 11D - MICROSTRUCTURE OF 6150 ALLOY STEEL TEMPERED AT 1200°F (649°C)
Etchant : Nital (Rockwell C-30)

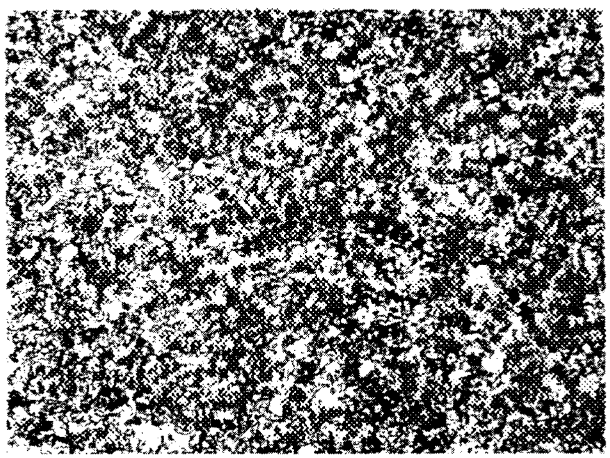


Mag 100X

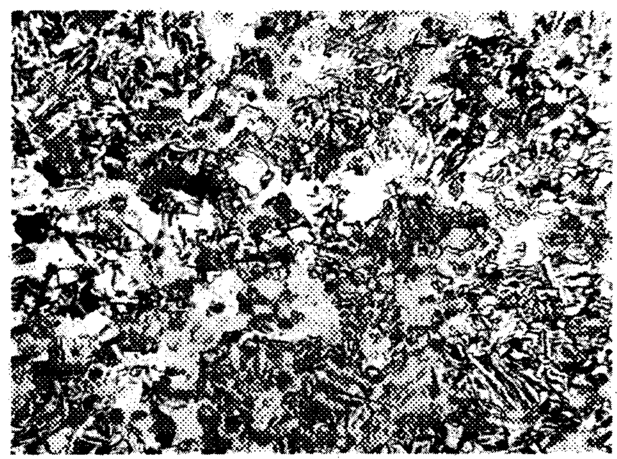


Longitudinal

Mag 500X



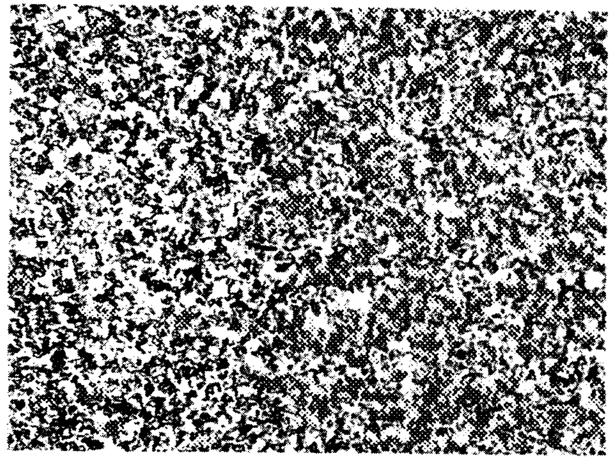
Mag 100X

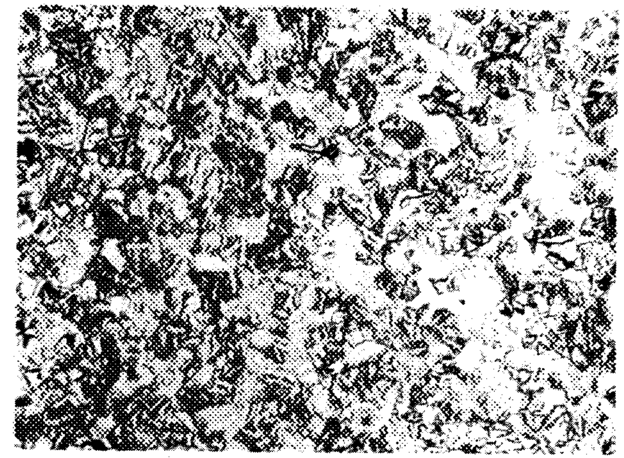


Transverse

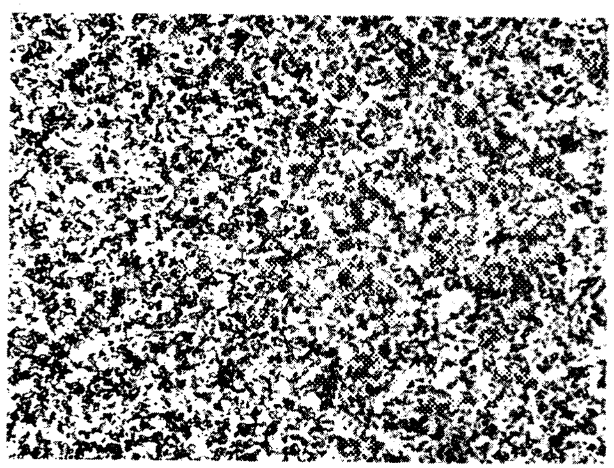
Mag 500X

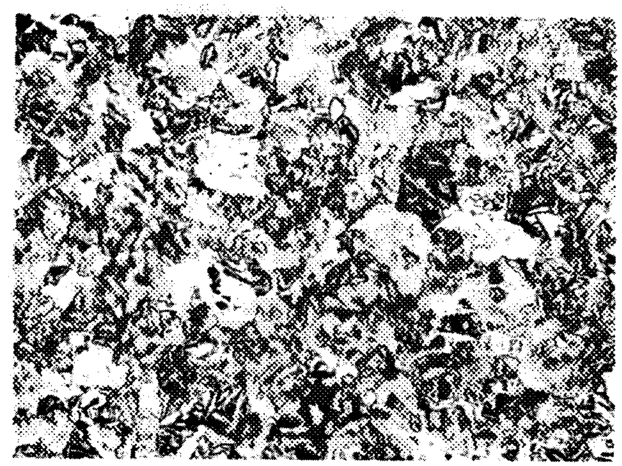
FIGURE 12A - MICROSTRUCTURE OF 8740 ALLOY STEEL IN THE AS-RECEIVED CONDITION
(HOT ROLLED - ANNEALED) (Rockwell C-25)
Etchant : Picric - Hydrochloric





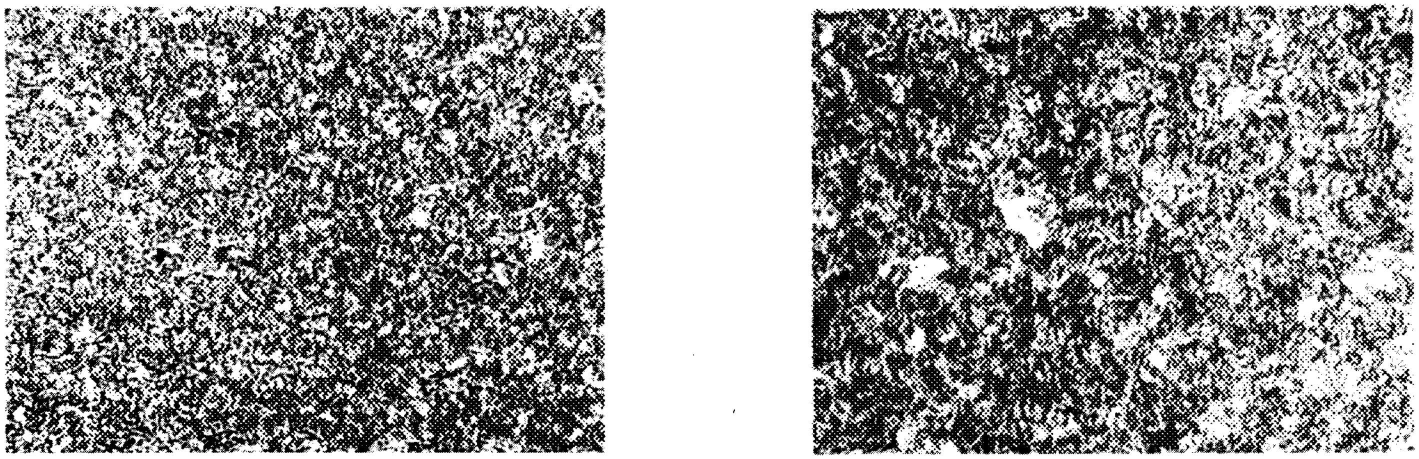
Mag 100X Longitudinal Mag 500X



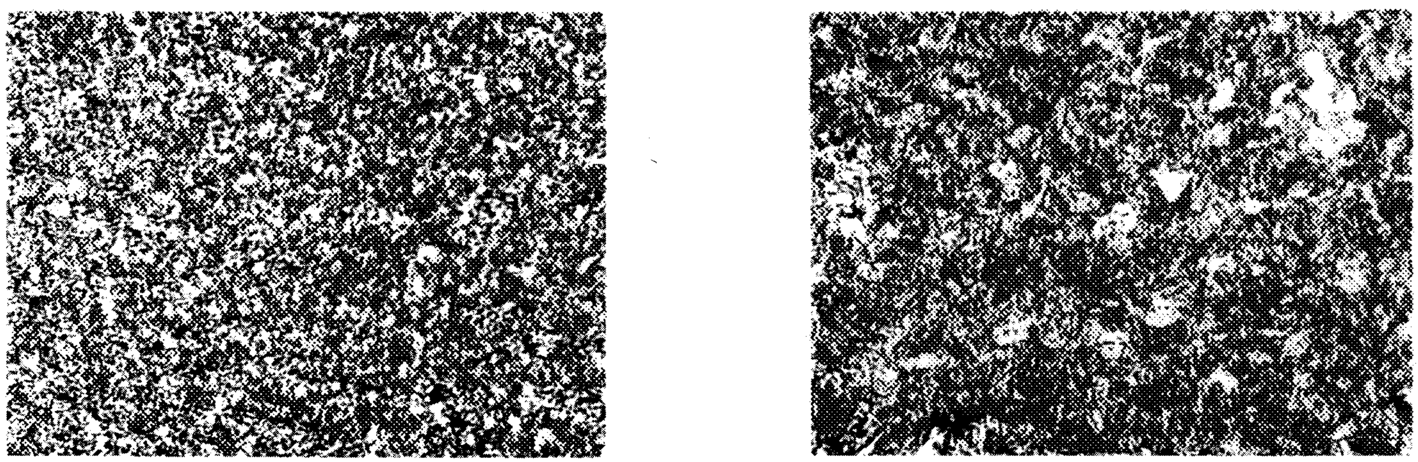


Mag 100X Transverse Mag 500X

FIGURE 12B - MICROSTRUCTURE OF 8740 ALLOY STEEL IN THE NORMALIZED CONDITION
Etchant : Picric - Hydrochloric (Rockwell C-25)

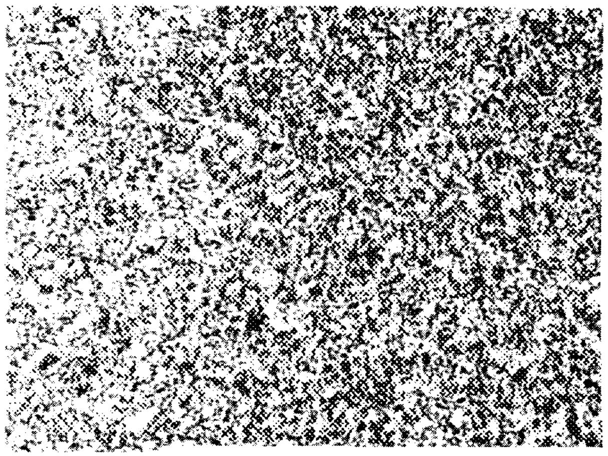


Mag 100X Longitudinal Mag 500X



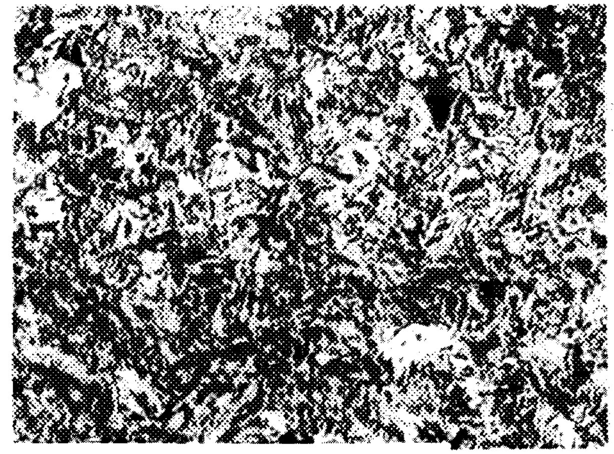
Mag 100X Transverse Mag 500X

FIGURE 12C - MICROSTRUCTURE OF 8740 ALLOY STEEL TEMPERED AT 850°F (454°C)
Etchant : Picric - Hydrochloric (Rockwell C-40)

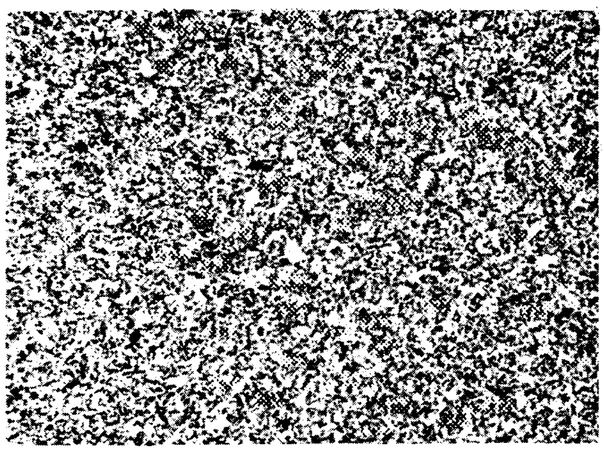


Mag 100X

Longitudinal

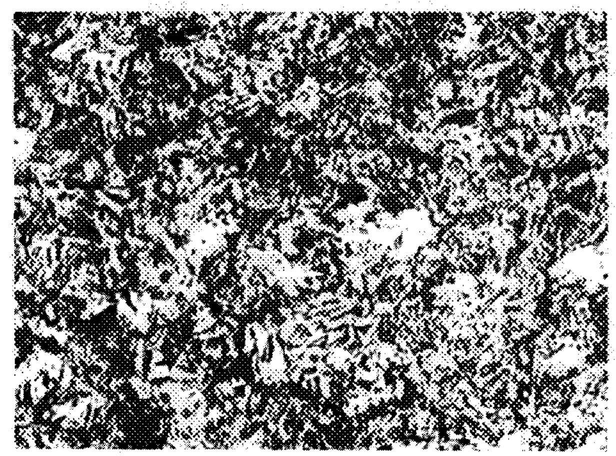


Mag 500X



Mag 100X

Transverse



Mag 500X

FIGURE 12D - MICROSTRUCTURE OF 8740 ALLOY STEEL TEMPERED AT 1175°F (635°C)
Etchant : Picric - Hydrochloric (Rockwell C-28)

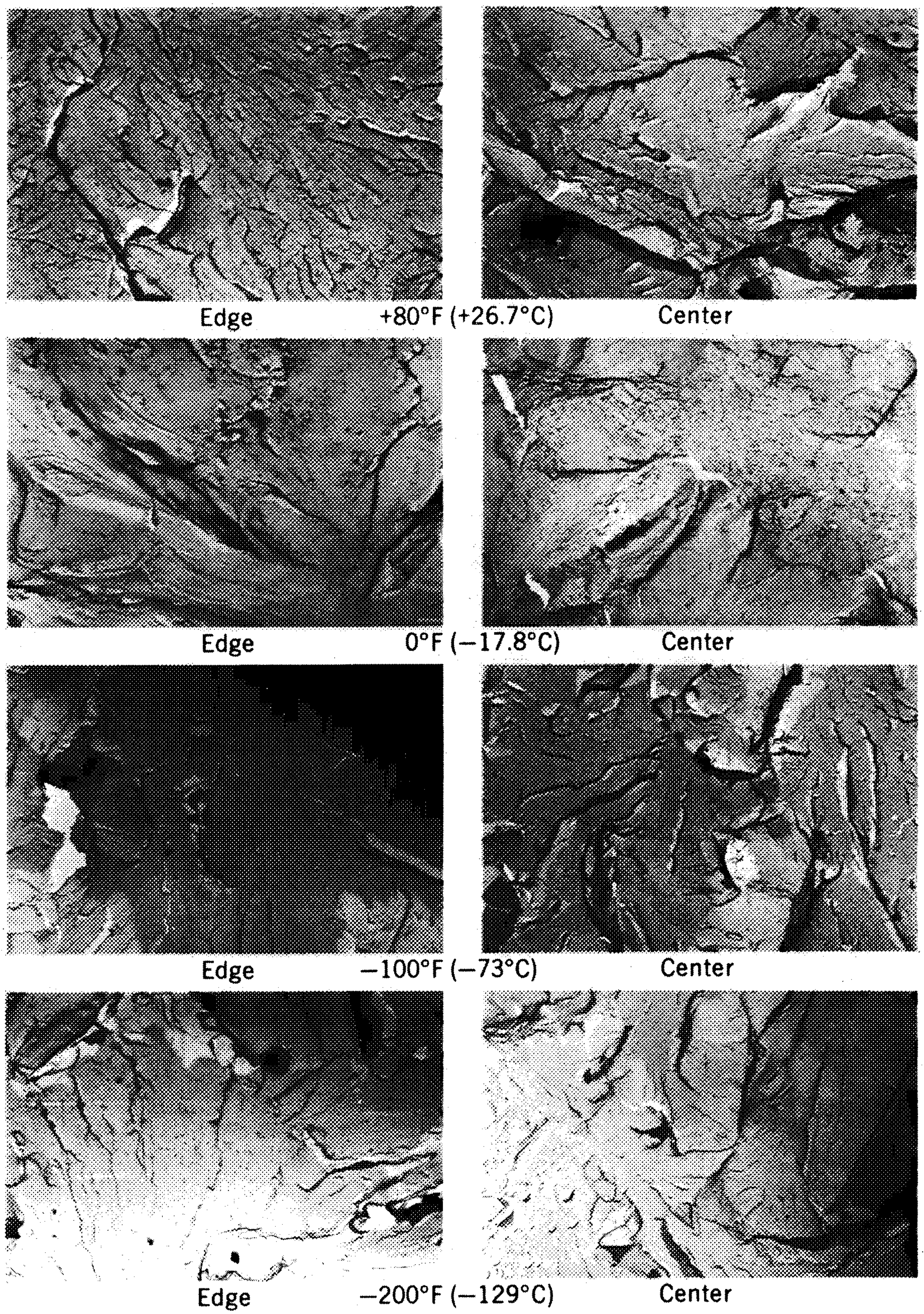


FIGURE 13A - TEM FRACTOGRAPHS OF 4130 ALLOY STEEL TEMPERED AT 725°F (385°C)
CHARPY V—NOTCHED IMPACT BAR SPECIMEN FRACTURES 2400X MAG

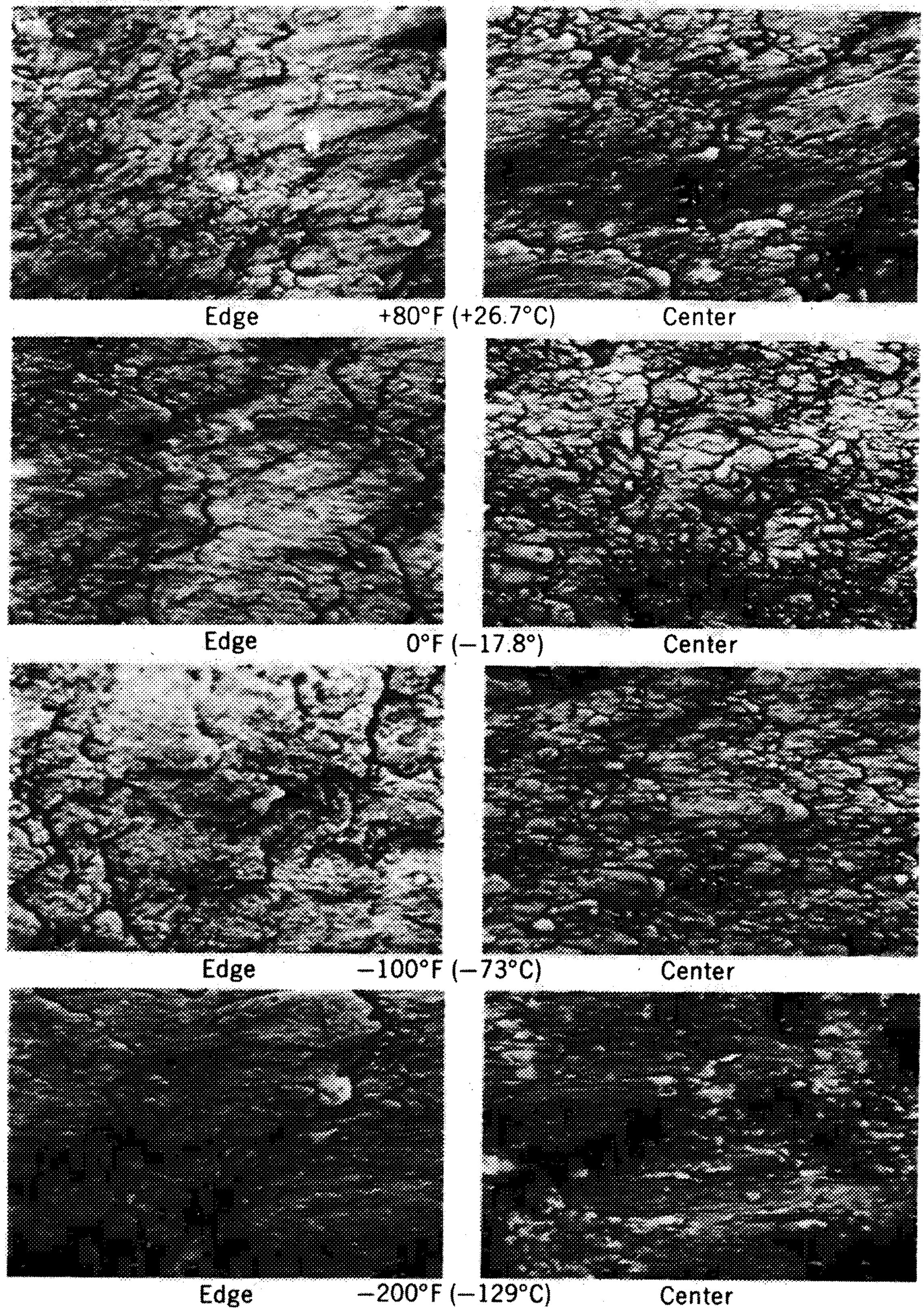
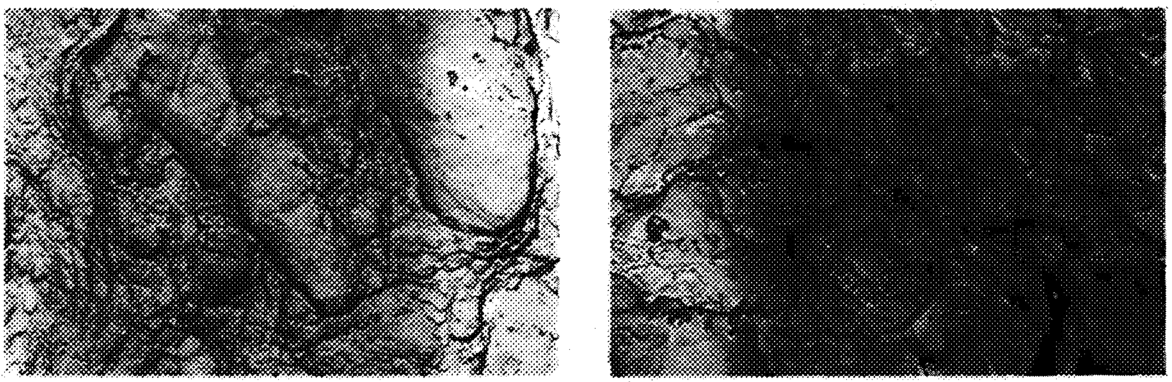
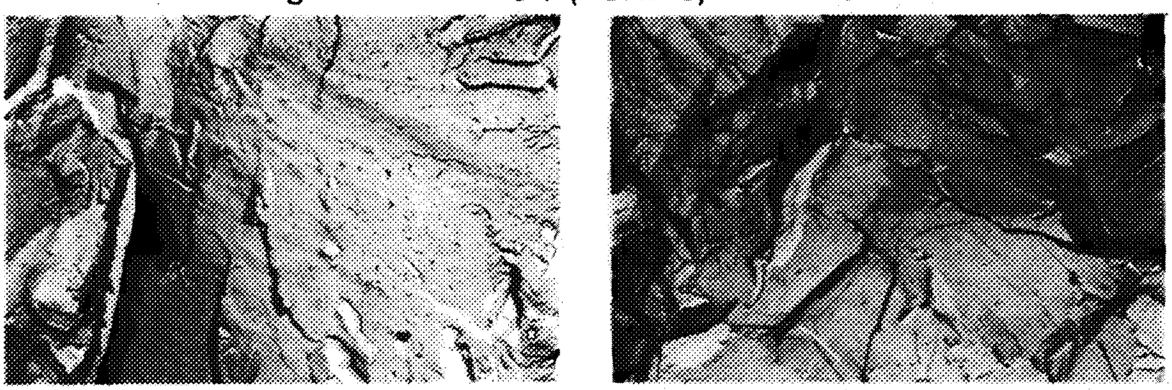


FIGURE 13B - SEM FRACTOGRAPHS OF 4130 ALLOY STEEL TEMPERED AT 725°F (385°C)
DOUBLE SHEAR SPECIMEN FRACTURES 2300X MAG

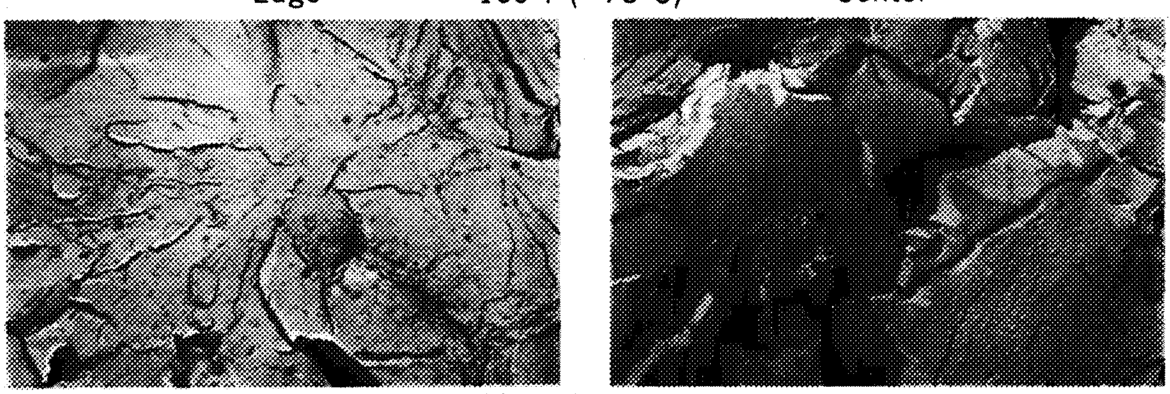
Edge +80°F (+26.7°C) Center



Edge 0°F (−17.8°C) Center

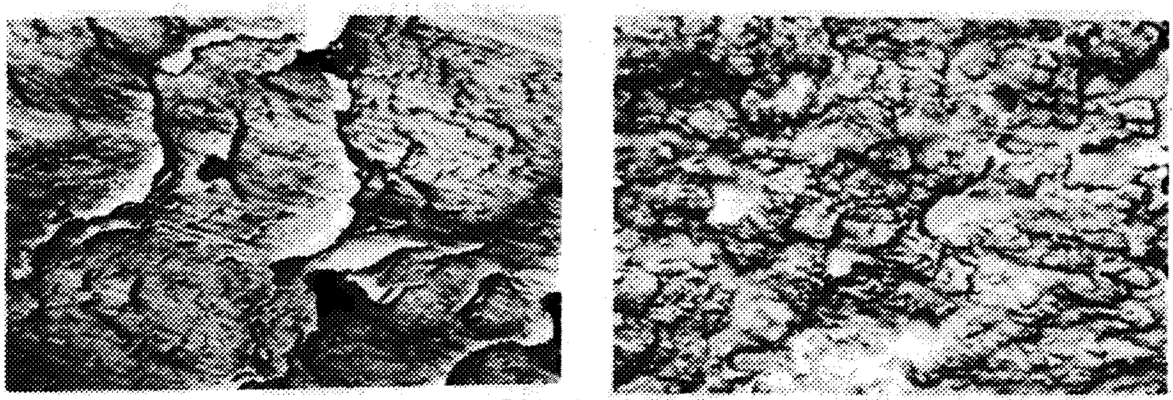


Edge −100°F (−73°C) Center

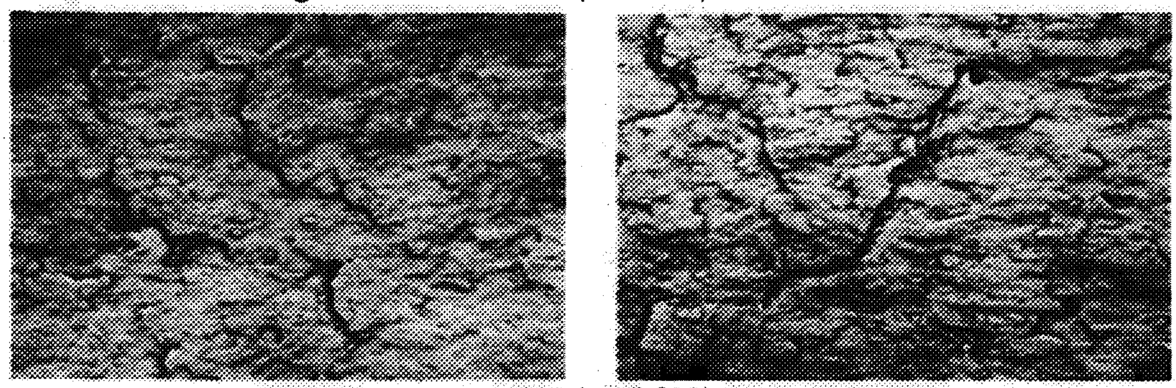


Edge −200°F (−129°C) Center

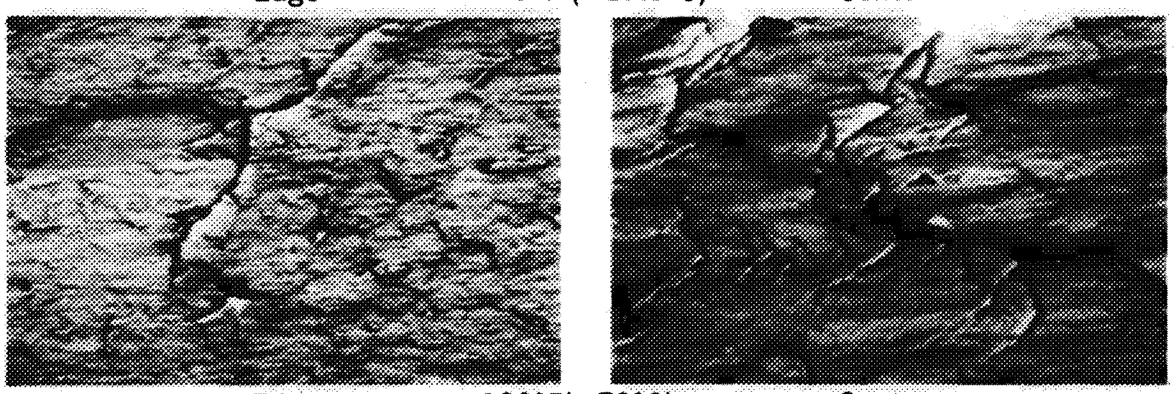
FIGURE 14A - TEM FRACTOGRAPHS OF 4130 ALLOY STEEL TEMPERED AT 1050°F (566°C)
CHARPY V—NOTCHED IMPACT BAR SPECIMEN FRACTURES 2400X MAG



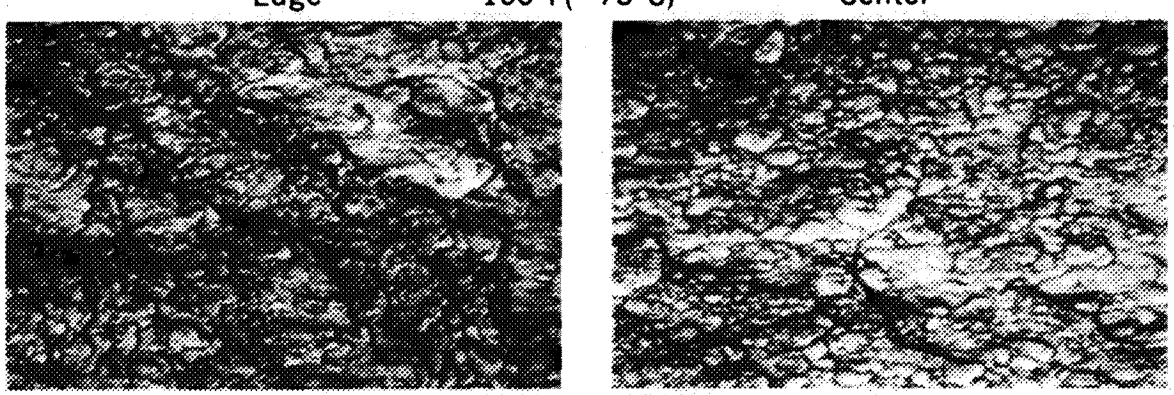
Edge +80°F (+26.7°C) Center



Edge 0°F (−17.8°C) Center



Edge −100°F(−73°C) Center



Edge −200°F (−129°C) Center

FIGURE 14B - SEM FRACTOGRAPHS OF 4130 ALLOY STEEL TEMPERED AT 1050°F (566°C)
DOUBLE SHEAR SPECIMEN FRACTURES 2300X MAG

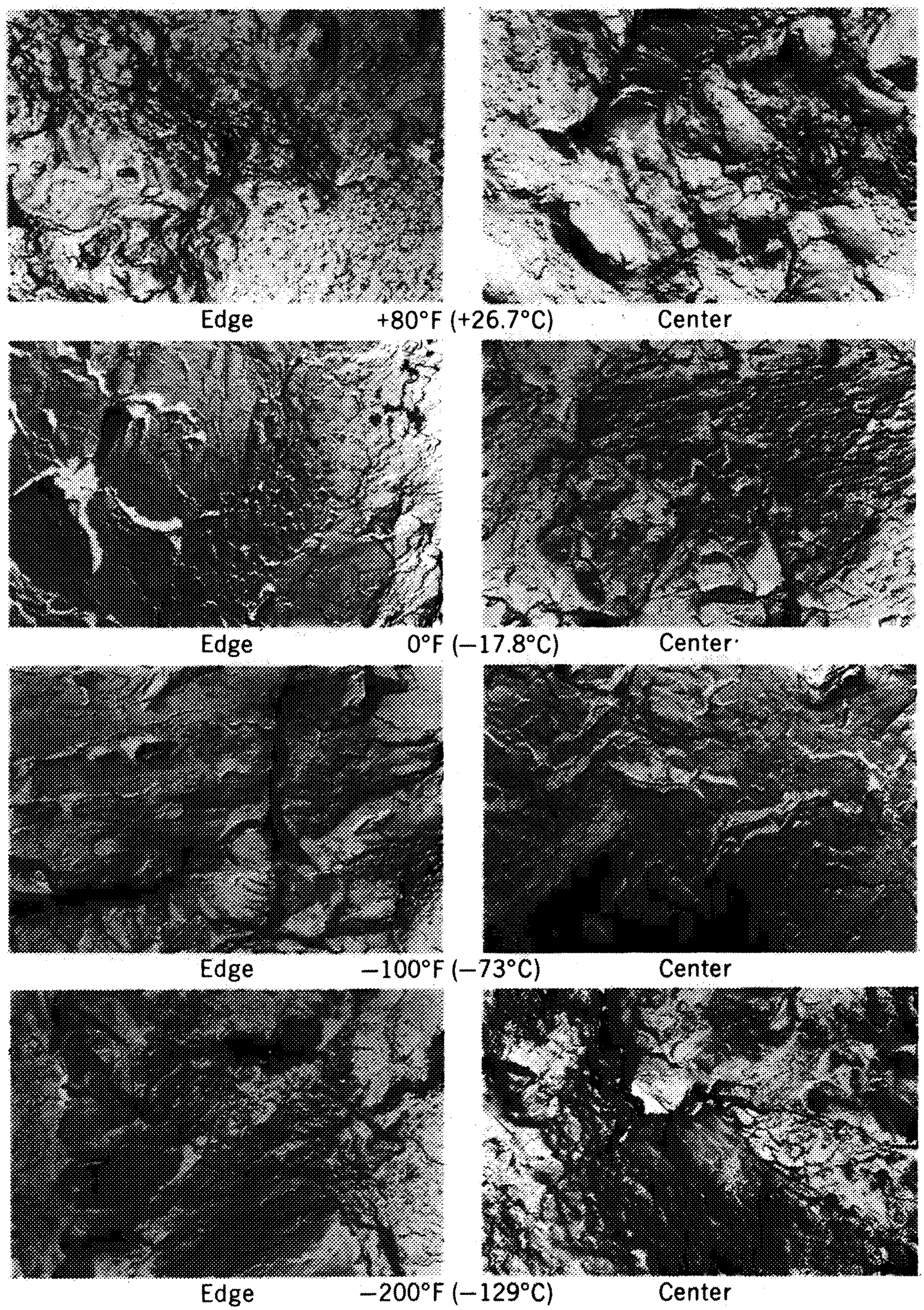


FIGURE 15A - TEM FRACTOGRAPHS OF 4140 ALLOY STEEL TEMPERED AT 725°F (385°C)
SMOOTH BAR TENSILE FRACTURES 3150X MAG

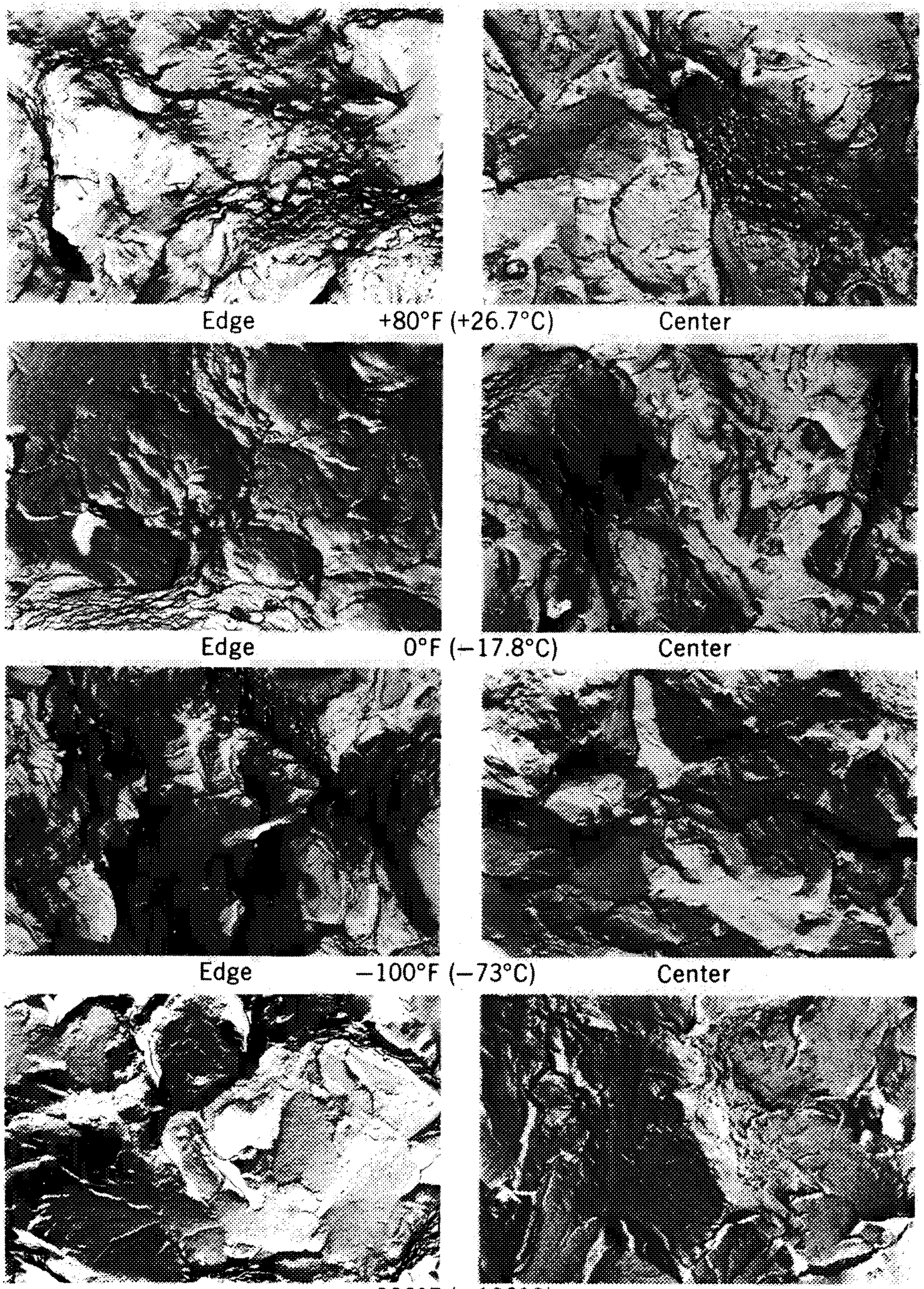
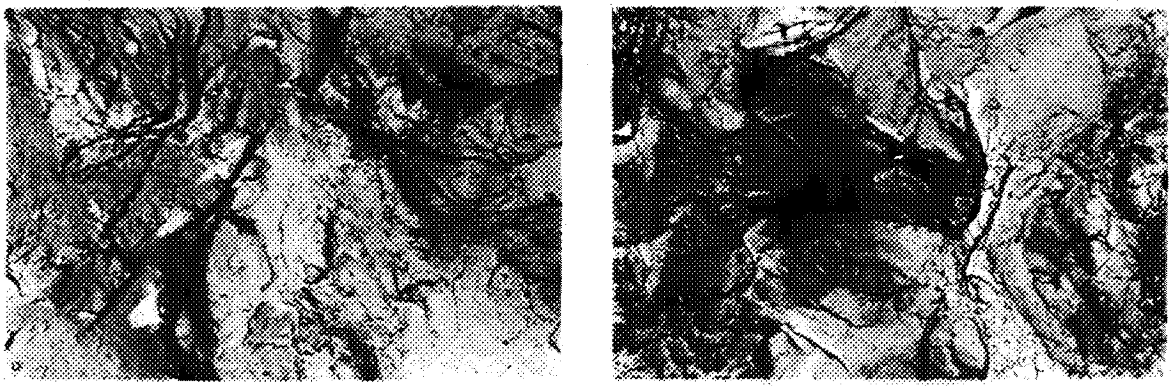
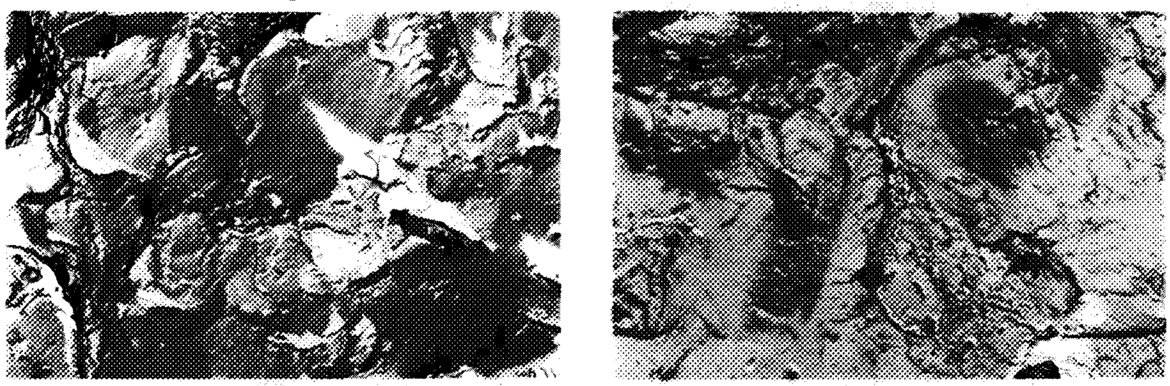


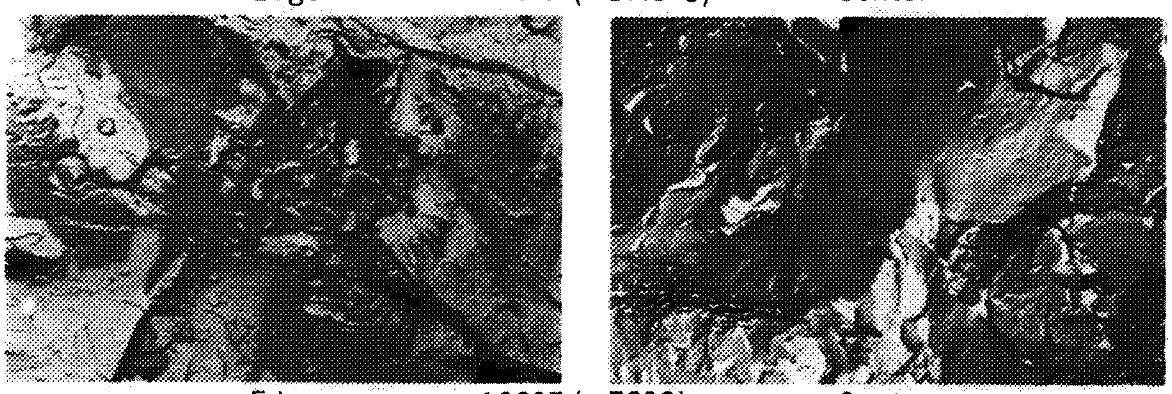
FIGURE 15B - TEM FRACTOGRAPHS OF 4140 ALLOY STEEL TEMPERED AT 725°F (385°C)
V—NOTCH BAR TENSILE FRACTURES 3150X MAG



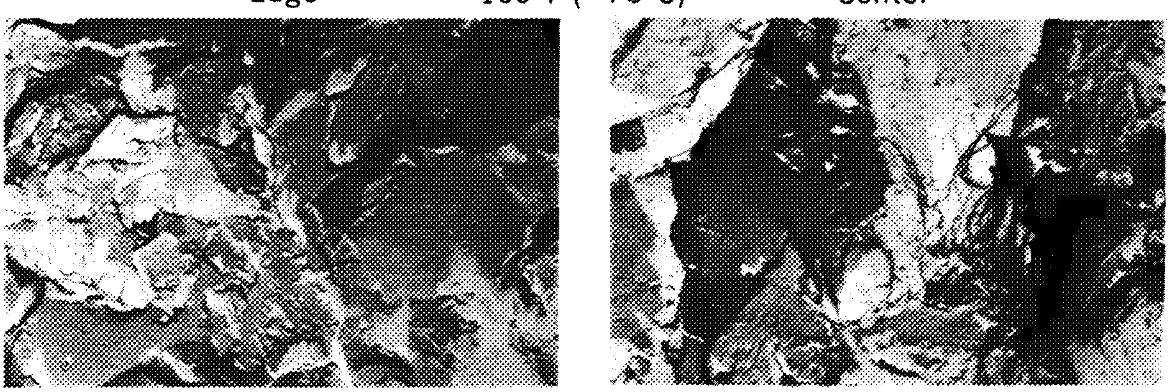
Edge +80°F (+26.7°C) Center



Edge 0°F (−17.8°C) Center

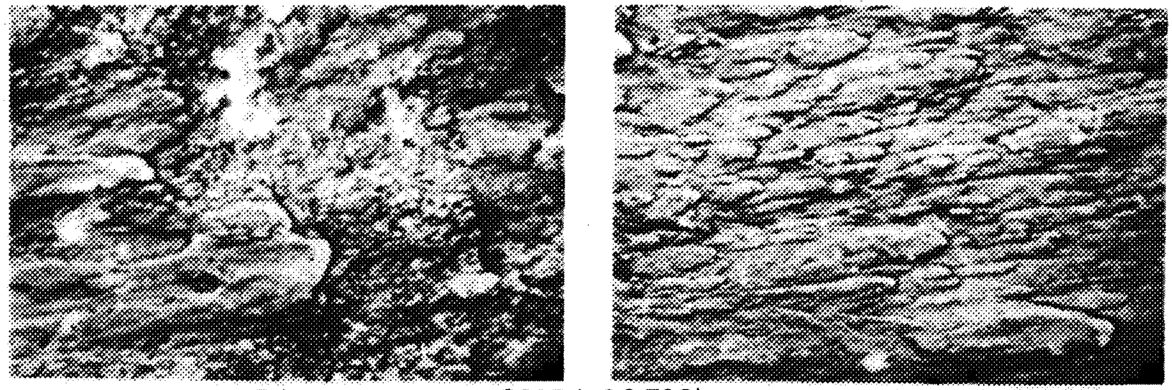


Edge −100°F (−73°C) Center

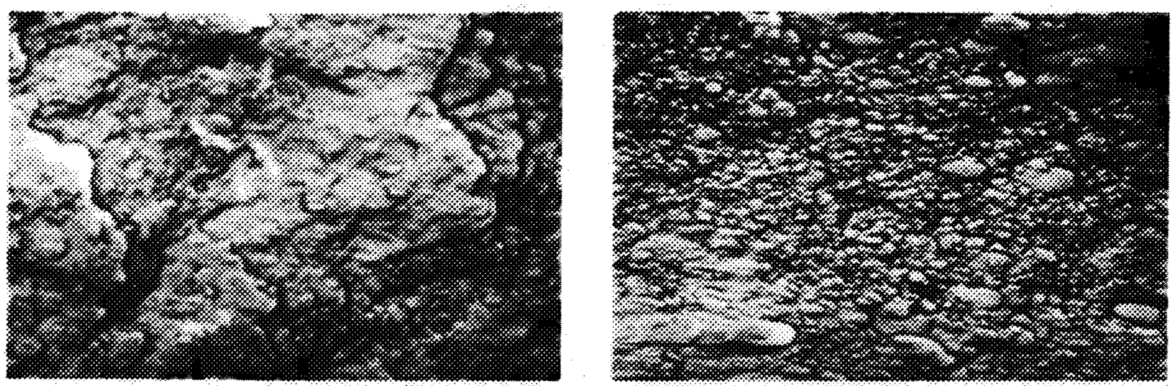


Edge −200°F (−129°C) Center

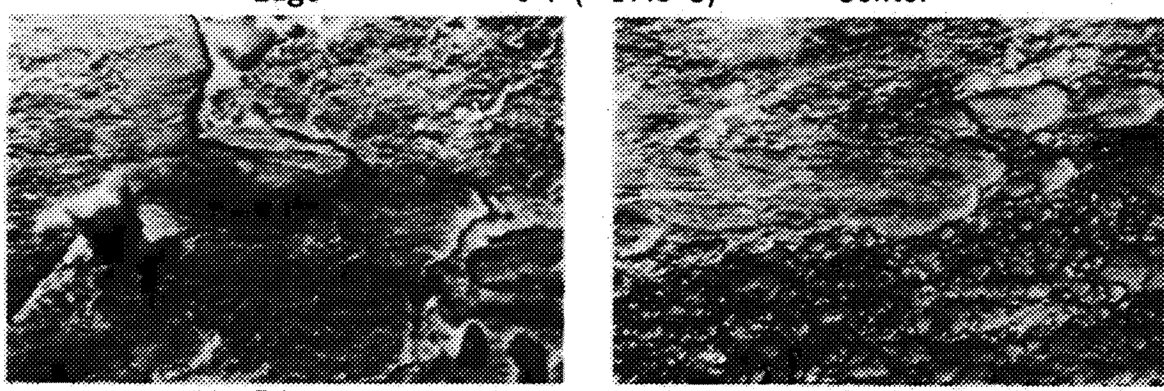
FIGURE 15C - TEM FRACTOGRAPHS OF 4140 ALLOY STEEL TEMPERED AT 725°F (385°C)
CHARPY V—NOTCHED IMPACT BAR SPECIMEN FRACTURES 3150X MAG



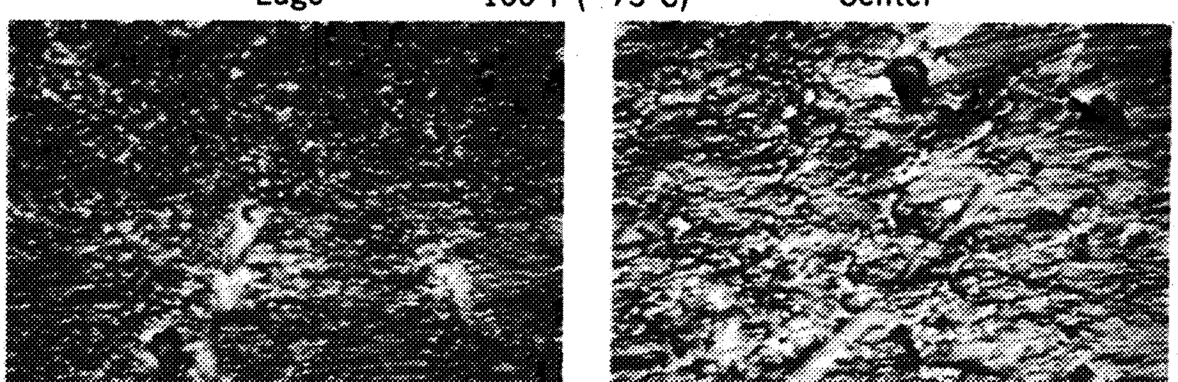
Edge +80°F (+26.7°C) Center



Edge 0°F (−17.8°C) Center



Edge −100°F (−73°C) Center



Edge −200°F (−129°C) Center

FIGURE 15D · SEM FRACTOGRAPHS OF 4140 ALLOY STEEL TEMPERED AT 725°F (385°C)
DOUBLE SHEAR SPECIMEN FRACTURES 2300X MAG

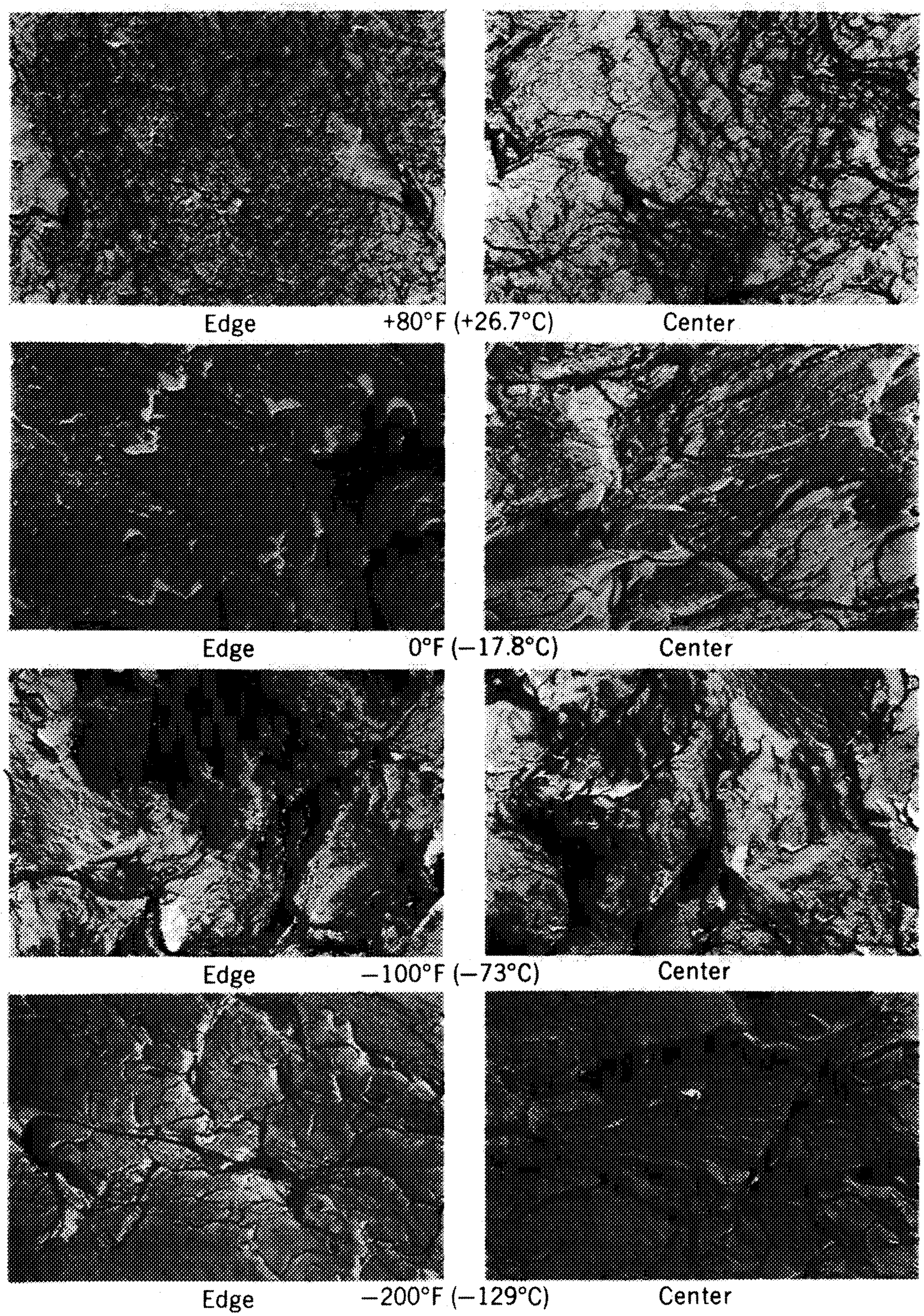


FIGURE 16A - TEM FRACTOGRAPHS OF 4140 ALLOY STEEL TEMPERED AT 1050°F (566°C)
SMOOTH BAR TENSILE FRACTURES 3150X MAG

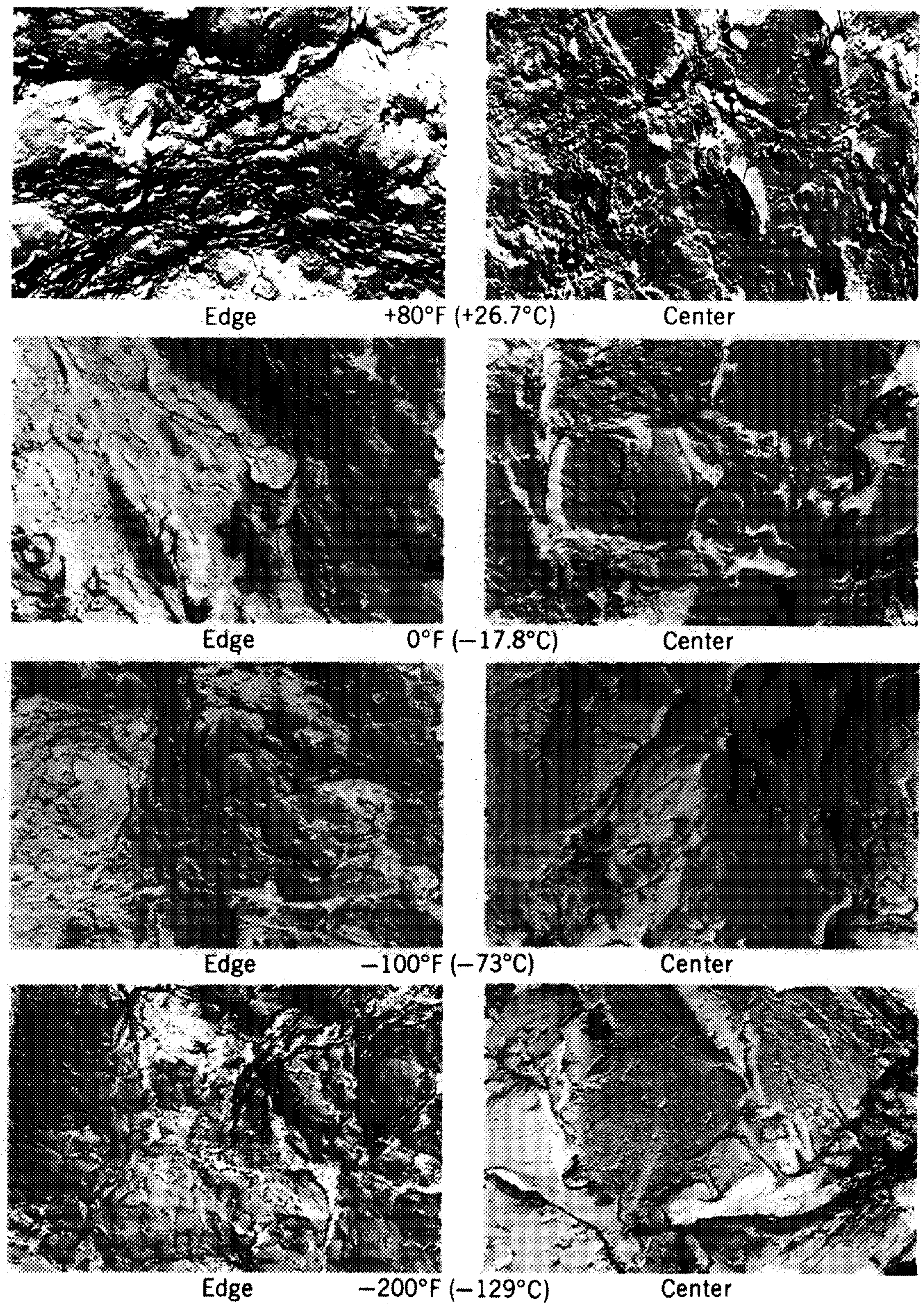
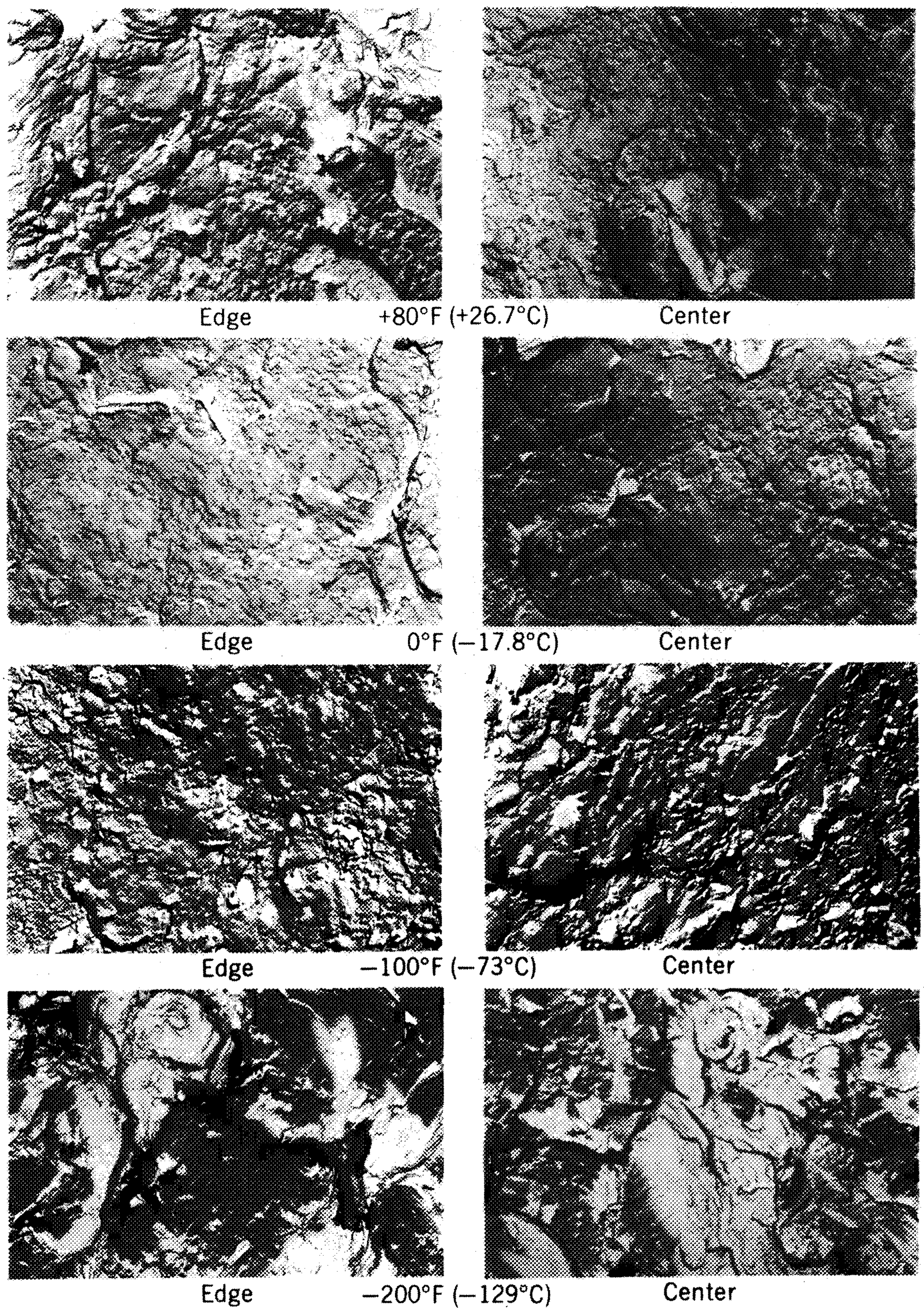


FIGURE 16B - TEM FRACTOGRAPHS OF 4140 ALLOY STEEL TEMPERED AT 1050°F (566°C)
V—NOTCH BAR TENSILE FRACTURES 3150X MAG



Edge +80°F (+26.7°C) Center

Edge 0°F (−17.8°C) Center

Edge −100°F (−73°C) Center

Edge −200°F (−129°C) Center

FIGURE 16C - TEM FRACTOGRAPHS OF 4140 ALLOY STEEL TEMPERED AT 1050°F (566°C)
CHARPY V—NOTCHED IMPACT BAR SPECIMENS 3150X MAG

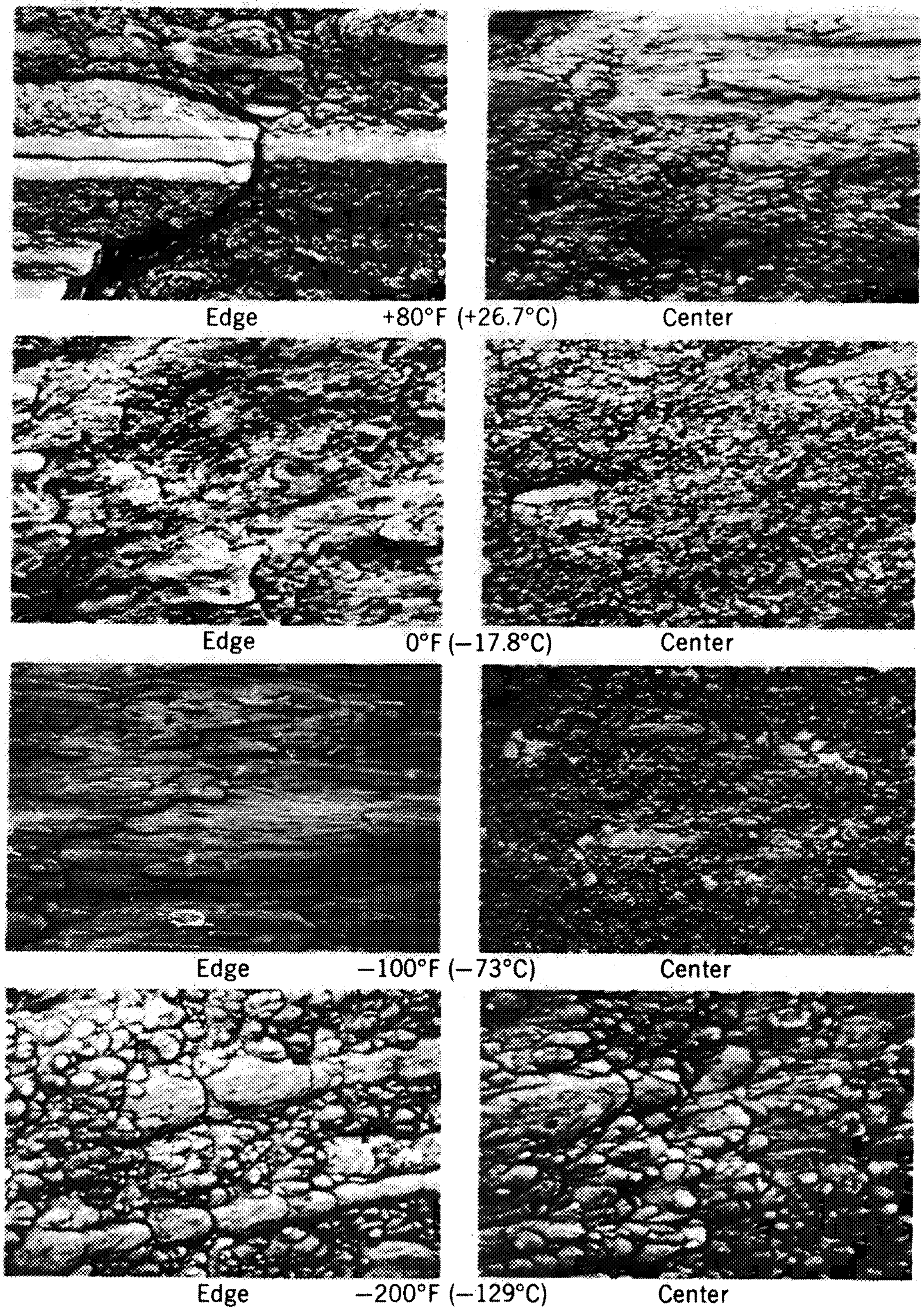


FIGURE 16D - SEM FRACTOGRAPHS OF 4140 ALLOY STEEL TEMPERED AT 1050°F (566°C)
DOUBLE SHEAR SPECIMEN FRACTURES 2300X MAG

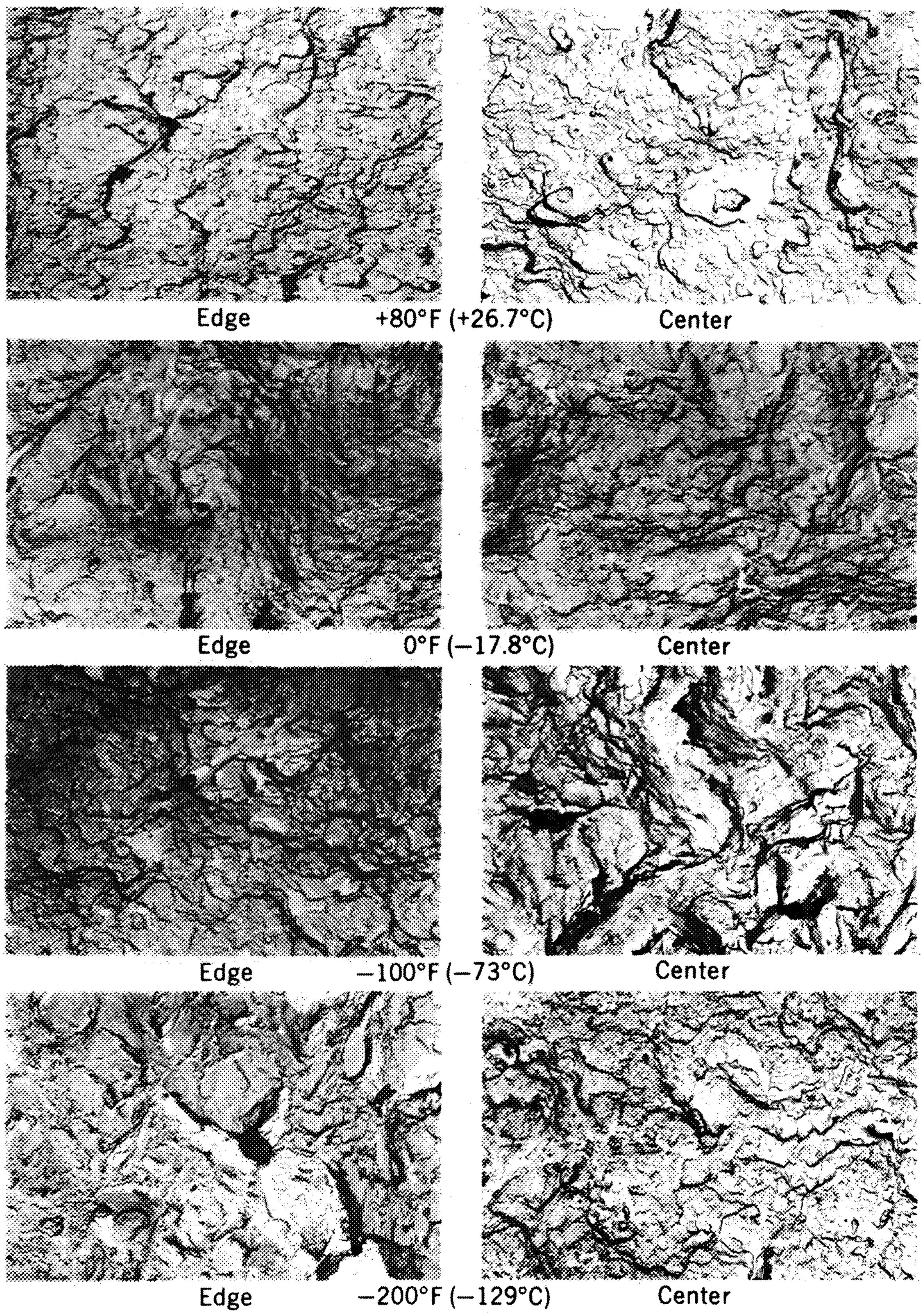
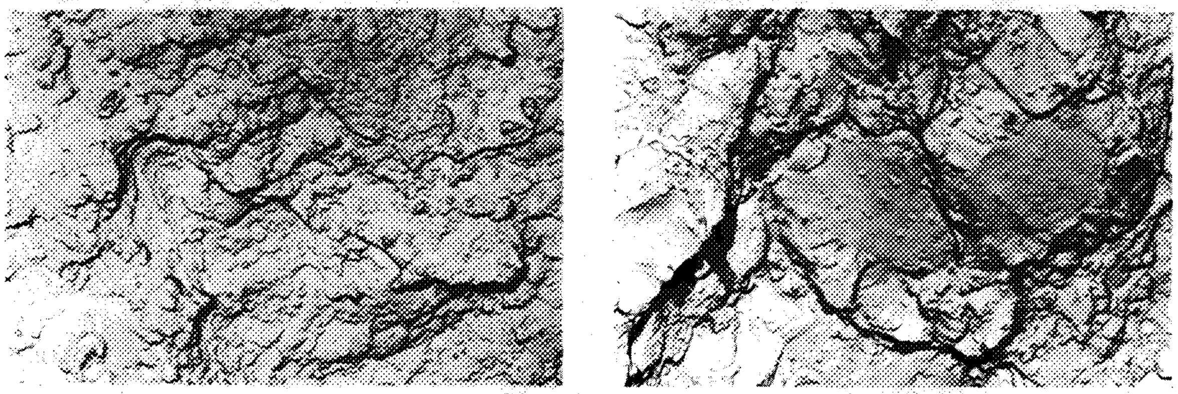
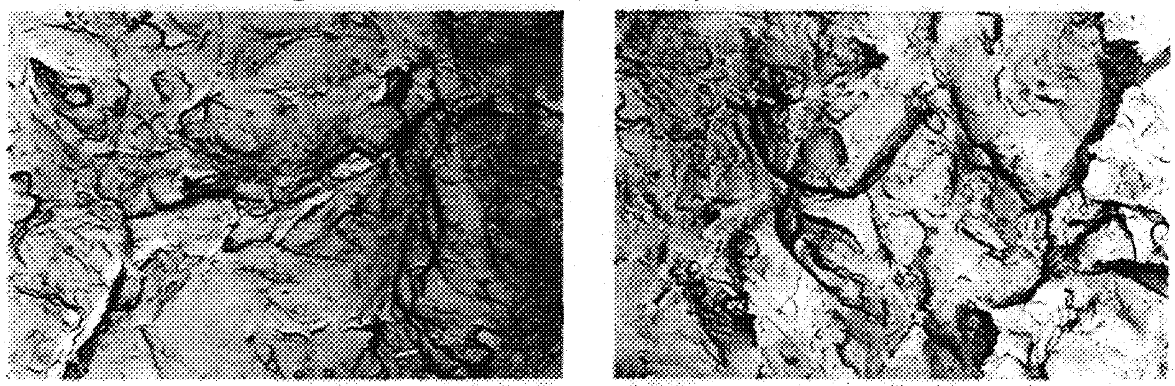


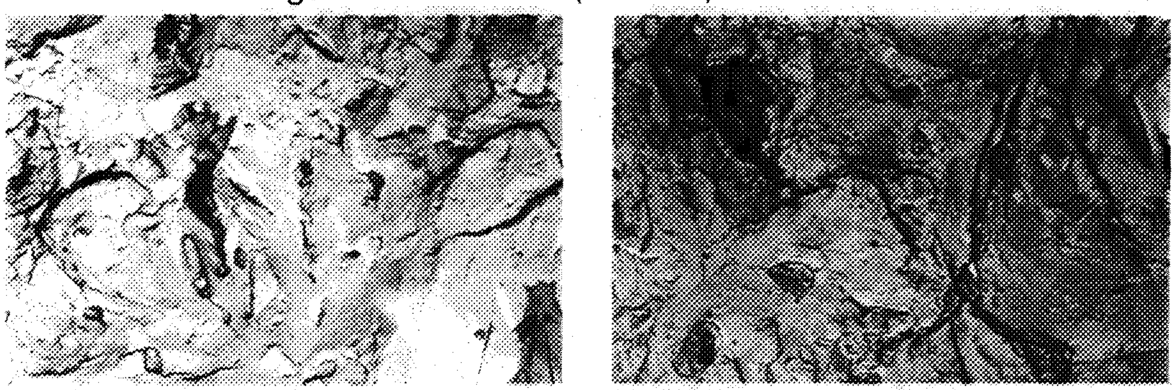
FIGURE 17A - TEM FRACTOGRAPHS OF 4340 ALLOY STEEL TEMPERED AT 825°F (440°C)
SMOOTH BAR TENSILE FRACTURES 2400X MAG



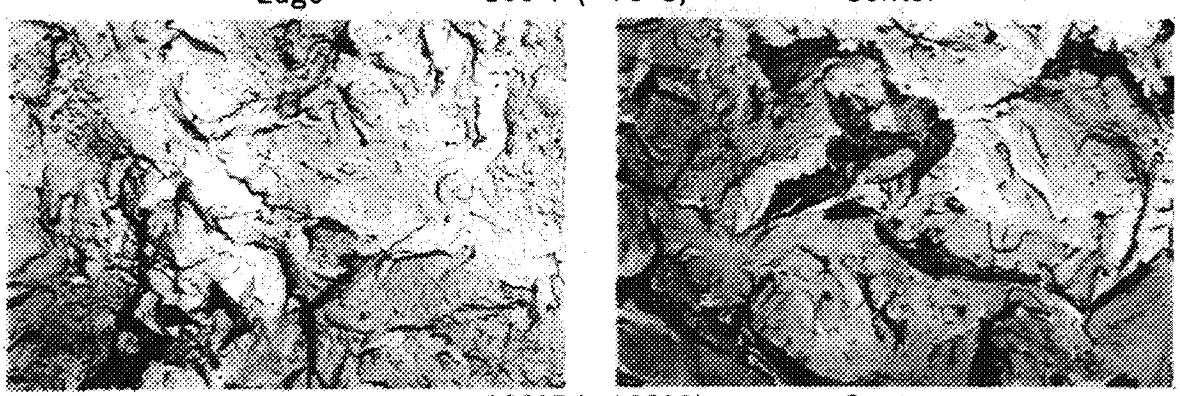
Edge +80°F (+26.7°C) Center



Edge 0°F (−17.8°C) Center



Edge −100°F (−73°C) Center



Edge −200°F (−129°C) Center

FIGURE 17B - TEM FRACTOGRAPHS OF 4340 ALLOY STEEL TEMPERED AT 825°F (440°C)
V—NOTCH BAR TENSILE FRACTURES 2400X MAG

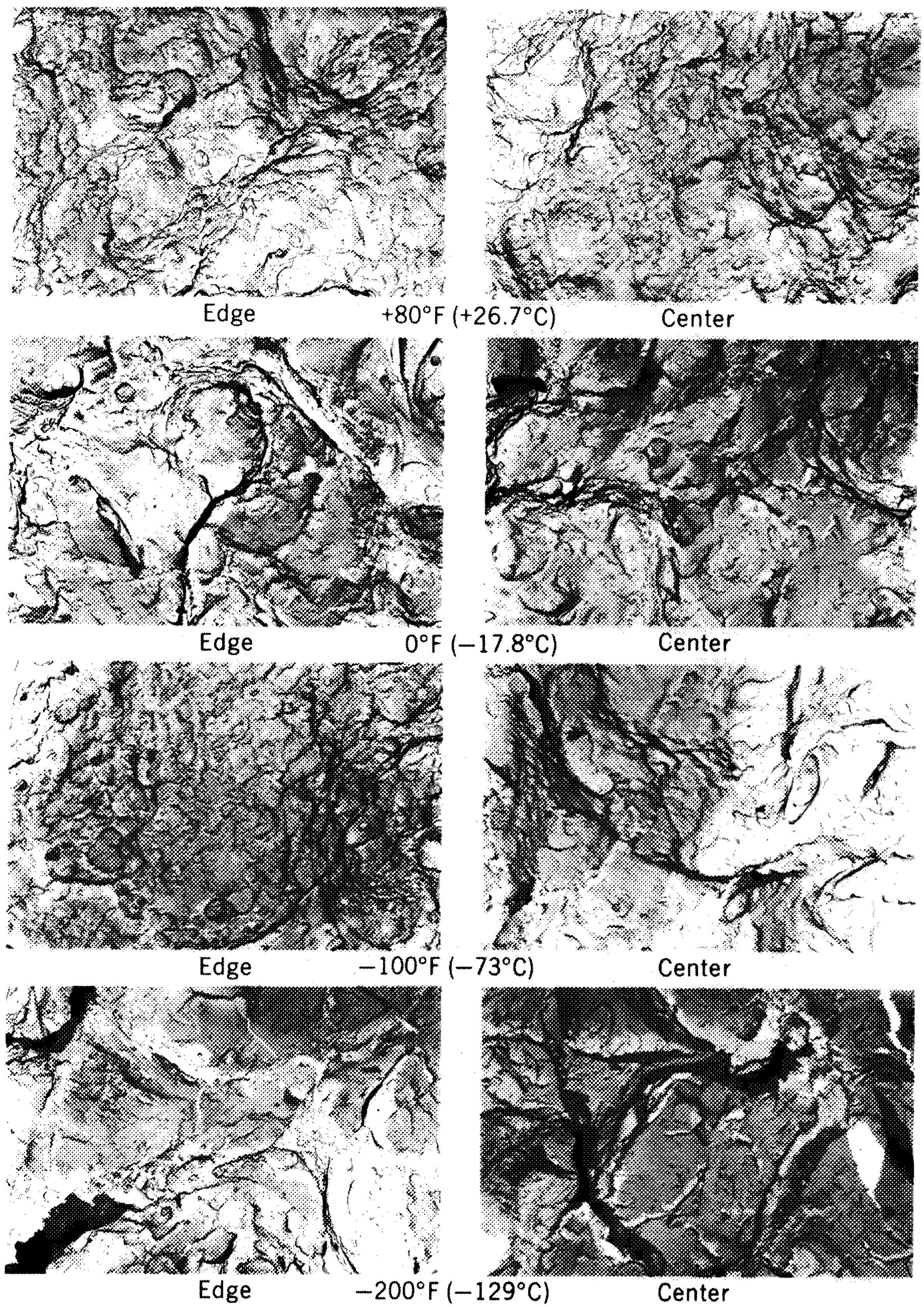


FIGURE 17C - TEM FRACTOGRAPHS OF 4340 ALLOY STEEL TEMPERED AT 825°F (440°C)
CHARPY V—NOTCHED IMPACT BAR SPECIMEN FRACTURES 2400X MAG

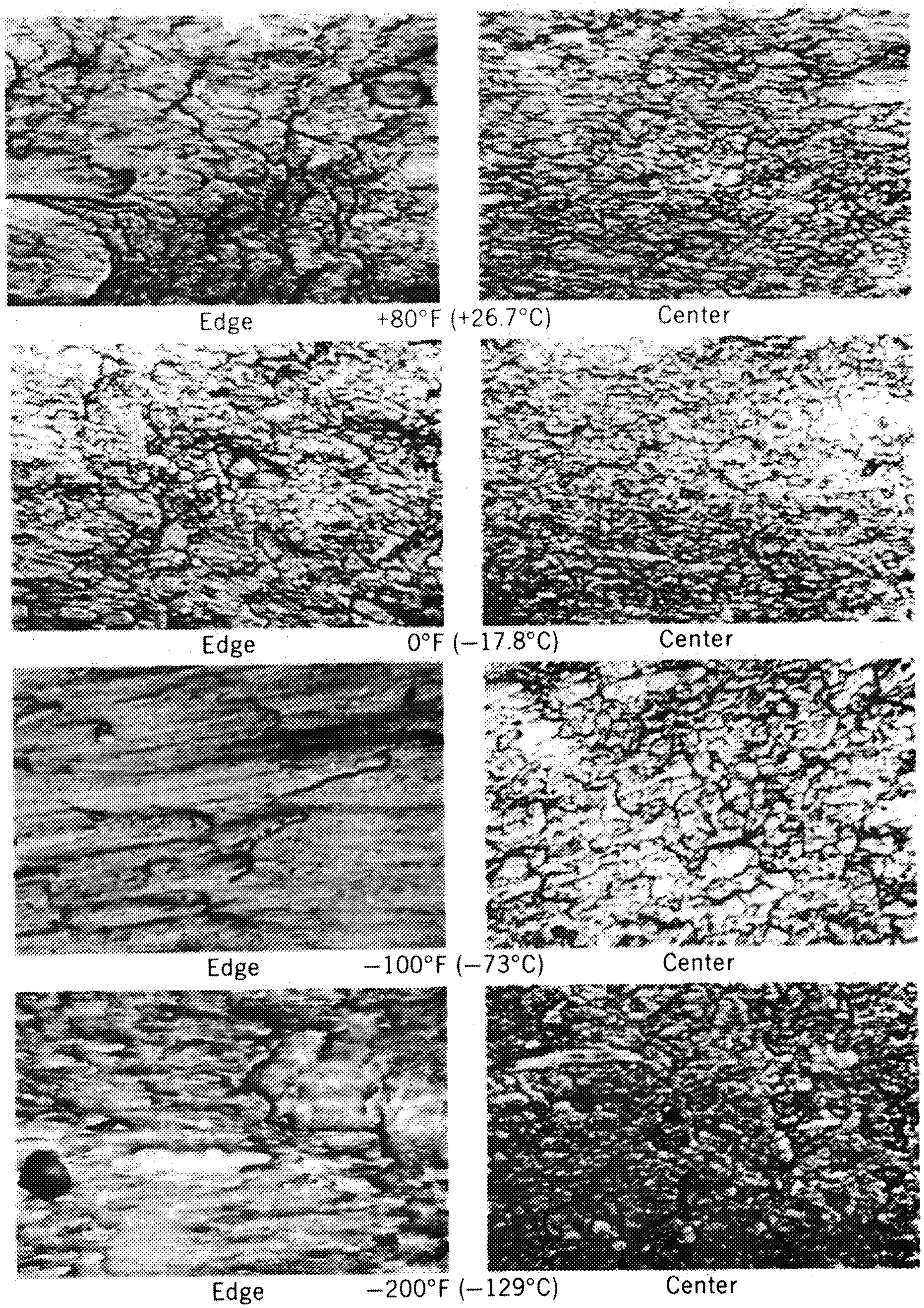


FIGURE 17D - SEM FRACTOGRAPHS OF 4340 ALLOY STEEL TEMPERED AT 825°F (440°C)
DOUBLE SHEAR SPECIMEN FRACTURES 2300X MAG

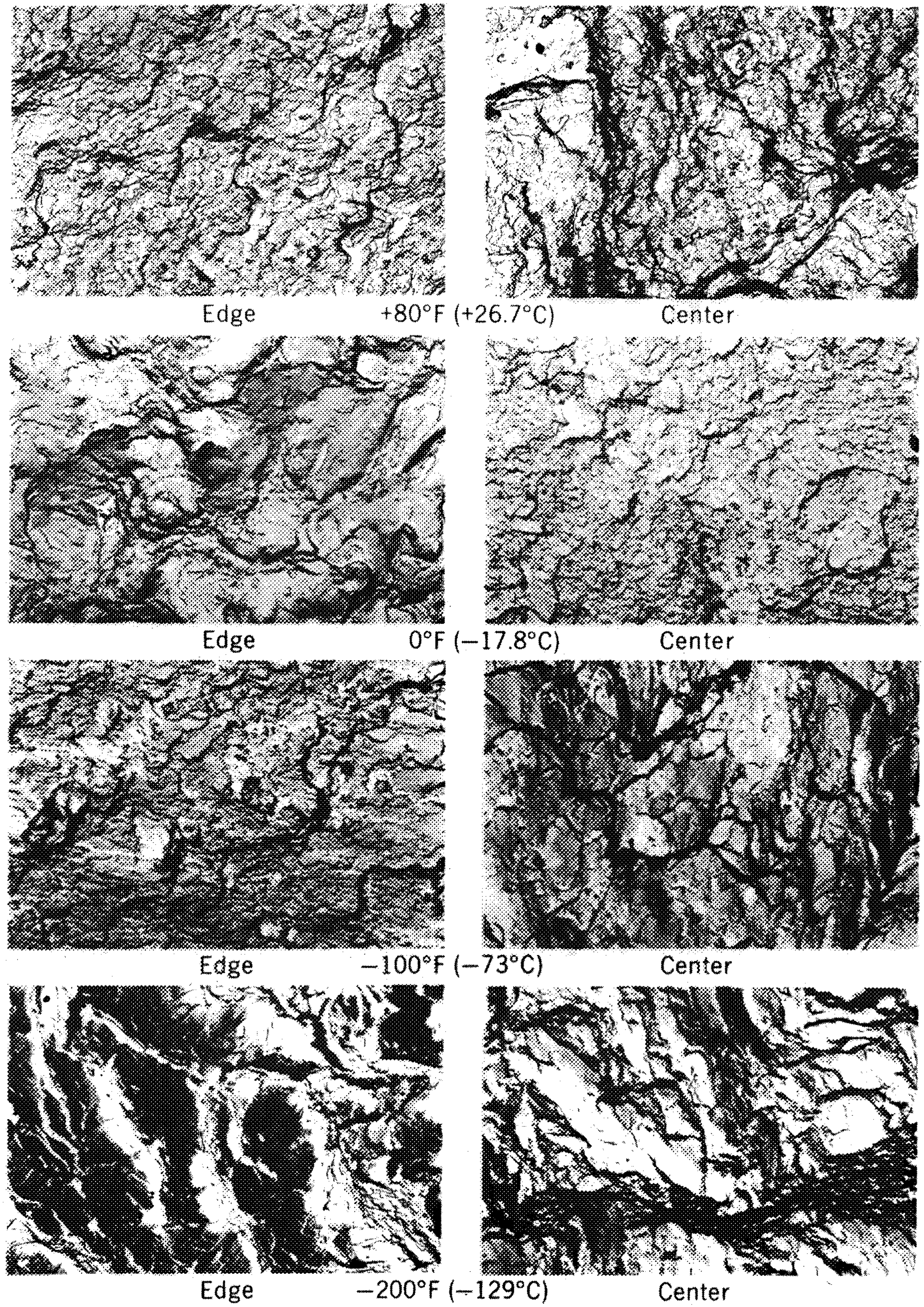


FIGURE 18A - TEM FRACTOGRAPHS OF 4340 ALLOY STEEL TEMPERED AT 1200°F (649°C)
SMOOTH BAR TENSILE FRACTURES 2400X MAG

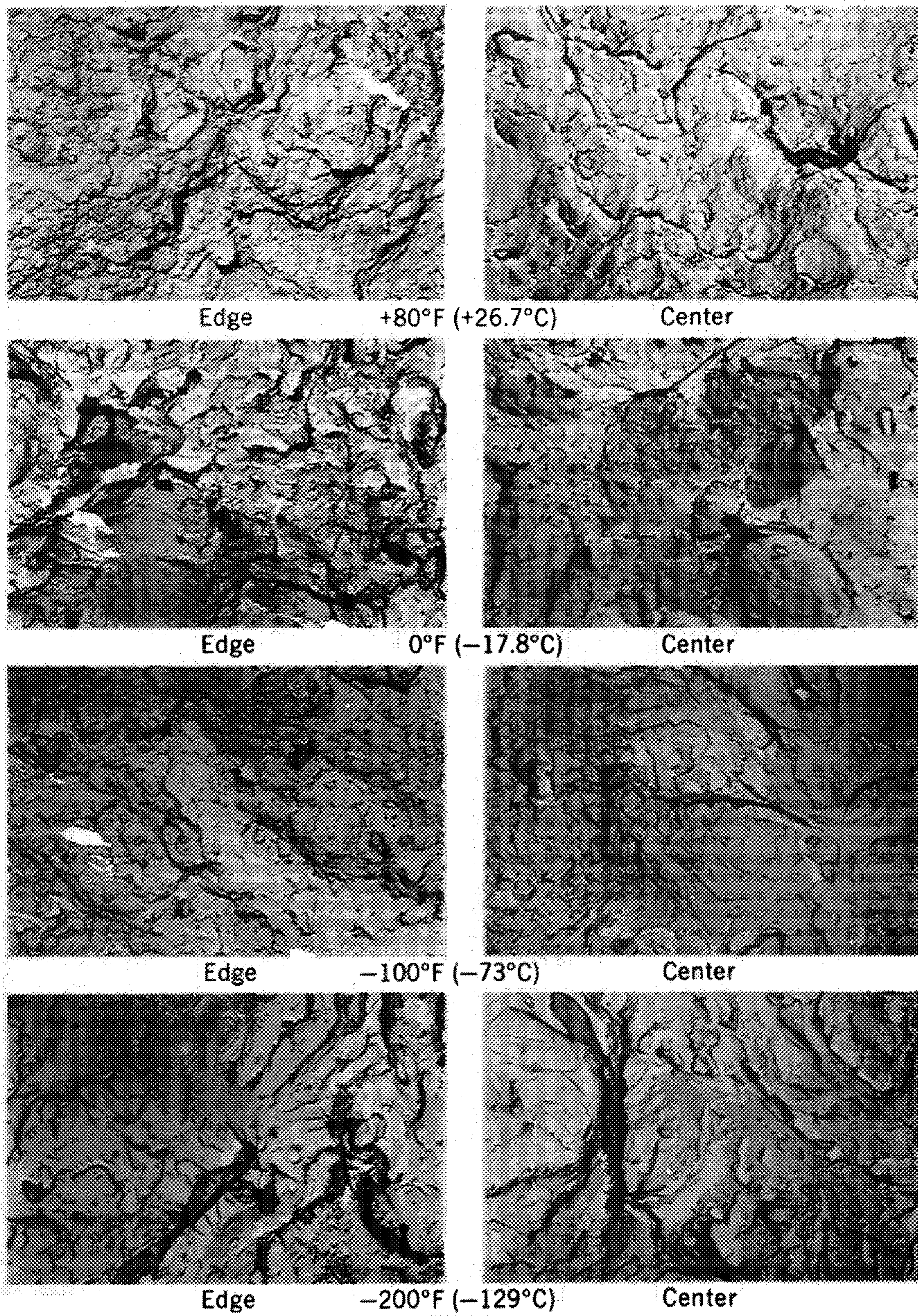


FIGURE 18B - TEM FRACTOGRAPHS OF 4340 ALLOY STEEL TEMPERED AT 1200°F (649°C)
V—NOTCH BAR TENSILE FRACTURES 2400X MAG

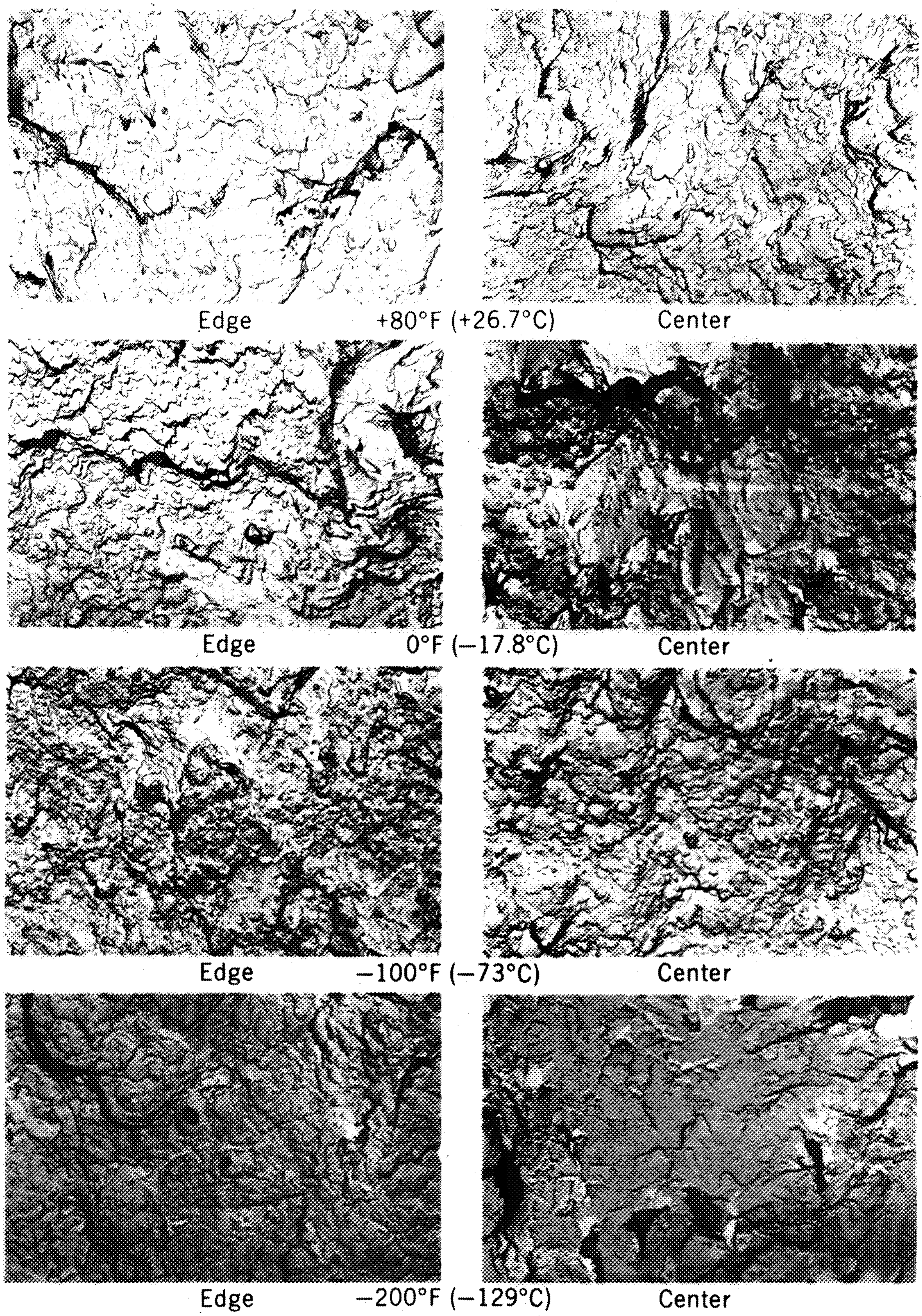


FIGURE 18C - TEM FRACTOGRAPHS OF 4340 ALLOY STEEL TEMPERED AT 1200°F (649°C)
CHARPY V—NOTCHED IMPACT BAR SPECIMEN FRACTURES 2400X MAG

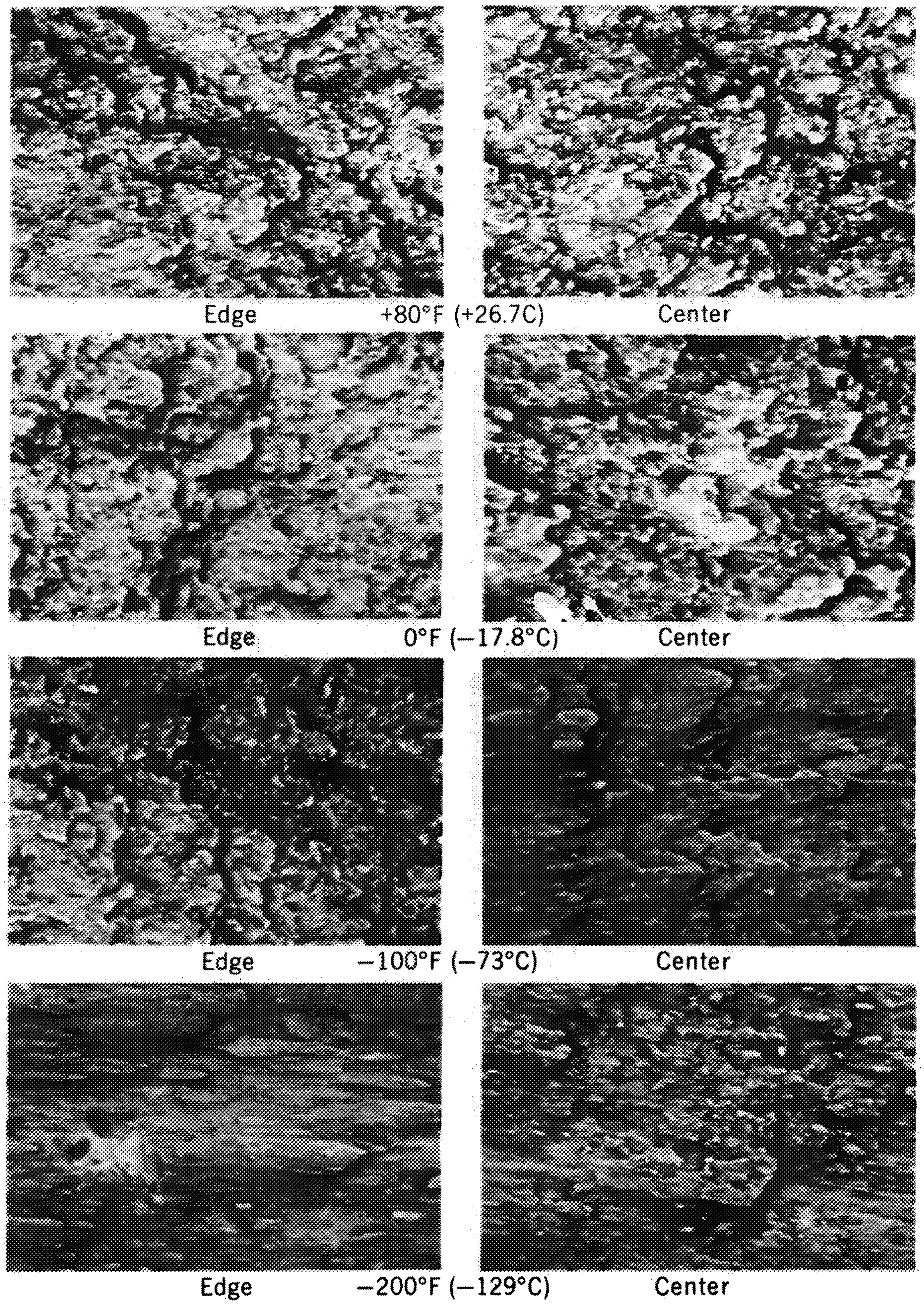


FIGURE 18D - SEM FRACTOGRAPHS OF 4340 ALLOY STEEL TEMPERED AT 1200°F (649°C)
DOUBLE SHEAR SPECIMEN FRACTURES 2300X MAG

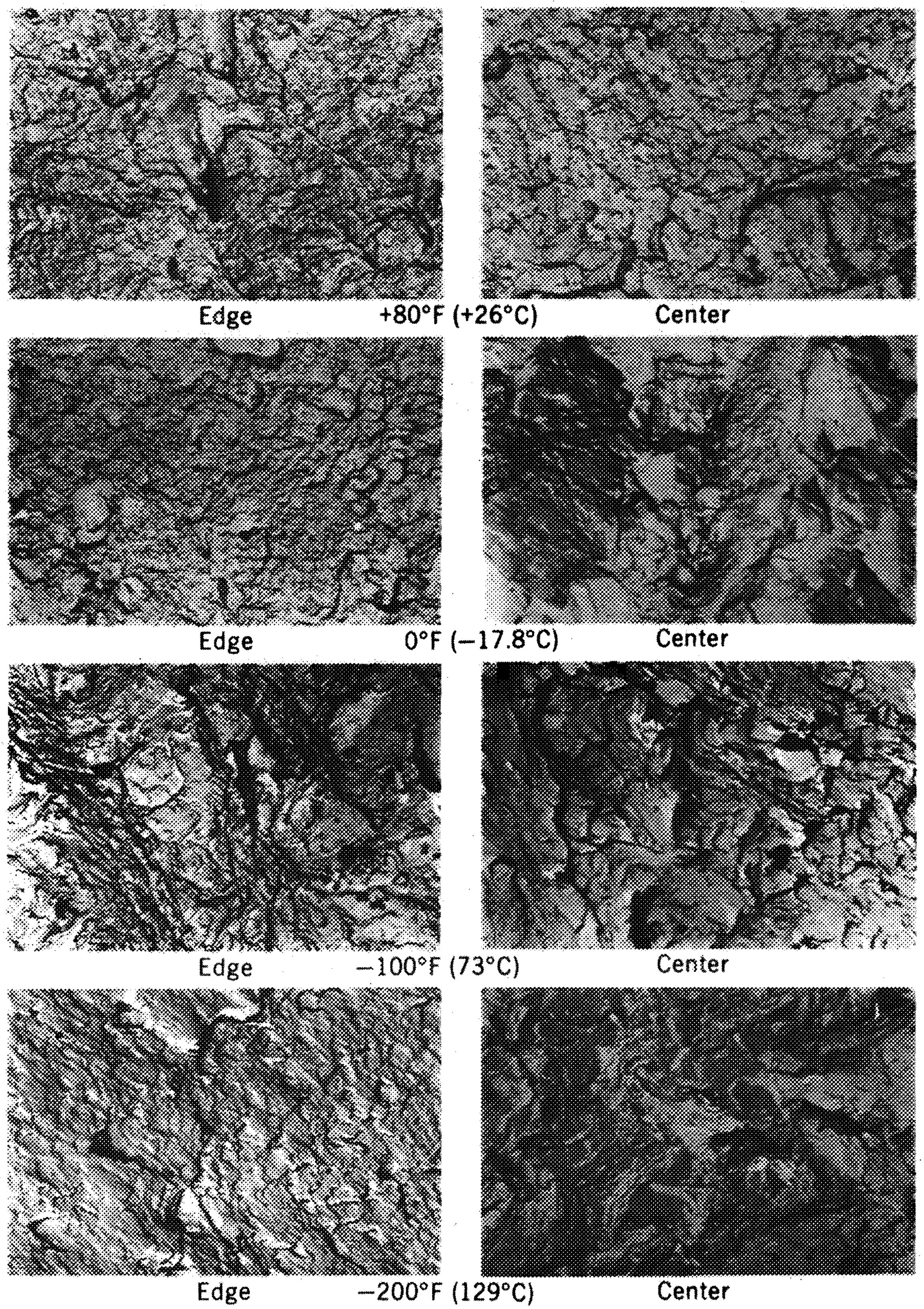
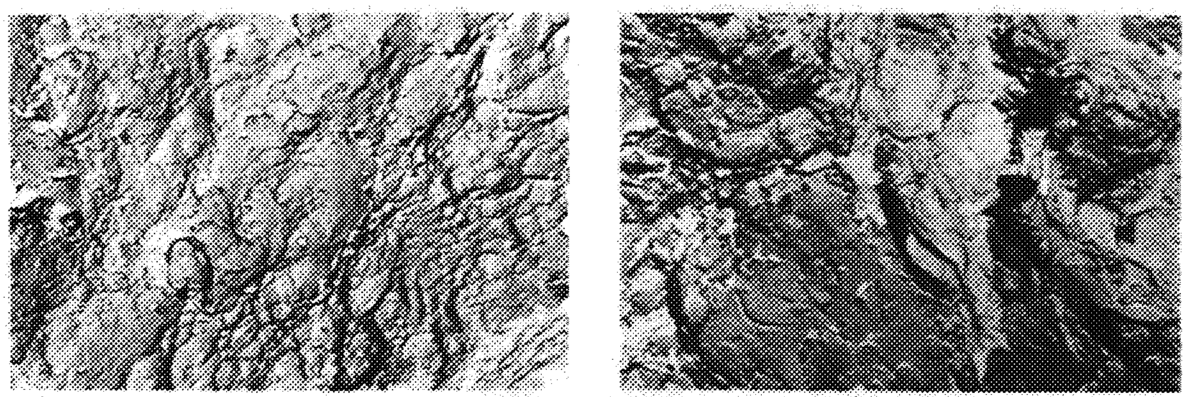
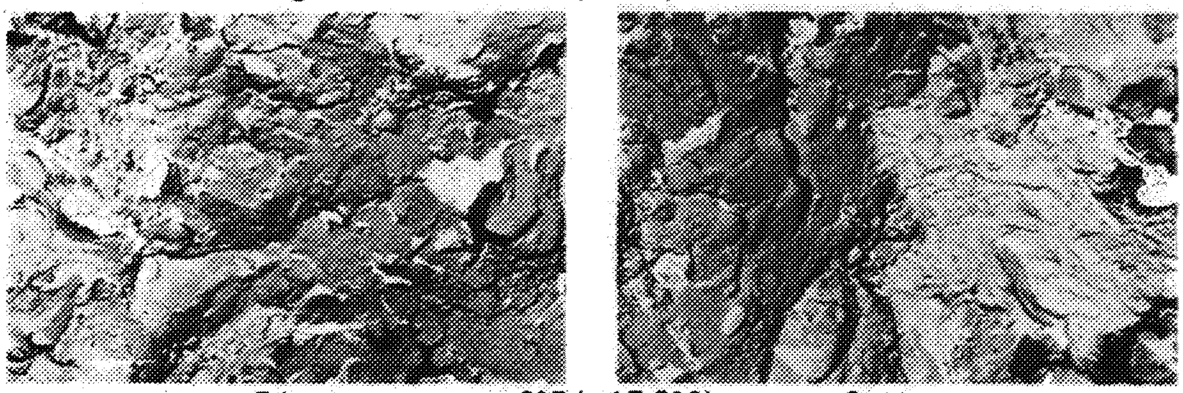


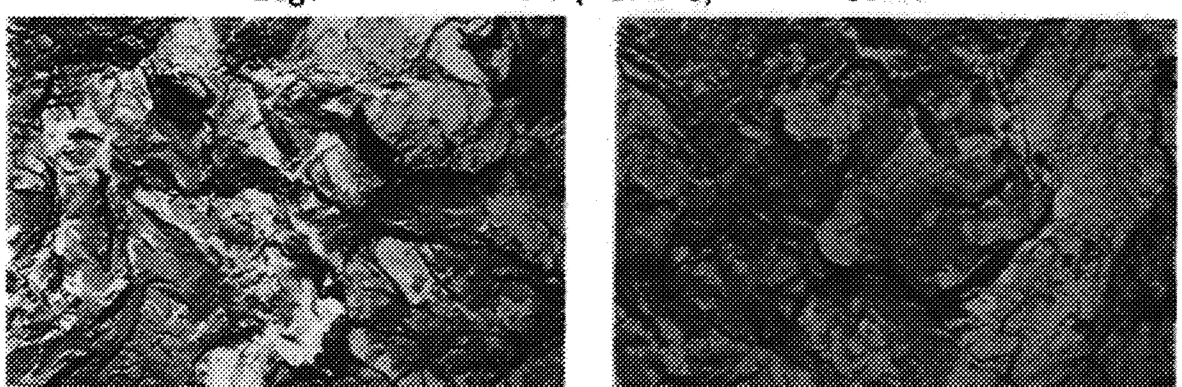
FIGURE 19A · TEM FRACTOGRAPHS OF 6150 ALLOY STEEL TEMPERED AT 950°F (510°C)
SMOOTH BAR TENSILE FRACTURES 3150X MAG



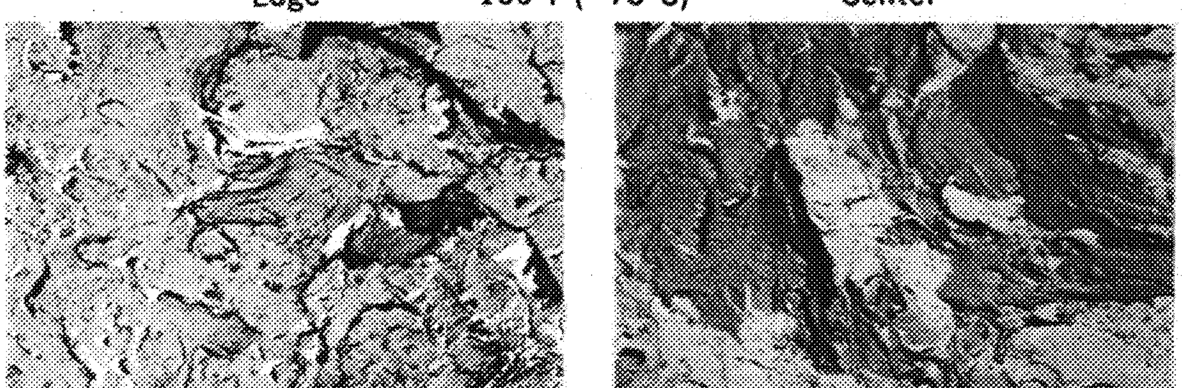
Edge +80°F (+26.C) Center



Edge 0°F (−17.8°C) Center



Edge −100°F (−73°C) Center



Edge −200°F (−129°C) Center

FIGURE 19B - TEM FRACTOGRAPHS OF 6150 ALLOY STEEL TEMPERED AT 950°F (510°C)
V—NOTCH BAR TENSILE FRACTURES 3150X MAG

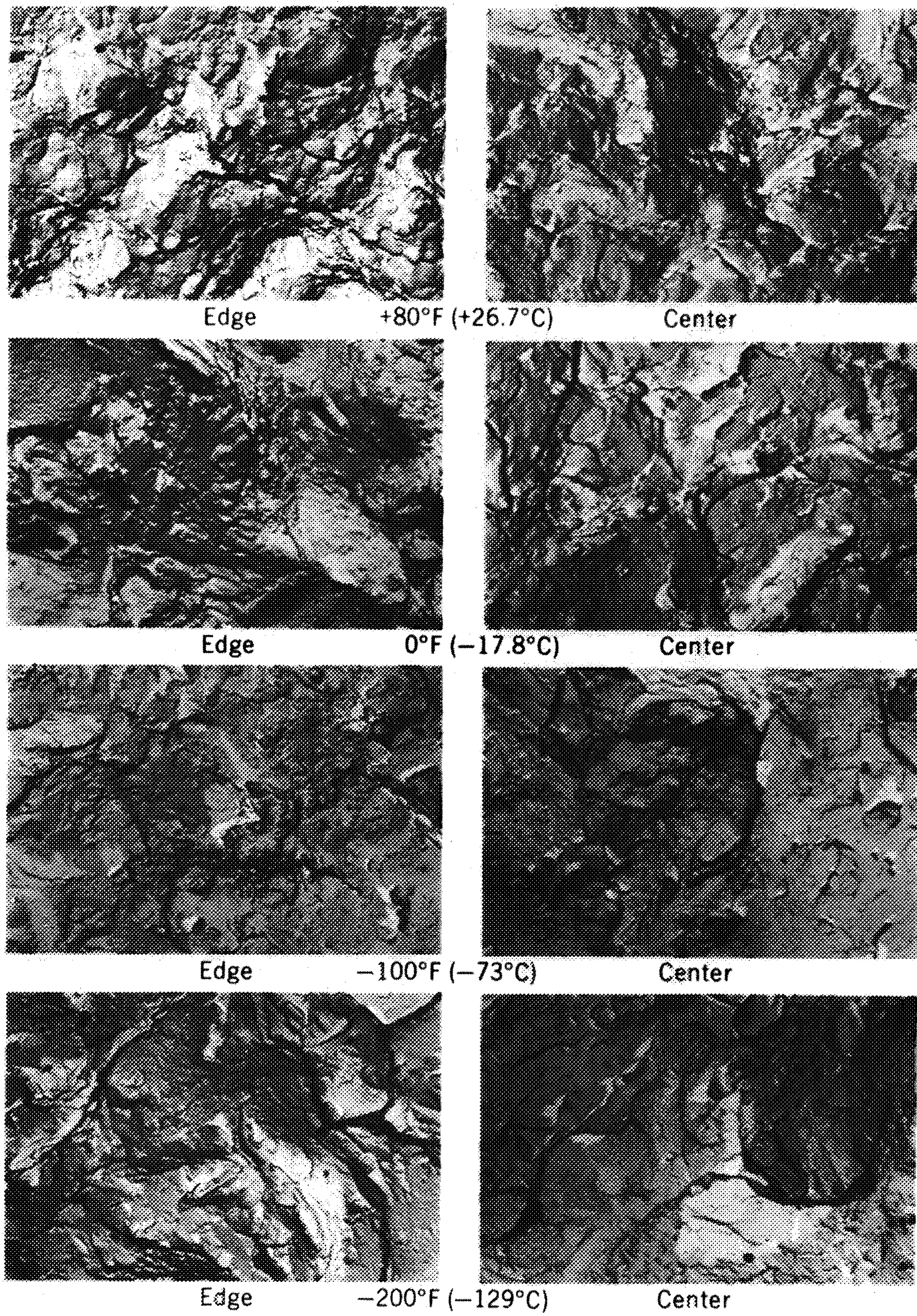


FIGURE 19C - TEM FRACTOGRAPHS OF 6150 ALLOY STEEL TEMPERED AT 950°F (510°C)
V—NOTCHED IMPACT BAR SPECIMEN FRACTURES 3150X MAG

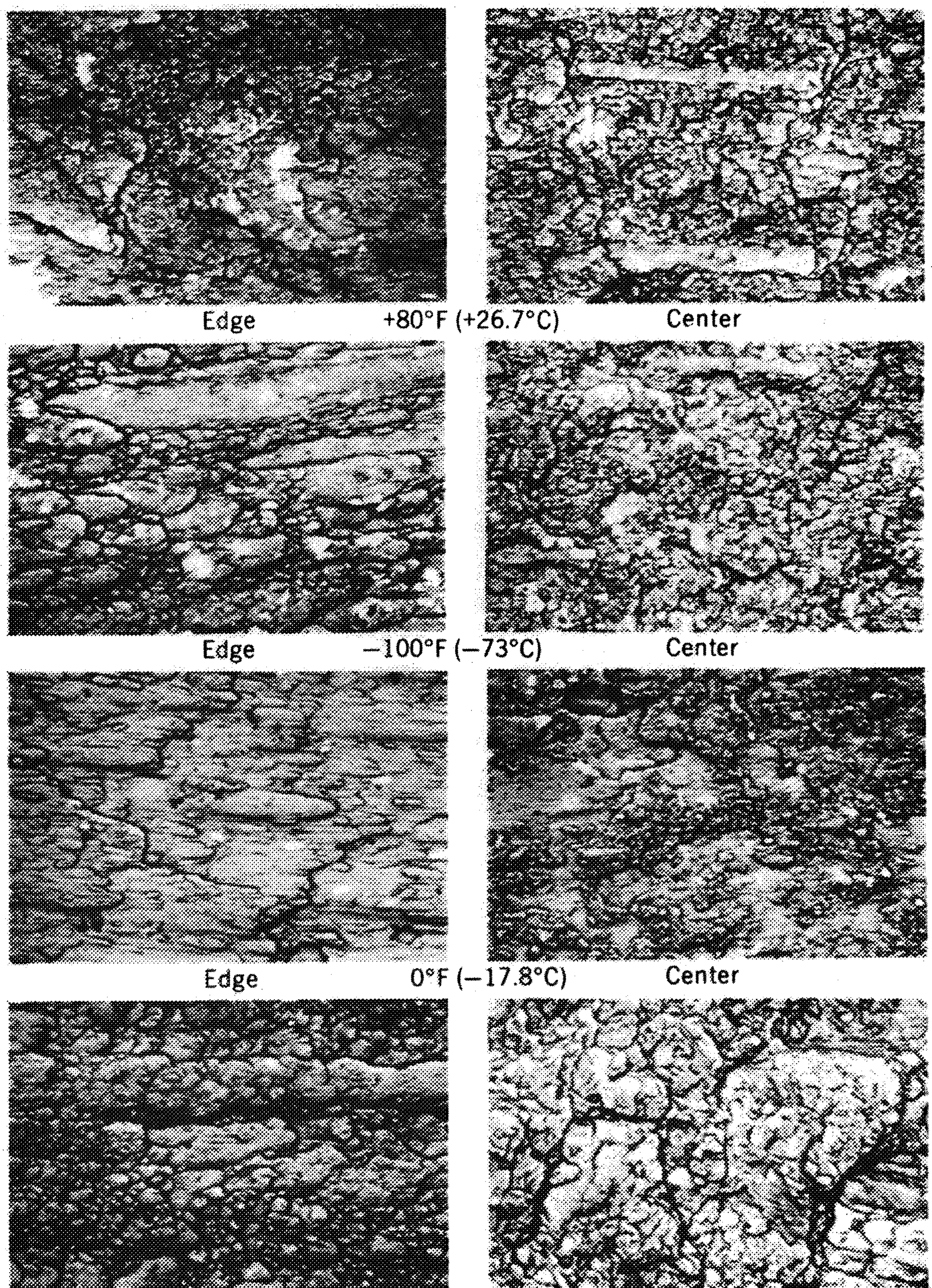
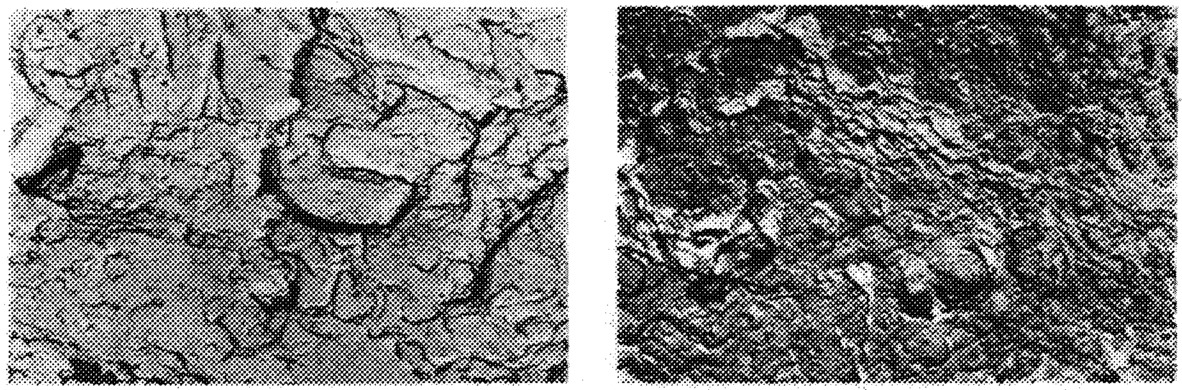
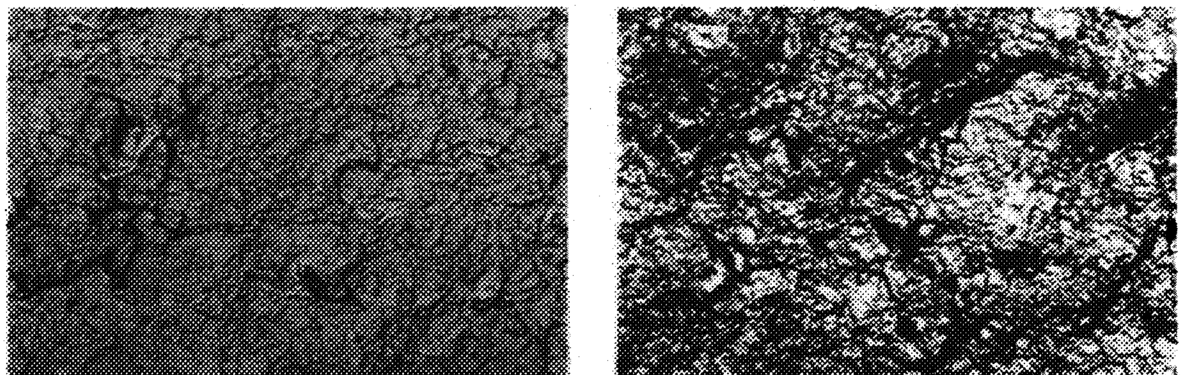


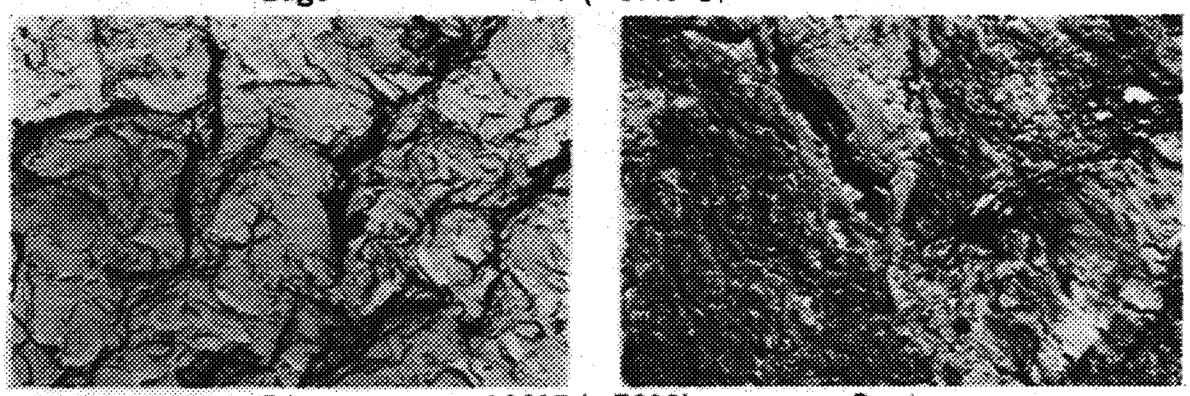
FIGURE 19D - SEM FRACTOGRAPHS OF 6150 ALLOY STEEL TEMPERED AT 950°F (510°C)
DOUBLE SHEAR SPECIMEN FRACTURES 2300X MAG



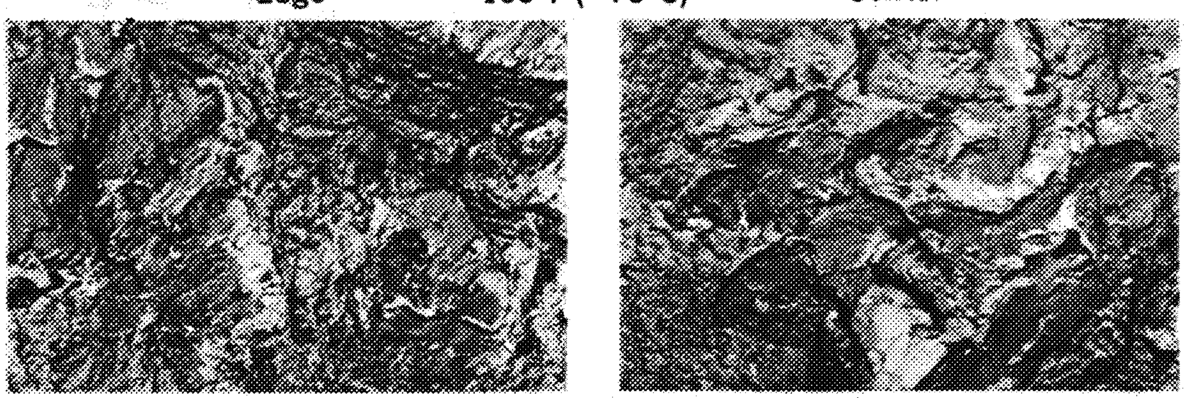
Edge +80°F (+26.7°C) Center



Edge 0°F (−17.8°C) Center

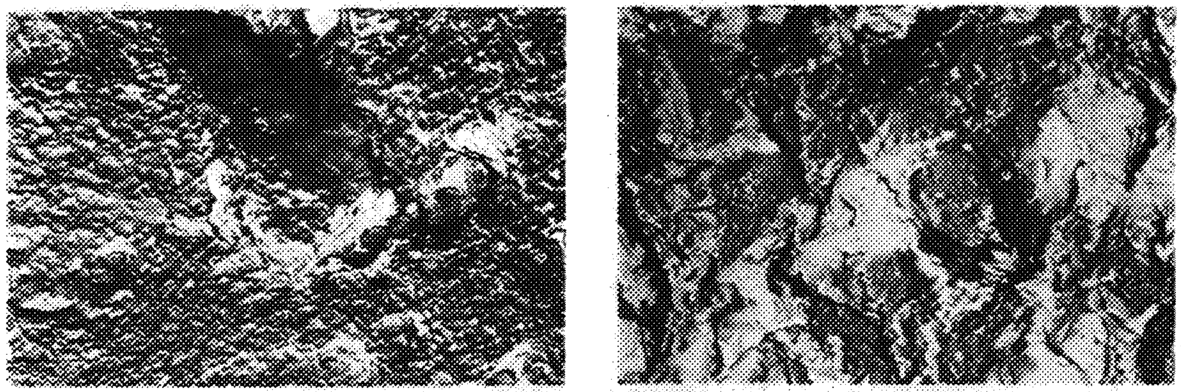


Edge −100°F (−73°C) Center

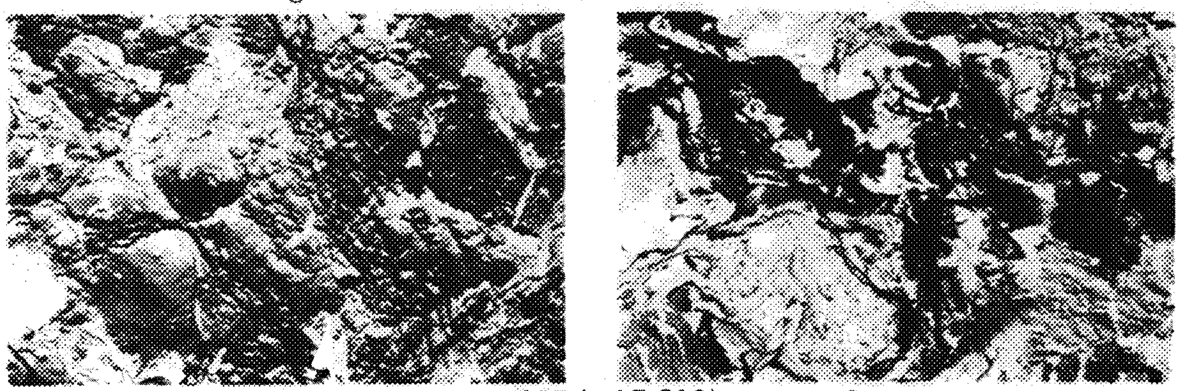


Edge −200°F −129°C) Center

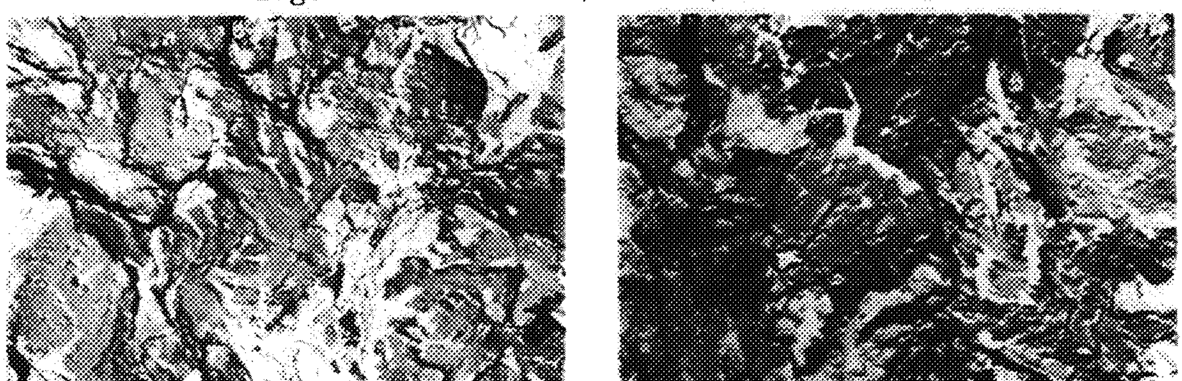
FIGURE 20A - TEM FRACTOGRAPHS OF 6150 ALLOY STEEL TEMPERED AT 1200°F (649°C)
SMOOTH BAR TENSILE FRACTURES 3150X MAG



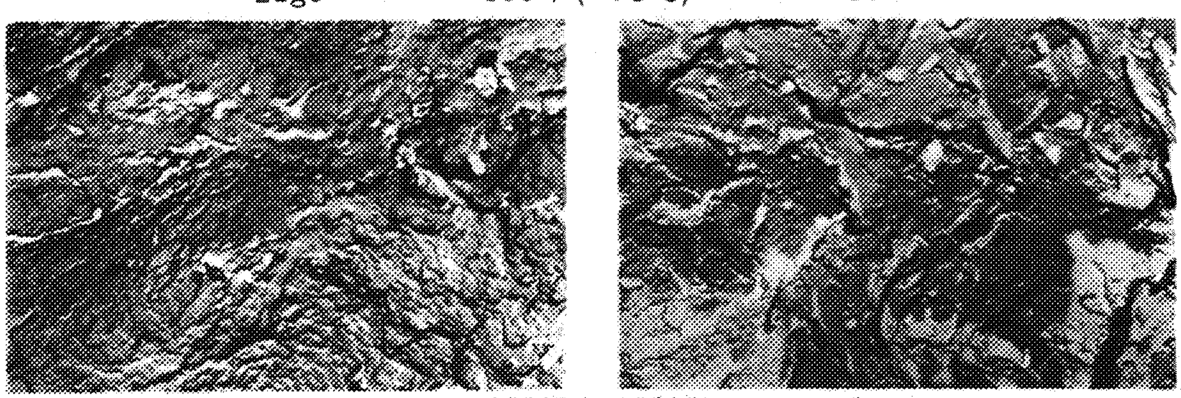
Edge +80°F (+26.7°C) Center



Edge 0°F (−17.8°C) Center



Edge −100°F (−73°C) Center



Edge −200°F (−129°C) Center

FIGURE 20B - TEM FRACTOGRAPHS OF 6150 ALLOY STEEL TEMPERED AT 1200°F (649°C)
V—NOTCH BAR TENSILE FRACTURES 3150X MAG

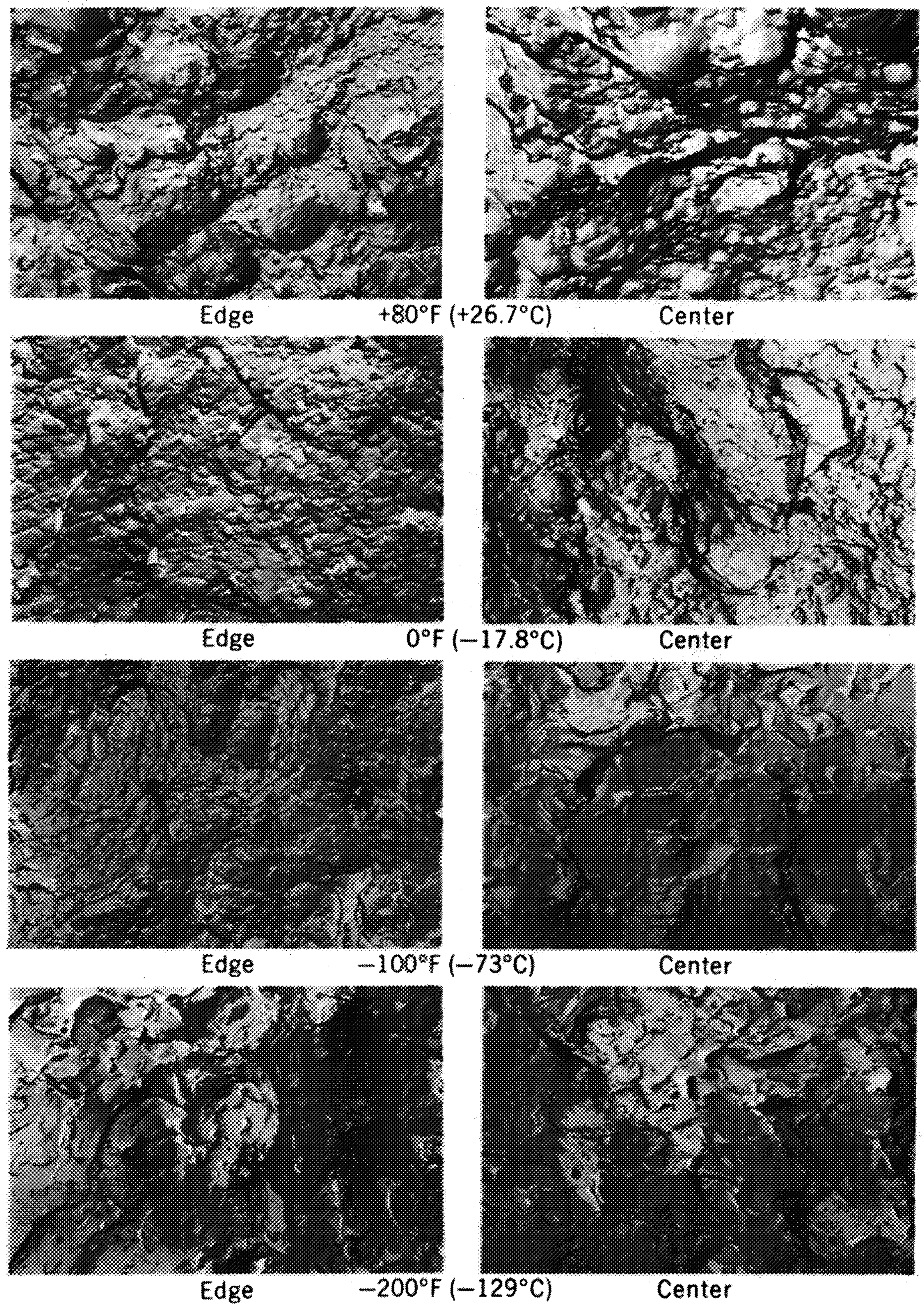


FIGURE 20C - TEM FRACTOGRAPHS OF 6150 ALLOY STEEL TEMPERED AT 1200°F (649°C)
CHARPY V—NOTCHED IMPACT BAR SPECIMEN FRACTURES 3150X MAG

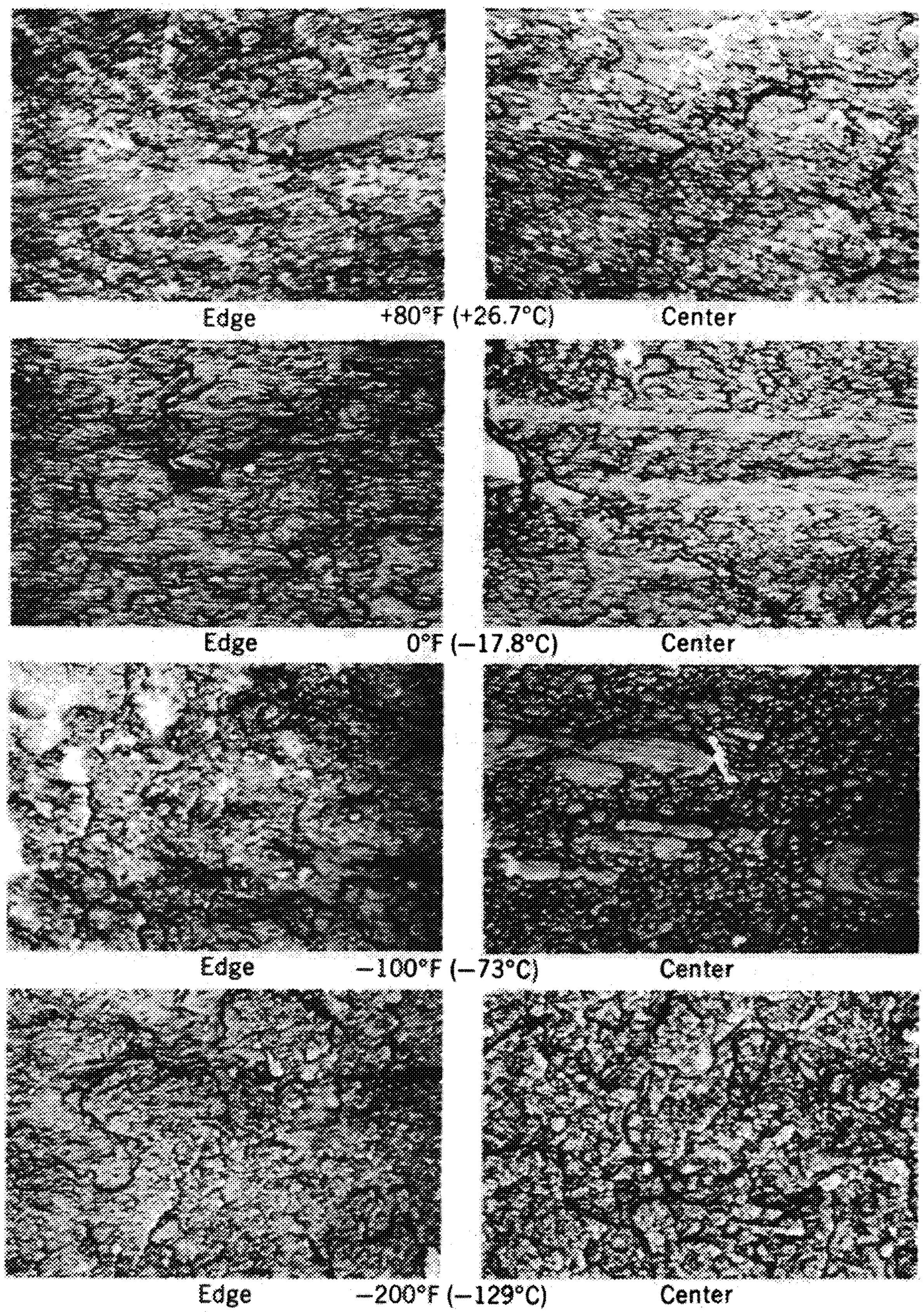
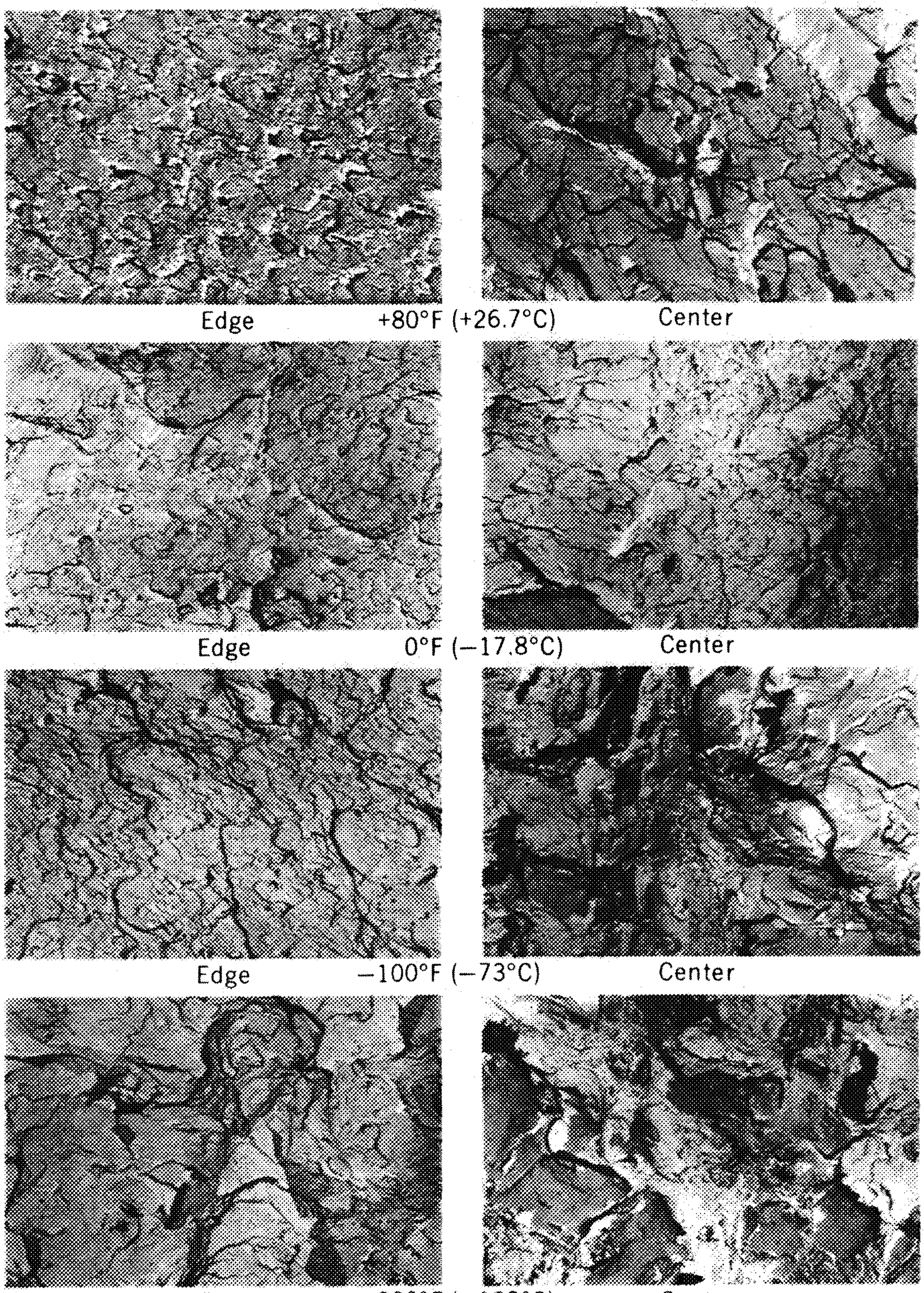


FIGURE 20D - SEM FRACTOGRAPHS OF 6150 ALLOY STEEL TEMPERED AT 1200°F (649°C)
DOUBLE SHEAR SPECIMEN FRACTURES 2300X MAG



Edge +80°F (+26.7°C) Center

Edge 0°F (−17.8°C) Center

Edge −100°F (−73°C) Center

Edge −200°F (−129°C) Center

FIGURE 21A · TEM FRACTOGRAPHS OF 8740 ALLOY STEEL TEMPERED AT 850°F (45 °C)
SMOOTH BAR TENSILE FRACTURES 3150X

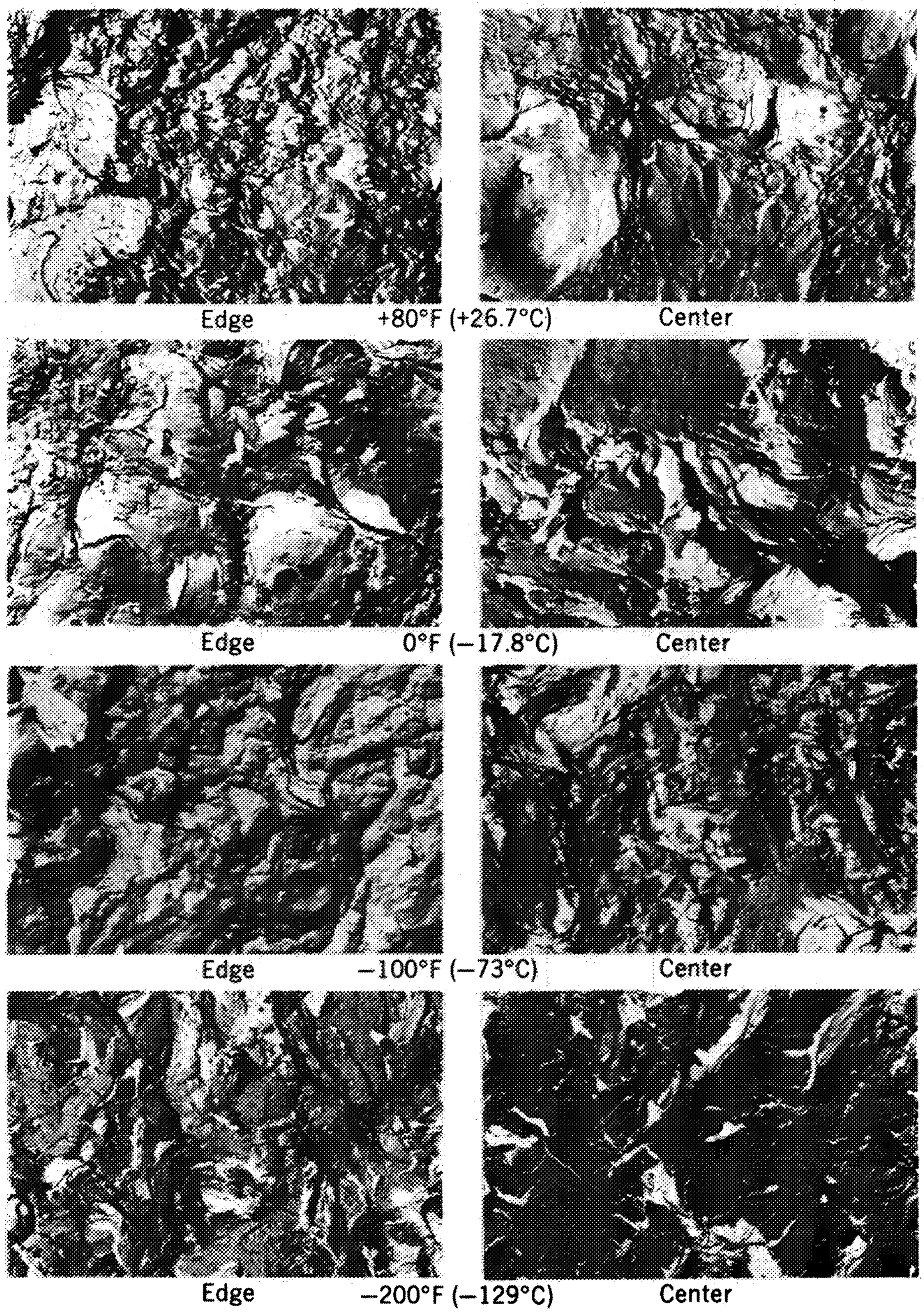


FIGURE 21B - TEM FRACTOGRAPHS OF 8740 ALLOY STEEL TEMPERED AT 850°F (454°C)
V—NOTCH BAR TENSILE FRACTURES 3150X MAG

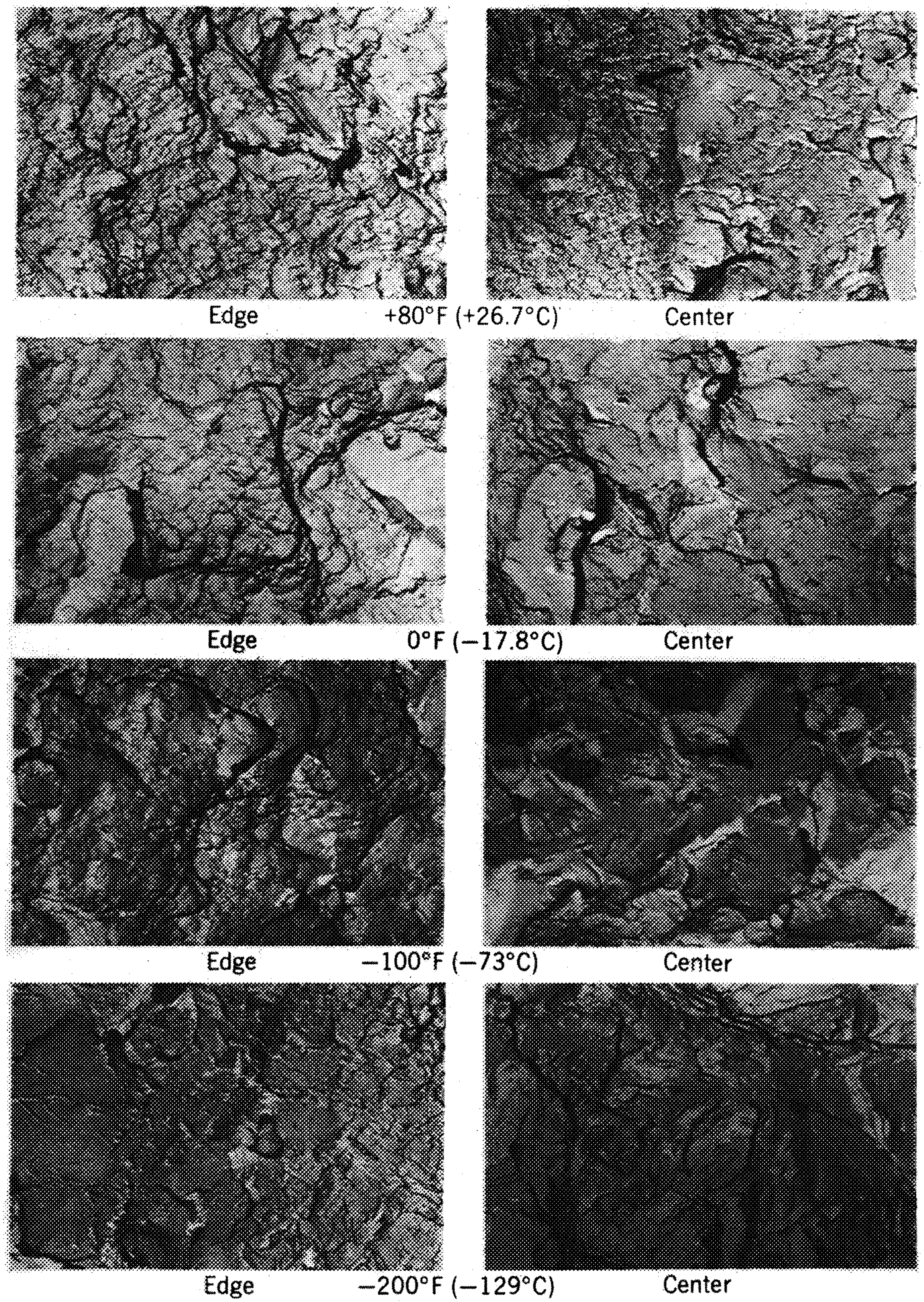
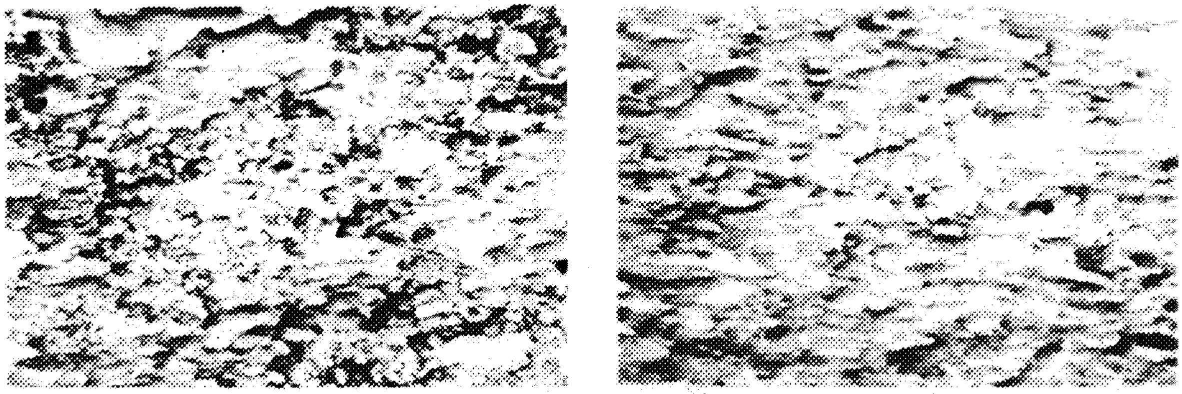
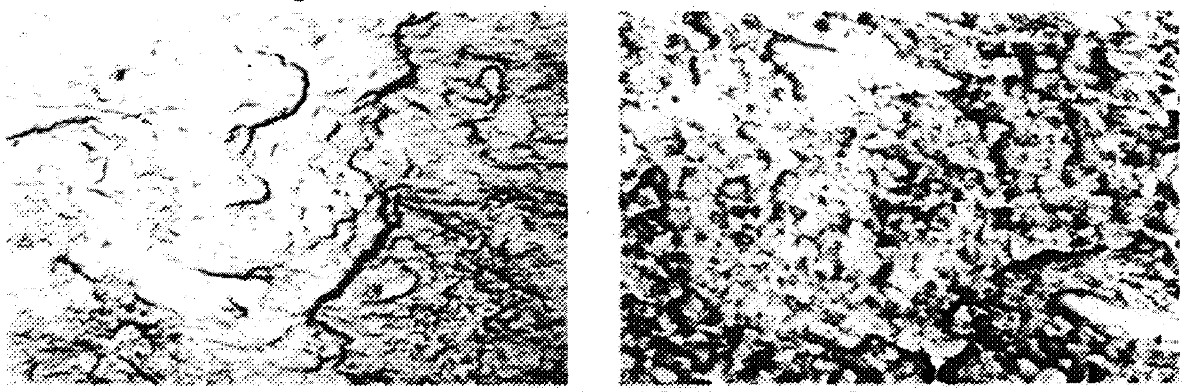


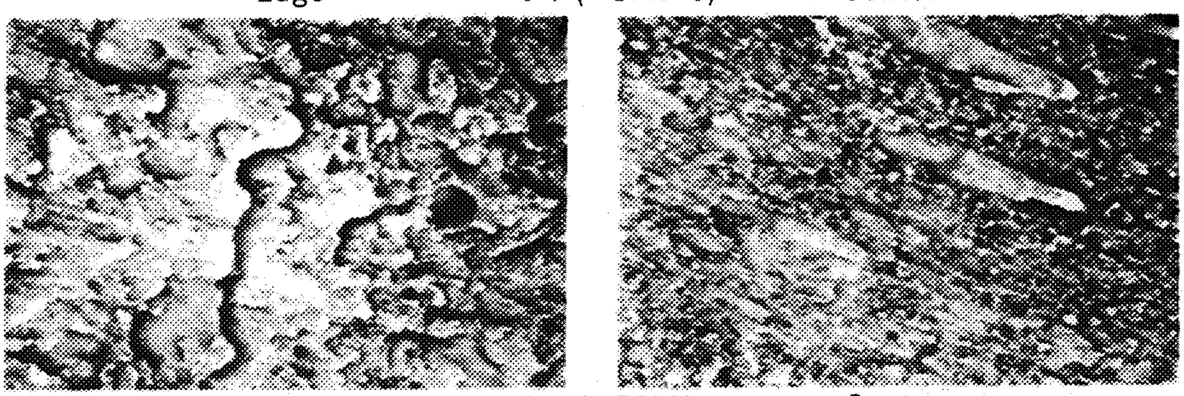
FIGURE 21C - TEM FRACTOGRAPHS OF 8740 ALLOY STEEL TEMPERED AT 850°F (454°C)
CHARPY V—NOTCHED IMPACT BAR SPECIMEN FRACTURES 3150X MAG



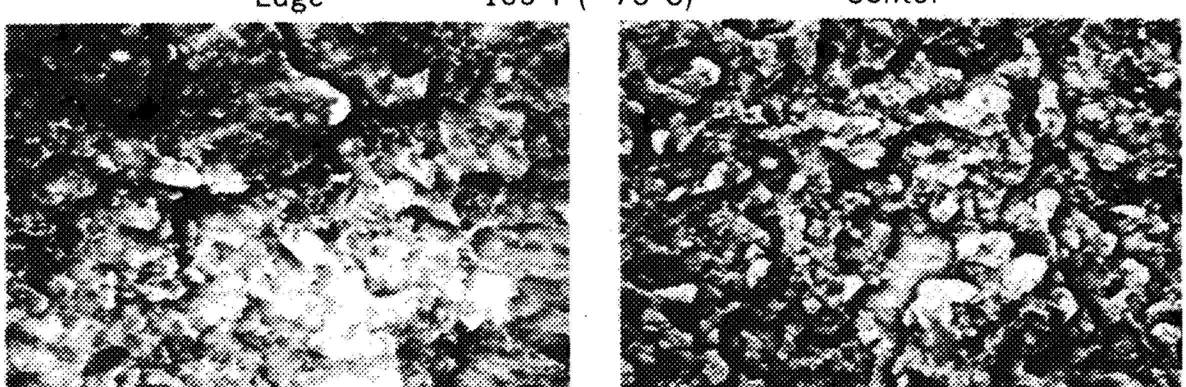
Edge +80°F (+26.7°C) Center



Edge 0°F (−17.8°C) Center



Edge −100°F (−73°C) Center



Edge −200°F (−129°C) Center

FIGURE 21D - SEM FRACTOGRAPHS OF 8740 ALLOY STEEL TEMPERED AT 850°F (454°C)
DOUBLE SHEAR SPECIMEN FRACTURES 2300X MAG

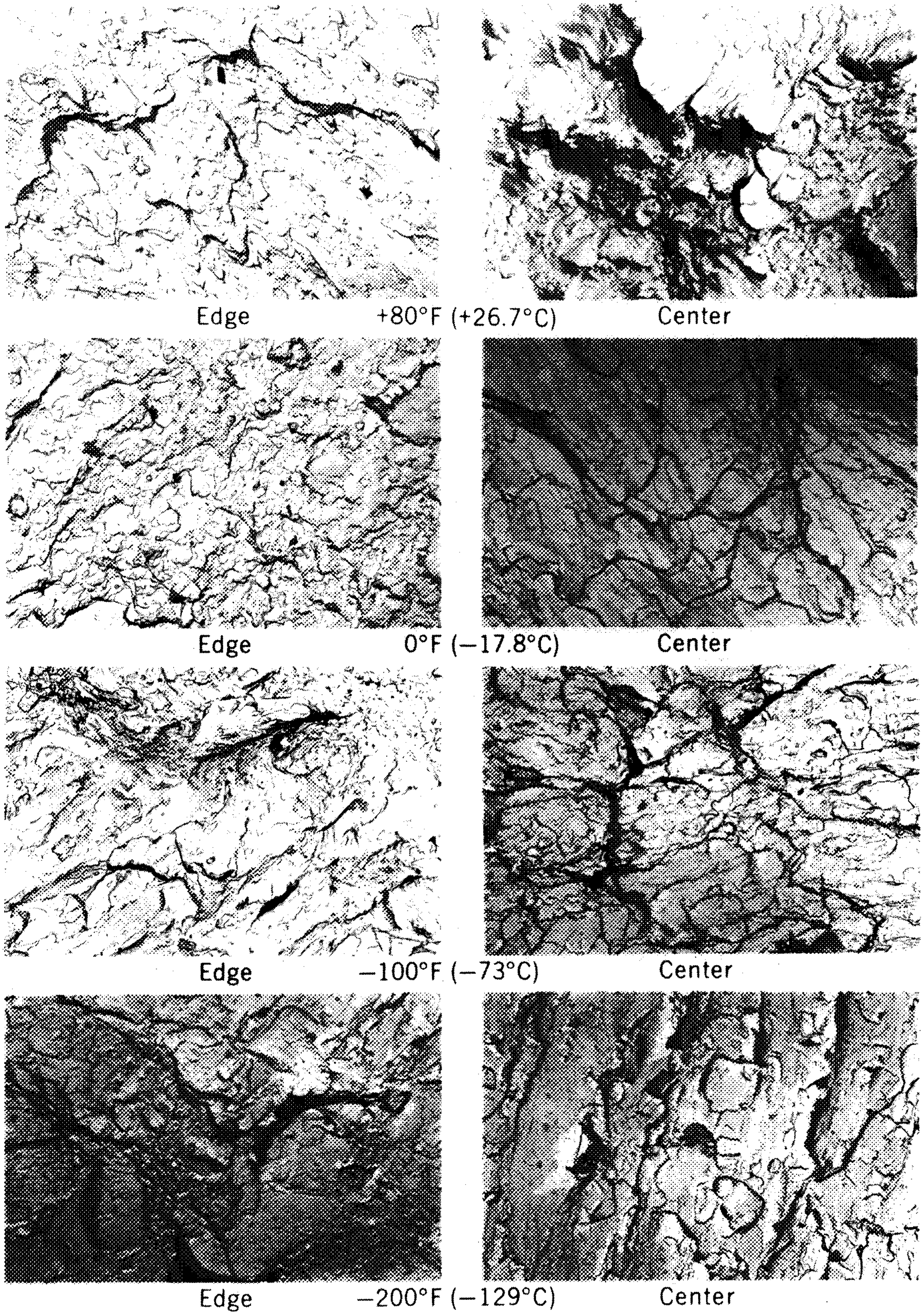


FIGURE 22A - TEM FRACTOGRAPHS OF 8740 ALLOY STEEL TEMPERED AT 1175°F (635°C)
SMOOTH BAR TENSILE FRACTURES 3150X MAG

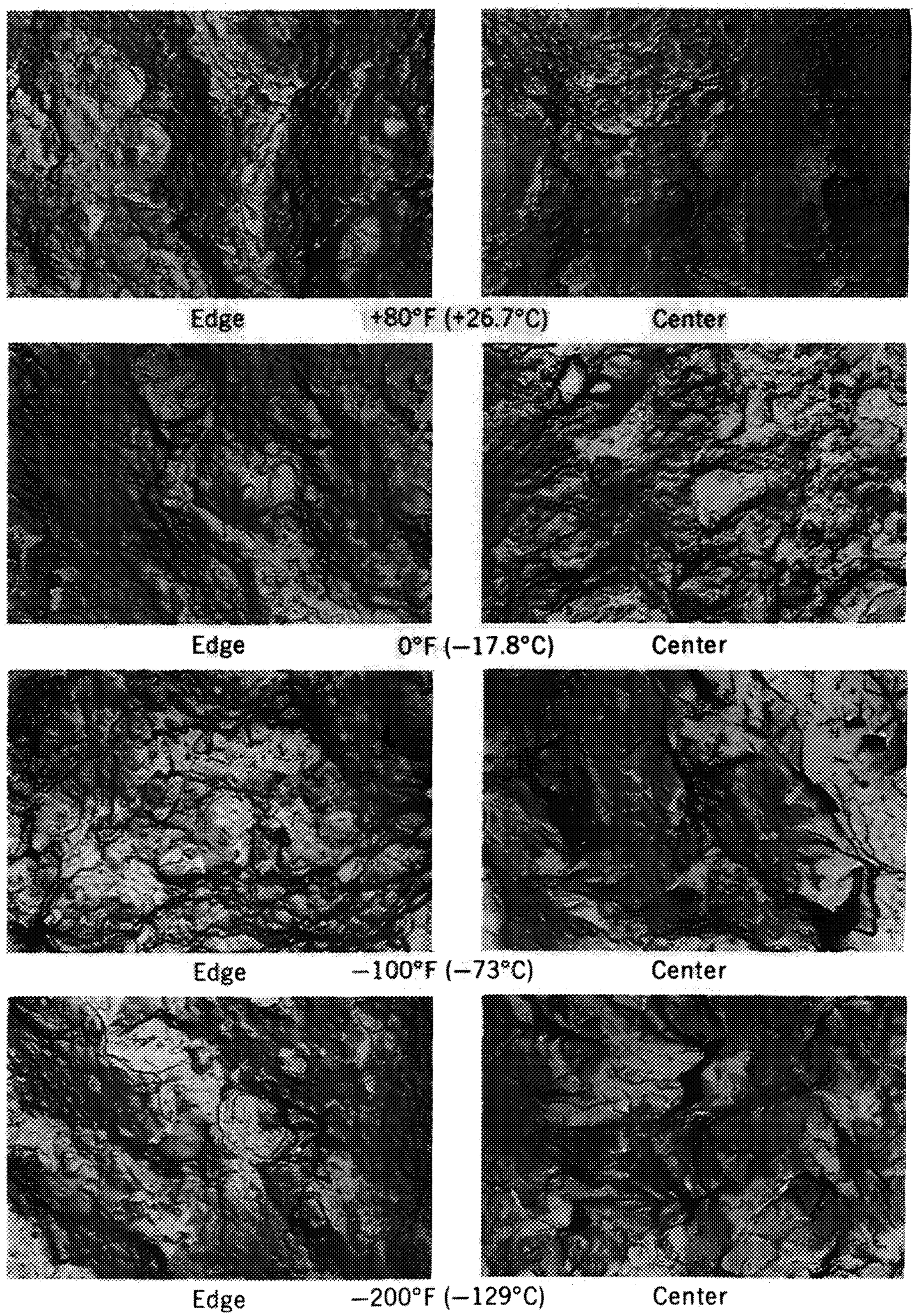


FIGURE 22B - TEM FRACTOGRAPHS OF 8740 ALLOY STEEL TEMPERED AT 1175°F (635°C)
V—NOTCH BAR TENSILE FRACTURES 3150X MAG

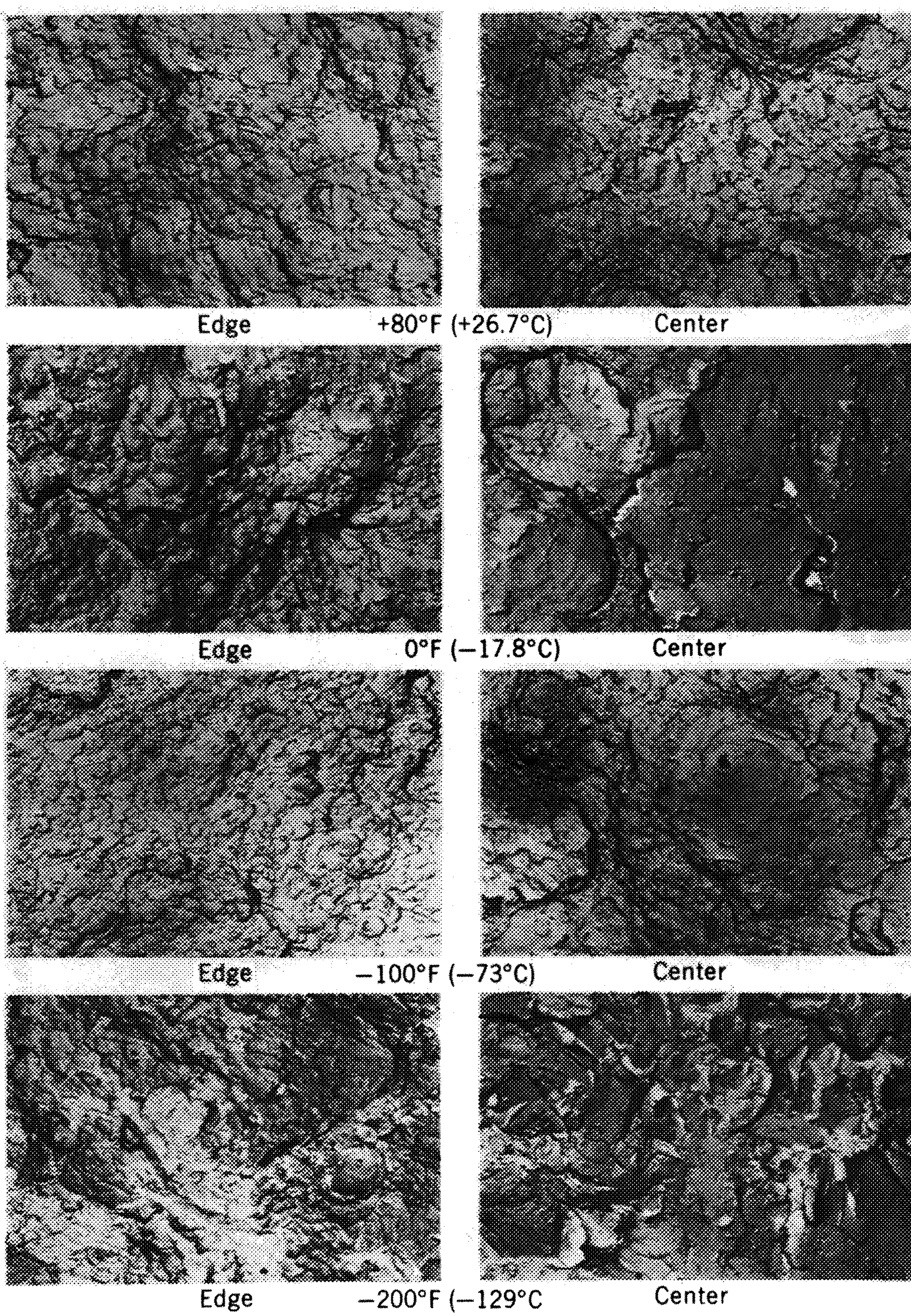
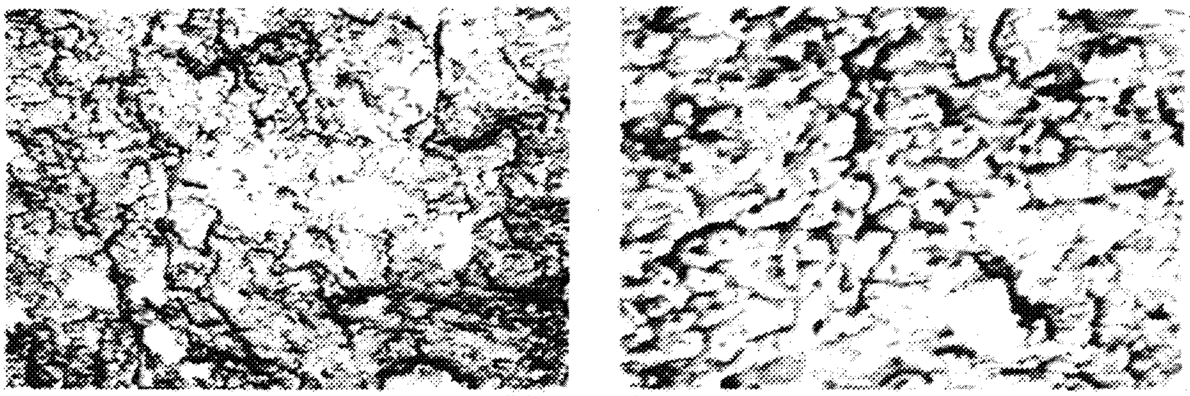
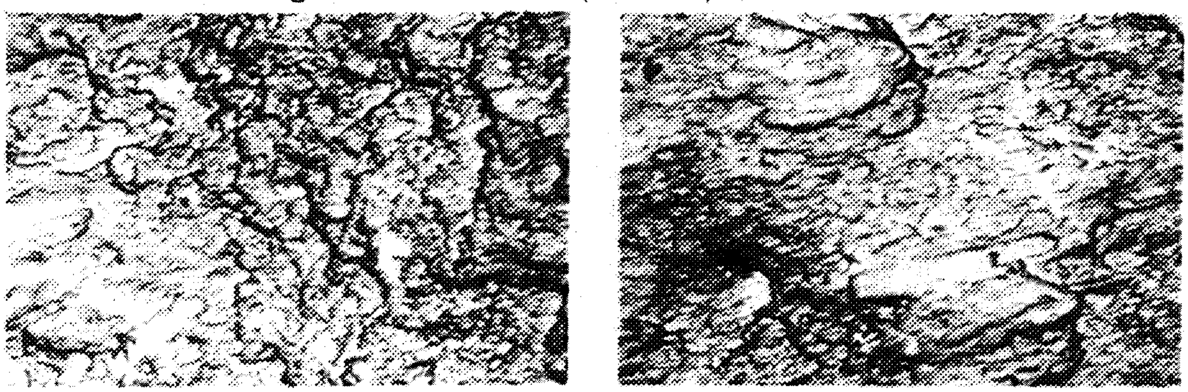


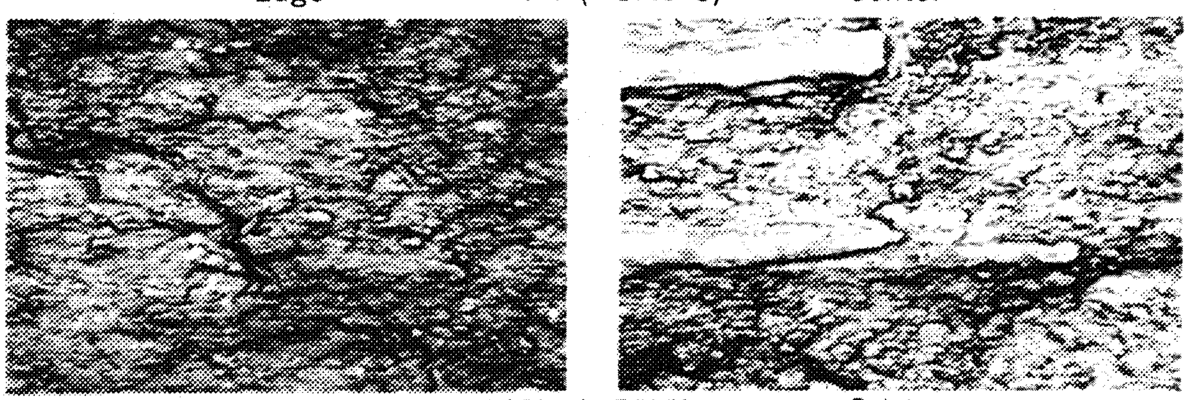
FIGURE 22C-TEM FRACTOGRAPHS OF 8740 ALLOY STEEL TEMPERED AT 1175°F (635°C)
CHARPY V—NOTCHED IMPACT BAR SPECIMEN FRACTURES 3150X MAG



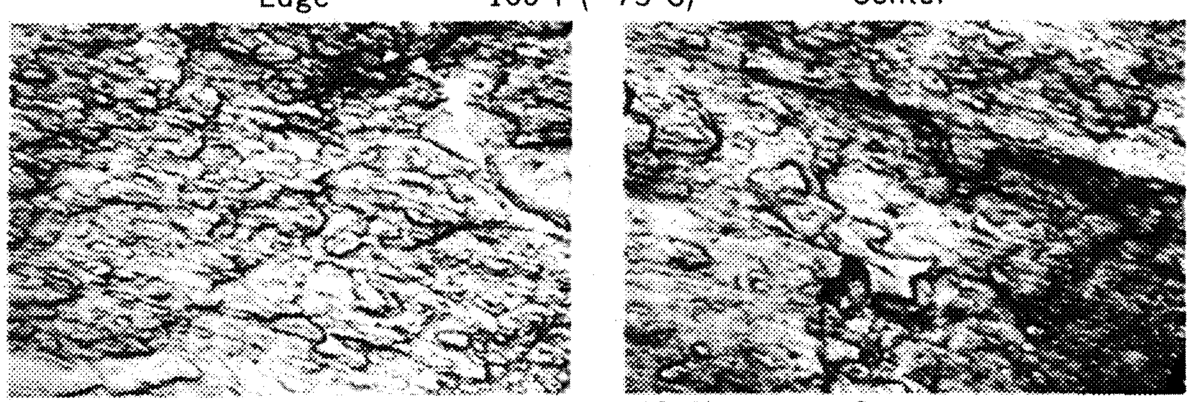
Edge +80°F (+26.7°C) Center



Edge 0°F (−17.8°C) Center



Edge −100°F (−73°C) Center



Edge −200°F (−129°C) Center

FIGURE 22D - SEM FRACTOGRAPHS OF 8740 ALLOY STEEL TEMPERED AT 1175°F (635°C)
DOUBLE SHEAR SPECIMEN FRACTURES 2300X MAG

APPROVAL

LOW TEMPERATURE MECHANICAL PROPERTIES, FRACTOGRAPHIC & METALLOGRAPHIC EVALUATION OF SEVERAL ALLOY STEELS

By
J. W. Montano

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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