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LOW TEMPERATURE MECHANICAL PROPERTIES OF HIGH STRENGTH A-286 BOLTS

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ABSTRACT

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This report presents the mechanical properties of high strength A-286 alloy bolts and reduced shank bolt specimens which were tested at temperatures from ambient to -423°F (-253°C). These bolts were manufactured by the Camcar Screw Company utilizing the "Ray-Carl" cold heading process. The mechanical properties of these bolts were compared with those of other high strength A-286 alloy bolts that were manufactured by different methods. It was concluded from the low temperature tests that the high-strength A-286 alloy bolts of 7/16-inch diameter, 20 threads per inch, are satisfactory for structural application in space vehicles at temperatures from ambient to -423°F (-253°C).

Author

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PROPULSION AND VEHICLE ENGINEERING LABORATORY

RESEARCH AND DEVELOPMENT OPERATIONS

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LOW TEMPERATURE MECHANICAL PROPERTIES OF HIGH STRENGTH A-286 BOLTS

SUMMARY

The mechanical properties of Camcar Screw Company's high strength A-286 alloy bolts and bolt specimens were determined for the temperature range of 75°F (23.9°C) to -423°F (-253°C). The ultimate tensile and yield strengths of the bolts and the reduced shank bolt specimens increased with decreasing temperatures as expected. The percent elongation values of the reduced shank specimens increased to a maximum at -320°F (-196°C). At -423°F (-253°C), there was a slight decrease in elongation; however, the value at this temperature was greater than at ambient temperature.

The notched/unnotched tensile ratios were greater than 1.0 at all test temperatures, which indicates that this material is relatively notch insensitive when used at cryogenic temperatures in tension applications. The mechanical properties of the Camcar bolts and bolt specimens compare favorably with high-strength A-286 alloy bolts produced by other manufacturers.

INTRODUCTION

Many factors other than the ultimate tensile strength are considered when choosing a material for high strength bolts that are to be used at cryogenic and elevated temperatures. Some of these factors are tensile yield strength, notched tensile strength, notched to unnotched tensile ratios, and percent elongation. Since these properties cannot be obtained directly from the bolts, it is necessary to modify the unthreaded portion of the bolt shank to permit a more critical evaluation of the fastener. In this report, the results that were obtained from reduced shank bolt specimens of A-286 steel are compared to the ultimate tensile and 0.2 percent yield strengths of the bolts, as calculated by use of the NAS 1348 diameter and the "Johnson's 2/3 Approximate Yield Method."

A-286 is a heat treatable stainless steel containing approximately 26 percent nickel, 16 percent chromium, 2 percent titanium, and smaller amounts of manganese, silicon, molybdenum, vanadium, aluminum, and boron. In the annealed condition, this alloy is as machinable as the regular chromium-nickel types of stainless steels (ref. 1). An additional increase in strength can be obtained by cold working the material. However, due to stress relaxation, the highly cold worked alloy is not suitable for use at temperatures over 1000°F (538°C) for long-time service (ref. 2).

High-strength bolts made from the A-286 alloy have been used for specific applications for some time. Previous work by this division (ref. 3 and 4) and investigations by other organizations have shown that A-286 has low temperature mechanical properties that make it suitable for applications at temperatures as low as -423°F (-253°C). In a continuing program to develop and evaluate materials for high performance fasteners, this division investigated A-286 bolts which were manufactured by Camcar Screw Company (a Division of Textron Industries, Incorporated) utilizing the "Ray-Carl" cold heading process.

The Camcar test bolts (RD 111-4008, 6758 C) were manufactured from A-286 material, heat No. K-61323. The minimum guaranteed properties of this material, as supplied by the steel producer, are 140,000 psi ultimate tensile strength and 85,500 psi yield strength.

EQUIPMENT AND TEST SPECIMENS

The equipment used in this investigation is described in reports by Miller (ref. 4) and Montano (ref. 5). Mechanical properties were determined at ambient and cryogenic temperatures as follows:

a. Twenty-five of the bolts were tested as received.

b. Twenty-five bolts were tested after machining a V-notch (Stress Concentration Factor of K_t=10) into the shank.

c. Twenty-five bolts were tested with a smooth, reduced section in the shank. The machined specimens permitted a more critical evaluation of the bolts. The test specimen configurations are illustrated in FIG 1, and actual test specimens are shown in FIG 1A through 1E.

RESULTS AND DISCUSSION

Manufacturers of bolts often use the technique known as "Johnson's 2/3 Approximate Yield Method" (ref. 6) for the determination of a bolt yield load. A load versus strain curve must be recorded, preferably by use of a bolt extensometer which has the ability to record movement in the threads, shank, and the head of the bolt. However, in this program, the load-strain curve was recorded by attaching a conventional extensometer to the unthreaded portion of the bolt shank. Data obtained in this manner compared favorably with data obtained by means of a bolt extensometer at ambient temperature. After the load-strain curve was recorded, the slope of the curve was determined, and a line representing 2/3 of this value was plotted. Another line was drawn parallel to the 2/3 slope line so that it was tangent to the load-strain curve near the proportional limit. The point of tangency indicated the yield load. Although the yield load of the bolt was determined, the exact area for calculating unit tensile strength was still an arbitrary value. There are at least four acceptable methods for calculating the area of threads in the Military Handbook H-28 and the National Aerospace Standard. The NAS 1348 diameter used for strength calculation of threaded bolts provided the best correlation of tensile yield and ultimate strengths with these properties of reduced-shank bolt specimens.

To ensure that the bolts were manufactured from the correct material and that manufacturing processes such as grinding or heat treating had not caused decarburization, a recheck of chemical composition was made by the wet analysis and spectrographic methods. Table I lists the chemical composition and condition of the test alloy as determined by two different laboratories.

Results of the low temperature tests are tabulated in Tables II through IV, and the mechanical properties are also illustrated in FIG 2 through 5.

Figure 2 illustrates the notched tensile strength, the ultimate tensile strength (minor diameter and NAS 1348 diameter), and the "Johnson's 2/3 Approximate Yield Strength" (NAS 1348 diameter) for the as-received Camcar bolts. Figure 2 also illustrates the ultimate tensile and yield strengths and the percent elongation of the reduced shank bolt specimens.

Figure 3 compares the notched tensile strength, the notched-to-unnotched tensile ratio, and the elongation values for high strength A-286 bolt specimens supplied by the Camcar Manufacturing Company, the

Standard Pressed Steel Company (SPS), and the Voi-Shan Manufacturing Company (VS) (ref. 7). This comparison shows a decrease in notched tensile strength, notched/unnotched ratio, and a decrease in the percent elongation in two inches for the highly cold worked A-286 bolts supplied by SPS. If the elongation values were reported in percent in one inch or percent in four diameters, the values would be greater; however, specimens of 2.0-inch gauge length were used. Figure 3 indicates almost identical properties for the Camcar and Voi-Shan fasteners.

The ultimate tensile and yield strengths of high strength A-286 reduced shank bolt specimen supplied by Camcar, SPS, and VS are compared in FIG 4. This comparison shows the greater ultimate tensile and yield strength of the 65 percent cold worked material used in the SPS bolts. The comparison also indicates the almost identical tensile properties of the Camcar and VS fasteners.

Figure 5 illustrates the as-received properties of Camcar, SPS, and VS bolts at temperatures from ambient to -423°F (-253°C). The ultimate tensile and yield strengths are based on the NAS 1348 diameter. "Johnson's 2/3 Approximate Yield Method" was used in calculating the yield strength. This comparison of data shows the SPS fastener to have much greater ultimate tensile strength and yield strength; however, the yield strength at -423°F (-253°C) approaches the ultimate tensile strength of the bolt. There is a close correlation of the ultimate tensile strength of the as-received Camcar bolts when calculated by use of the NAS 1348 diameter with the ultimate tensile strength of the reduced shank bolt specimens. This correlation is true also of the 0.2 percent yield strength of the bolts when calculated by the "Johnson's 2/3 Approximate Yield Method" by using the NAS 1348 diameter and the reduced shank specimen yield strength.

Figure 6 illustrates the microstructure of the center portion of the unthreaded shank and also of the threaded area of a Camcar bolt. The grain size and orientation indicates a large amount of cold work. Microhardness measurements in the threaded area yielded a Rockwell C hardness of 46 (converted from DPH).

Figure 7 compares the macrostructure of the cold-formed Camcar bolt head, showing the flow lines, with the Vickers DPH and Rockwell C hardness values. These hardness readings showed the maximum hardness (R_c 45) to be located at the center of the bolt head flow lines. Conventional hot headed bolts have the minimum hardness at this exact location, thereby inducing a condition which can result in head failure at elevated temperatures. The "Ray-Carl" cold heading process should prove beneficial in this respect for sustained performance at elevated temperature.

CONCLUSIONS

The mechanical properties of high strength A-286 bolts which were fabricated by Camcar Manufacturing Company were satisfactory over the temperature range of 75°F (23.9°C) to -423°F (-253°C). Ultimate tensile strength and 0.2 percent yield strength increased with decreasing temperature for the as-received bolts and for the reduced shank bolt specimens. The strength increase attained by the "Ray-Carl" cold headed bolts can be utilized in space flight vehicle applications. This process did not affect detrimentally the hardness of the bolt head, nor did it cause a sharp drop in elongation at low temperatures.

It is concluded that the Camcar high strength A-286 alloy bolts compare favorably with high strength A-286 bolts supplied by other manufacturers and are satisfactory for service at temperatures from ambient to -423°F (-253°C).

REFERENCES

1. Precipitation Hardenable Stainless Steels. Republic Steel, 1961.

2. Relaxation Properties of A-286 Fasteners at 1200°F, ER168-2663-1, Elastic Stop Nut Corporation of America. November 1956.

3. Morgan, W. R.: Low Temperature Mechanical Properties of A-286 Alloy and Its Weldments. IN-P&VE-M-62-4, May 1962.

4. Miller, P. C.: Low Temperature Mechanical Properties of Several Aluminum Alloys and Their Weldments. MTP-S&M-M-61-16, October 1961.

5. Montano, J. W.: Low Temperature Mechanical Properties of "Unitemp" 212 Alloy. IN-P&VE-M-63-14, December 7, 1963.

6. HIAD USAF AFSCM, Vol. 1 - Part B - Chapter 4.

7. Montano, J. W.: Mechanical Properties of High Strength A-286 Bolts at Cryogenic Temperatures. IN-P&VE-M-64-1, February 25, 1964.

TABLE I

CHEMICAL COMPOSITION OF BAR STOCK AND TEST BOLTS

	Fe	Ni	Cr	Ti	Mo	V	C	B	Mn	Si	P	S	Al	Cu
Bar Stock +	Main	25.49	14.79	1.94	1.31	0.27	0.04	0.0052	1.23	0.54	0.016	0.008	0.18	-
Bolt ++	Main	25.50	14.64	2.00	1.22	0.32	0.06	0.0026	1.33	0.51	-	0.009	0.13	0.12

\+ Anderson Brothers Analysis
++ MSFC Analysis

TABLE II

LOW TEMPERATURE MECHANICAL PROPERTIES OF HIGH STRENGTH
A-286 BOLTS, 7/16-INCH DIAMETER, 20 THREADS PER INCH

Test Temp. °F	Minor Diameter Inches	Area[1] Minor Diameter Sq. In.	NAS 1348 Diameter Inches	Area[2] NAS 1348 Diameter Sq. In.	Maximum Load Lbs.	Tensile Strength (Minor Area) psi	Tensile Strength (NAS 1348) psi	Johnson's[3] 2/3 Yield Load Lbs.	J 2/3 Yield Strength (NAS 1348) psi
Ambient	0.3723	0.1089	0.4011	0.1264	25,975	238,500	205,500	21,750	172,100
	0.3726	0.1090	0.4017	0.1267	25,875	237,400	204,200	21,900	172,800
	0.3728	0.1091	0.4015	0.1266	25,950	237,800	205,000	22,500	177,700
	0.3730	0.1093	0.4014	0.1265	26,125	239,000	206,500	22,200	175,500
	0.3728	0.1091	0.4013	0.1265	26,025	238,500	205,700	22,050	174,300
Average					26,000	238,200	205,400	22,080	174,500
-100	0.3728	0.1091	0.4014	0.1265	28,300	259,400	223,700	24,000	189,700
	0.3725	0.1090	0.4013	0.1265	28,200	258,700	222,900	24,600	194,500
	0.3726	0.1090	0.4016	0.1267	27,800	255,000	219,400	26,400	208,400
	0.3728	0.1091	0.4016	0.1267	27,600	253,000	217,800	26,100	206,000
	0.3721	0.1087	0.4015	0.1266	27,800	255,700	219,600	-	-
Average					27,900	256,400	220,700	25,275	199,600
-200	0.3728	0.1091	0.4013	0.1265	29,500	270,400	201,600	25,500	201,600
	0.3728	0.1091	0.4018	0.1268	29,600	271,300	196,400	24,900	196,400
	0.3725	0.1090	0.4012	0.1264	29,600	272,000	194,600	24,600	194,600
	0.3727	0.1091	0.4015	0.1266	29,600	271,300	208,500	26,400	208,500
	0.3727	0.1091	0.4014	0.1265	29,600	271,300	208,700	26,400	208,700
Average					29,600	271,300	202,000	25,560	202,000

1Area, minor diameter; area calculated per Table III, HDBK H-28 (1957) Part 1

2Area, maximum per NAS 1348 for externally threaded fasteners in 160 through 260 KSI range with threads rolled after heat treatment

3Load, Johnson's 2/3 Approximate Method - HIAD USAF AFSCM Vol. 1 - Part B - Chapter 4

Manual Strain Rate = 0.15 inch/minute

Table II (Continued)

Test Temp. °F	Minor Diameter Inches	Area[1] Minor Diameter Sq. In.	NAS 1348 Diameter Inches	Area[2] NAS 1348 Diameter Sq. In.	Maximum Load Lbs.	Tensile Strength (Minor Area) psi	Tensile Strength (NAS 1348) psi	Johnson's[3] 2/3 Yield Load Lbs.	J 2/3 Yield Strength (NAS 1348) psi
-320	0.3725	0.1090	0.4013	0.1265	32,100	294,500	253,800	-	-
	0.3726	0.1090	0.4014	0.1265	31,850	292,200	251,800	26,700	211,100
	0.3721	0.1087	0.4014	0.1265	32,100	295,300	253,800	27,300	215,800
	0.3720	0.1087	0.4014	0.1265	32,250	296,700	254,900	-	-
	0.3726	0.1090	0.4015	0.1266	32,200	295,400	254,300	29,400	232,200
Average					32,100	294,800	253,700	27,800	219,700
-423	0.3724	0.1089	0.4014	0.1265	34,100	313,100	269,600	29,700	234,800
	0.3727	0.1091	0.4016	0.1267	33,900	310,700	267,600	29,100	229,700
	0.3728	0.1091	0.4016	0.1267	33,300	305,200	262,800	28,200	222,600
	0.3725	0.1090	0.4014	0.1265	33,000	302,800	260,900	28,500	225,300
	0.3725	0.1090	0.4015	0.1266	33,200*	304,600*	262,000*	25,300*	199,700*
Average					33,575	308,000	265,200	28,875	228,100

*Exclude from results - This bolt loaded to 31,500 pounds, then reloaded to failure.

1 Area, Minor diameter; area calculated per Table III, HDBK H-28 (1957) Part 1

2 Area, maximum per NAS 1348 for externally threaded fasteners in 160 through 260 KSI range with threads rolled after heat treatment

3 Load, Johnson's 2/3 Approximate Method - HIAD USAF AFSCM Vol. 1 - Part B - Chapter 4

Manual Strain Rate = 0.15 inch/minute

TABLE III

LOW TEMPERATURE MECHANICAL PROPERTIES OF
HIGH STRENGTH A-286 BOLT SPECIMENS WITH REDUCED SHANKS

Test Temp. °F	Diameter Inches	Area Sq. In.	Maximum Load Lbs.	Tensile Strength psi	Yield Load Lbs.	Yield Strength psi	Elongation In 2 Inches Percent
Ambient	0.3011	0.0712	14,700	206,500	13,800	193,800	8.0
	0.3007	0.0710	14,700	207,000	13,740	193,500	8.75
	0.3002	0.0708	14,650	206,900	13,740	194,100	9.0
	0.2962	0.0689	14,300	207,500	13,380	194,200	8.75
	0.2658*	0.0555	11,550	208,100*	10,890*	196,200*	8.25*
Average				207,200		193,900	8.6
-100	0.2999	0.0706	15,660	221,800	14,250	201,800	10.5
	0.2998	0.0706	15,600	221,000	14,370	203,500	11.0
	0.2996	0.0705	15,600	221,300	14,370	203,800	10.5
	0.2989	0.0702	15,510	220,900	14,310	203,800	11.0
	0.2966	0.0691	15,250	220,700	13,950	201,900	10.5
Average				221,100		203,000	10.7
-200	0.3006	0.0710	16,475	232,000	-	-	10.5
	0.3001	0.0707	16,375	231,600	14,750	208,600	10.5
	0.2993	0.0703	16,225	230,800	14,670	208,700	10.5
	0.2989	0.0702	16,150	230,000	14,550	207,300	10.5
	0.2974	0.0695	16,350	235,200	14,850	213,700	10.5
Average				231,900		209,600	10.5
-320	0.3003	0.0708	18,675	263,800	15,780	222,900	14.5
	0.3003	0.0708	18,725	264,500	16,440	232,200	17.5
	0.2995	0.0704	18,625	264,500	16,200	230,100	15.0
	0.2994	0.0704	18,600	264,200	15,750	223,700	16.0
	0.2978	0.0696	18,475	265,400	15,600	224,100	16.0
Average				264,500		226,600	15.8
-423	0.3001	0.0707	20,250	286,400	17,280	244,400	12.0
	0.2998	0.0706	20,000	283,300	17,310	245,200	10.0**
	0.2998	0.0706	20,250	286,800	17,250	244,300	12.0
	0.2998	0.0706	20,000	283,300	-	-	10.5
	0.2997	0.0705	19,900	282,300	17,220	244,300	9.75***
Average				284,400		244,600	11.5

*Exclude - Due to undersize specimen
**Exclude - Specimen compressed before elongation was measured
***Exclude - Elongation marks not visible - Estimated clamp mark distance

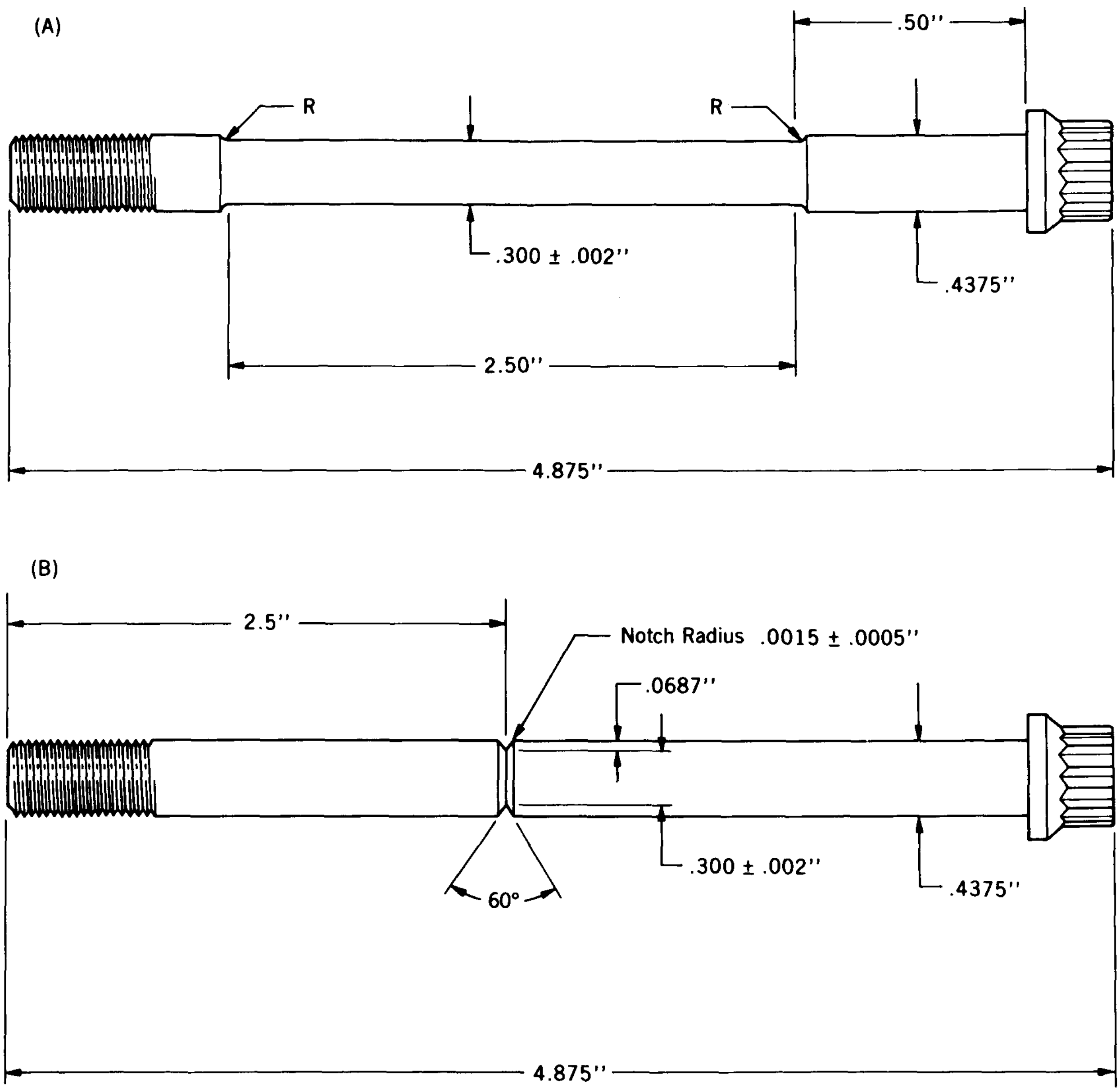
Manual Strain Rate = 0.15 inch/minute

TABLE IV

LOW TEMPERATURE TENSILE STRENGTH OF NOTCHED BOLT SPECIMENS
AND NOTCHED/UNNOTCHED TENSILE RATIOS
OF HIGH STRENGTH A-286

Test Temperature °F	Notched (K_t=10) Tensile Strength psi	Specimens Notched/Unnotched Tensile Ratio
Ambient	287,800	
	274,300	
	286,600	
	272,500	
	287,200	
Average	281,700	1.361
-100	305,600	
	290,900	
	291,400	
	306,100	
	291,600	
Average	297,100	1.344
-200	317,500	
	305,000	
	294,500	
	313,600	
	-	
	307,600	1.326
-320	334,000	
	329,600	
	339,100	
	333,100	
	341,600	
Average	335,500	1.268
-423	343,600	
	336,800	
	-	
	340,500	
	339,800	
Average	340,000	1.195

Manual Strain Rate = 0.15 inch/minute



A-286 Stainless Steel Alloy

FIGURE 1 BOLT TEST SPECIMEN CONFIGURATIONS (A) REDUCED SHANK (B) V–NOTCH

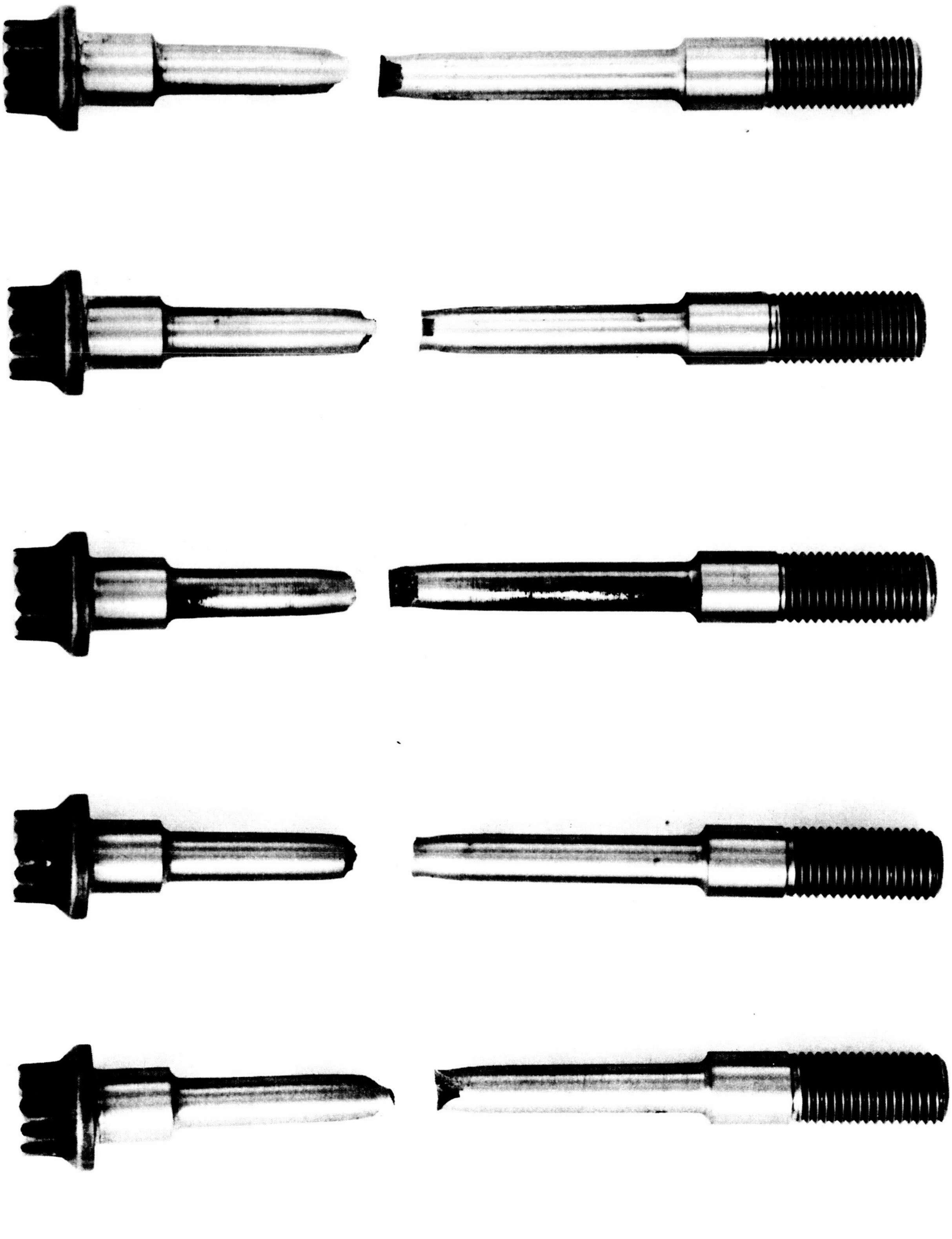


FIGURE 1A A-286 REDUCED SHANK BOLT SPECIMENS TESTED AT AMBIENT TEMPERATURE

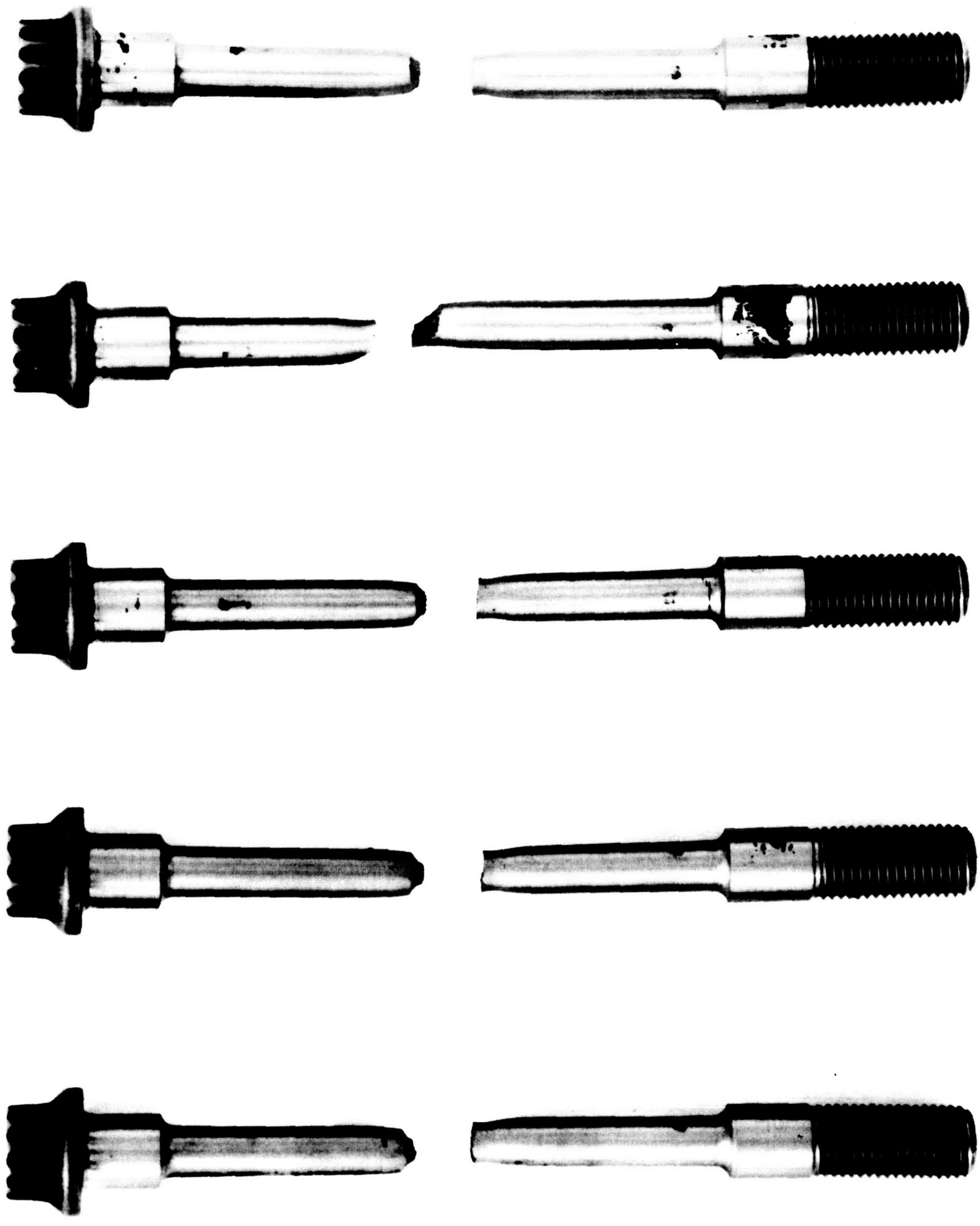


FIGURE 1B A-286 REDUCED SHANK BOLT SPECIMENS TESTED AT −100°F (−73°C)

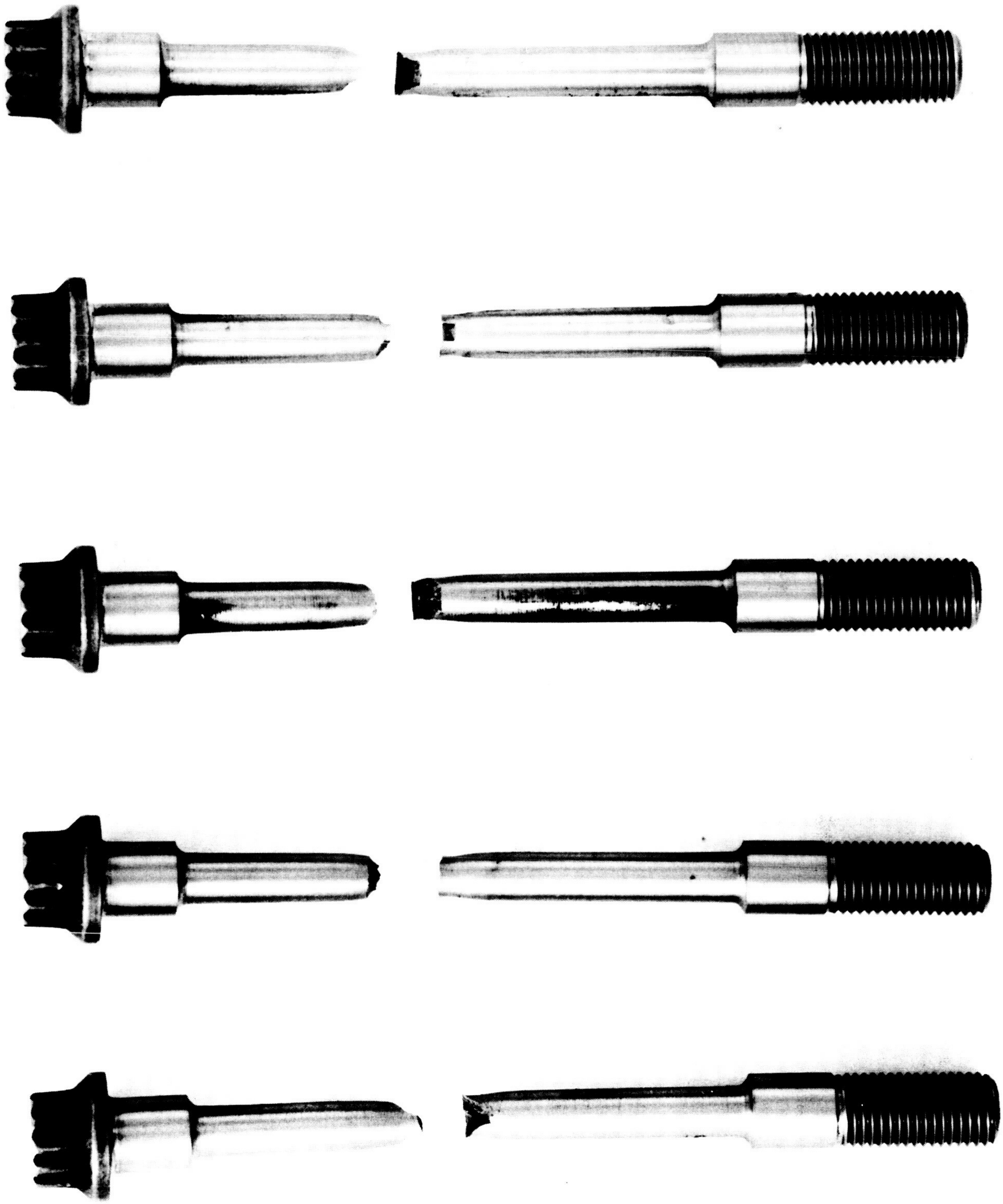


FIGURE 1C A-286 REDUCED SHANK BOLT SPECIMENS TESTED AT −200°F (−129°C)

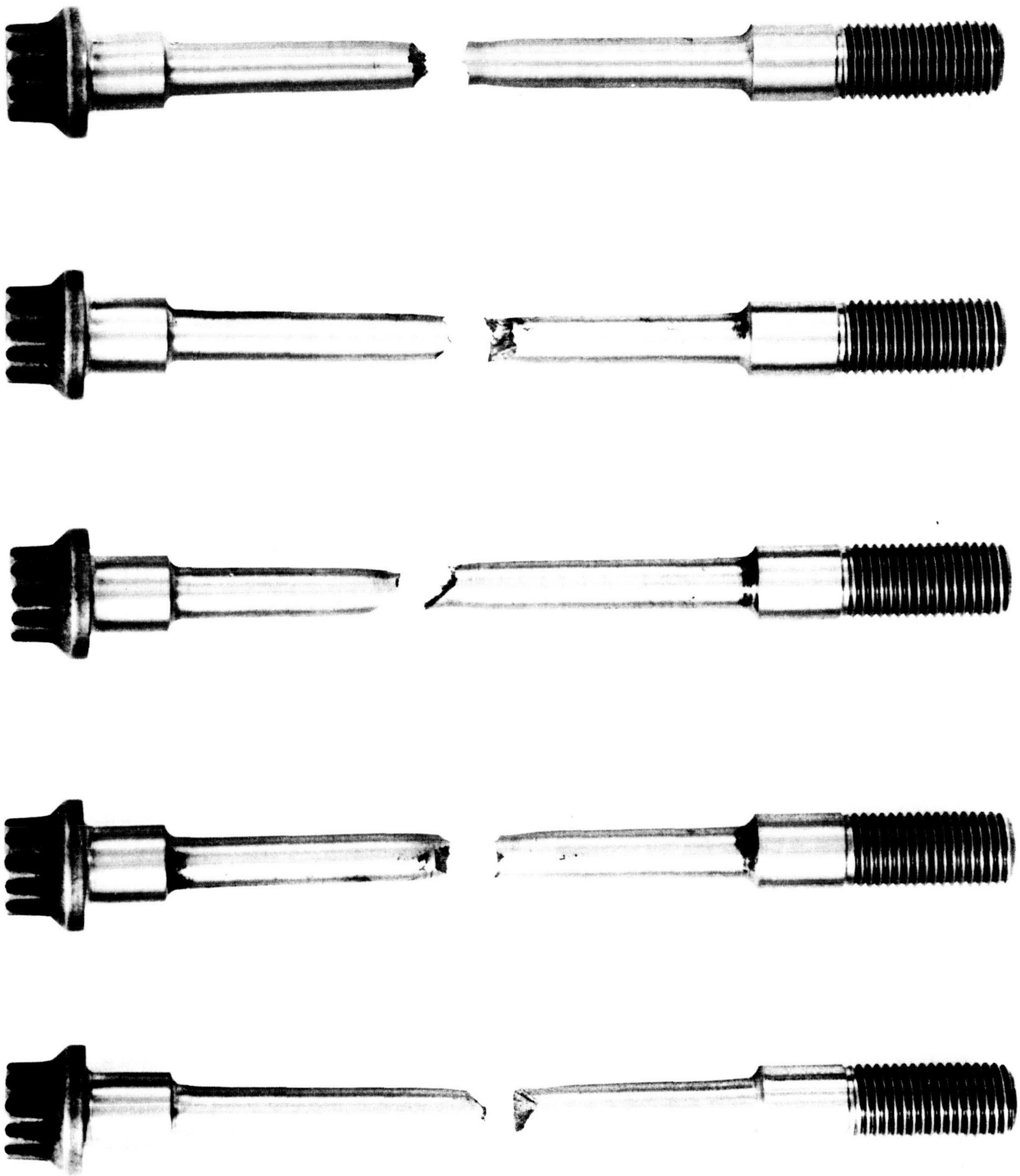


FIGURE 1D A-286 REDUCED SHANK BOLT SPECIMENS TESTED AT −320°F (−196°C)

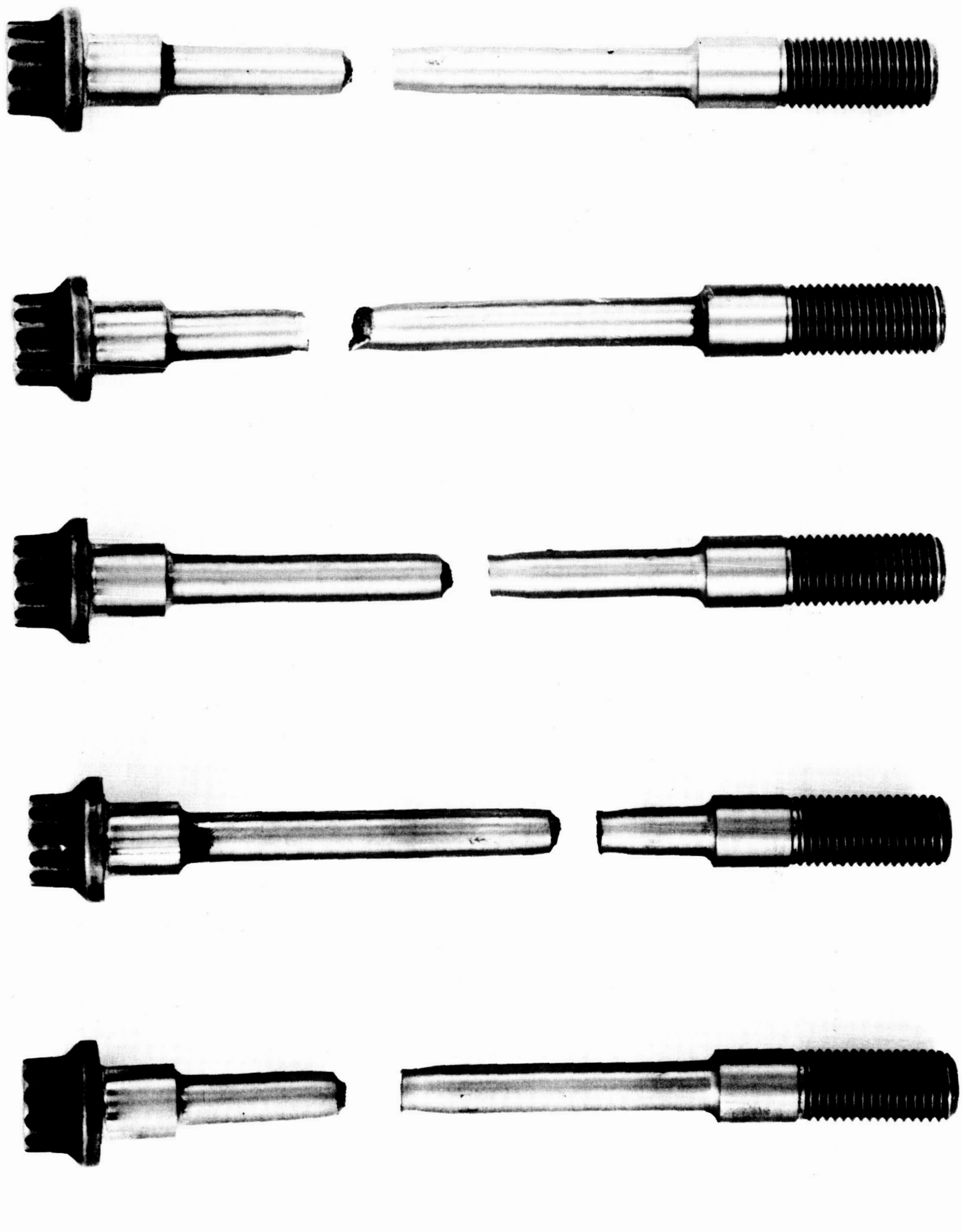


FIGURE 1E A-286 REDUCED SHANK BOLT SPECIMENS TESTED AT −423°F (−253°C)

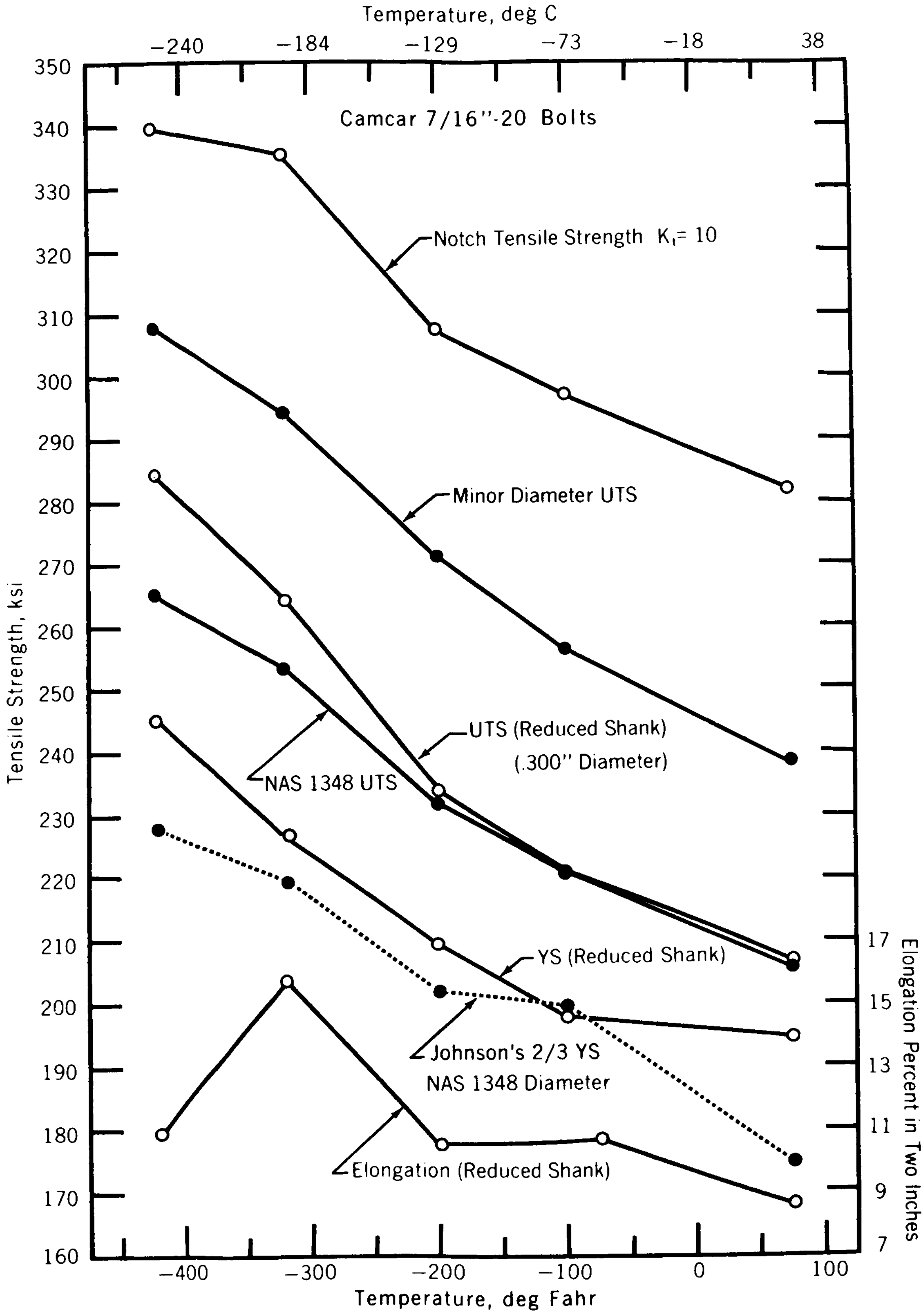


FIGURE 2 LOW TEMPERATURE MECHANICAL PROPERTIES OF HIGH STRENGTH A-286 BOLTS, 7/16–INCH DIAMETER

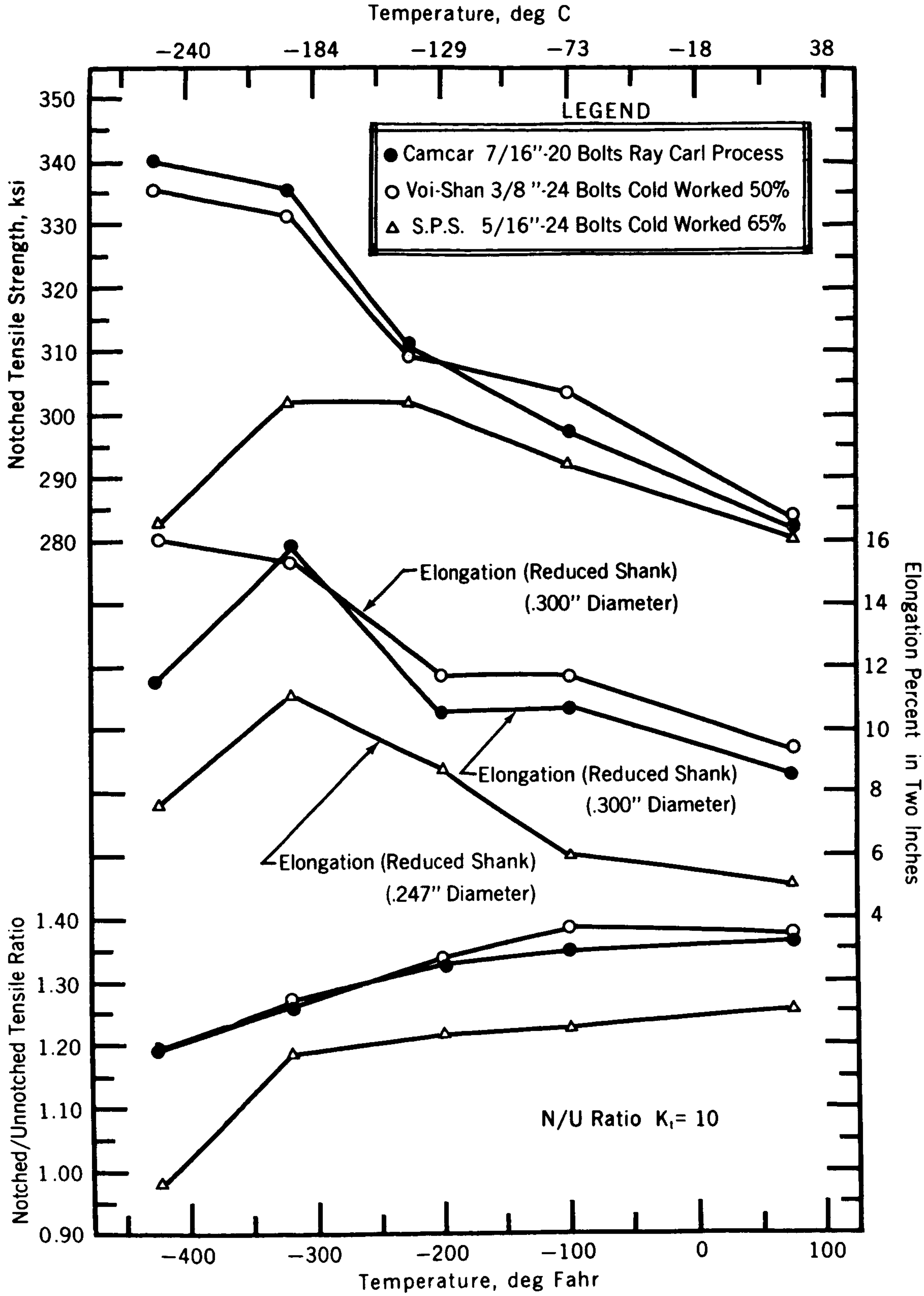


FIGURE 3 LOW TEMPERATURE MECHANICAL PROPERTIES OF HIGH STRENGTH A-286 BOLT SPECIMENS

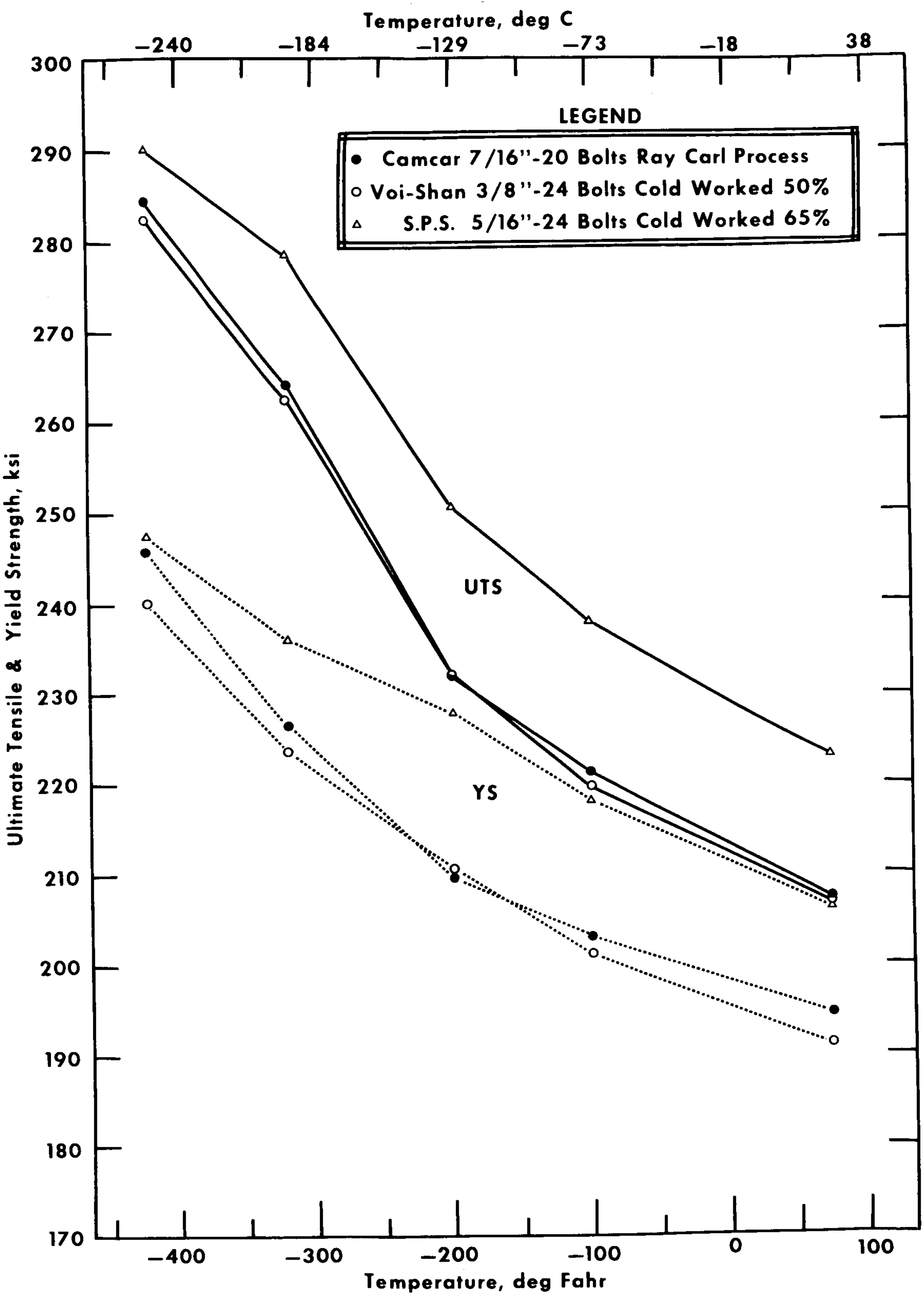


FIGURE 4 LOW TEMPERATURE ULTIMATE TENSILE AND YIELD STRENGTHS OF HIGH STRENGTH A-286 BOLT SPECIMENS

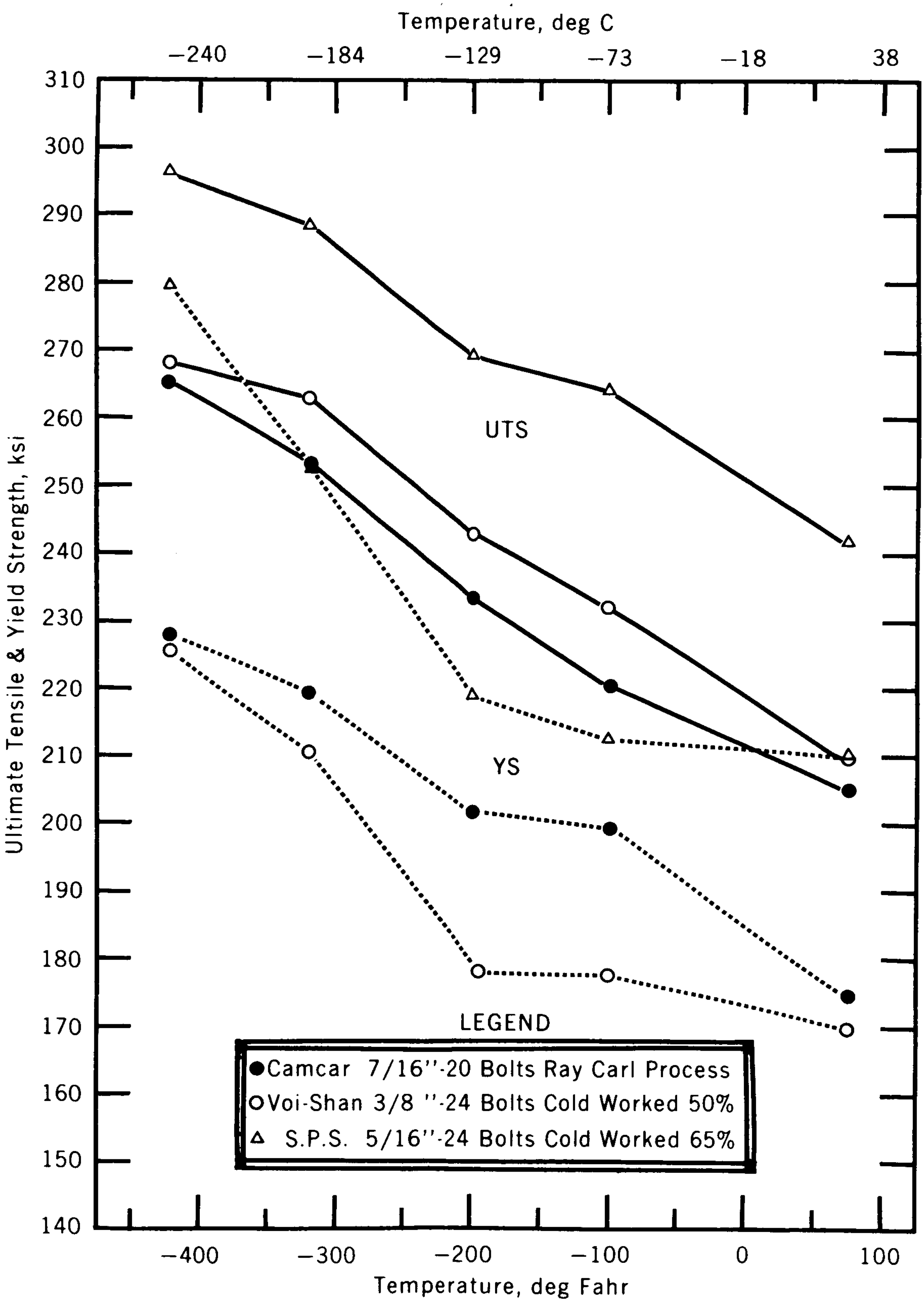
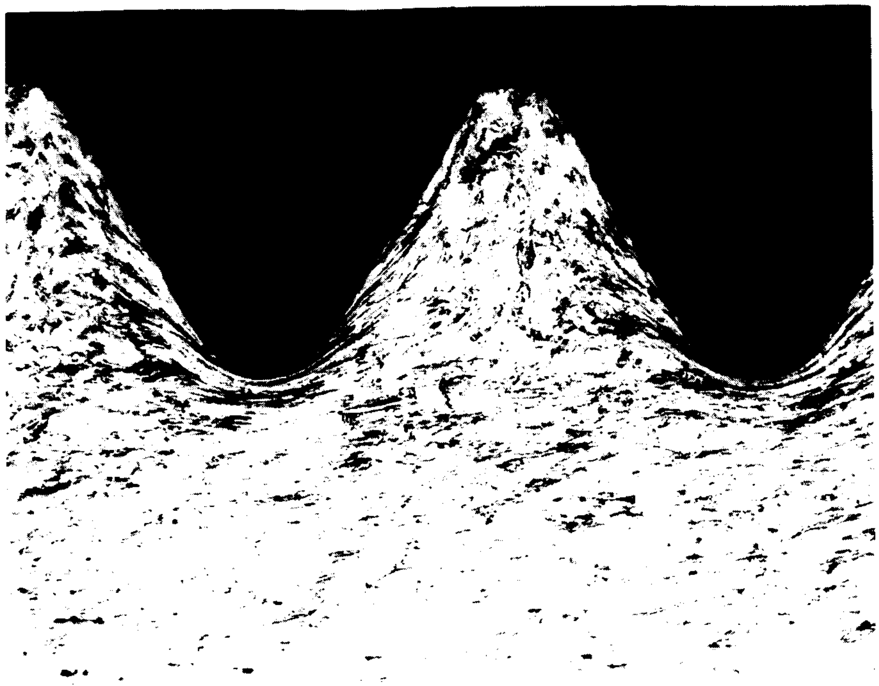
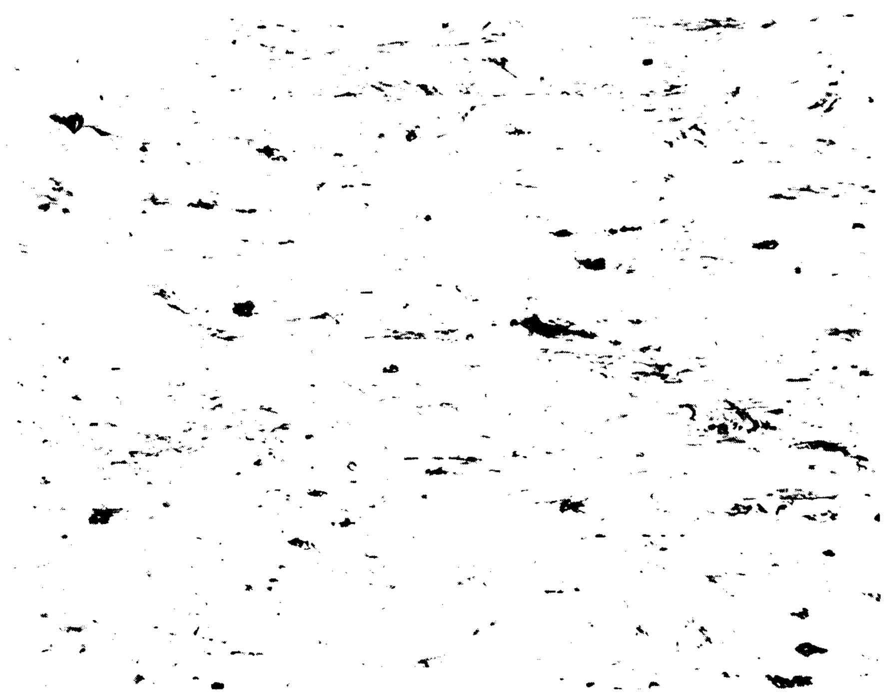


FIGURE 5 LOW TEMPERATURE ULTIMATE TENSILE AND JOHNSON'S 2/3 YIELD STRENGTHS OF HIGH STRENGTH A-286 BOLTS (NAS 1348 AREA)



Glyceregia Etch Mag 50X



Glyceregia Etch MAG 100X

FIGURE 6 MICROSTRUCTURE OF CAMCAR A-286 BOLT THREADS AND BOLT SHANK

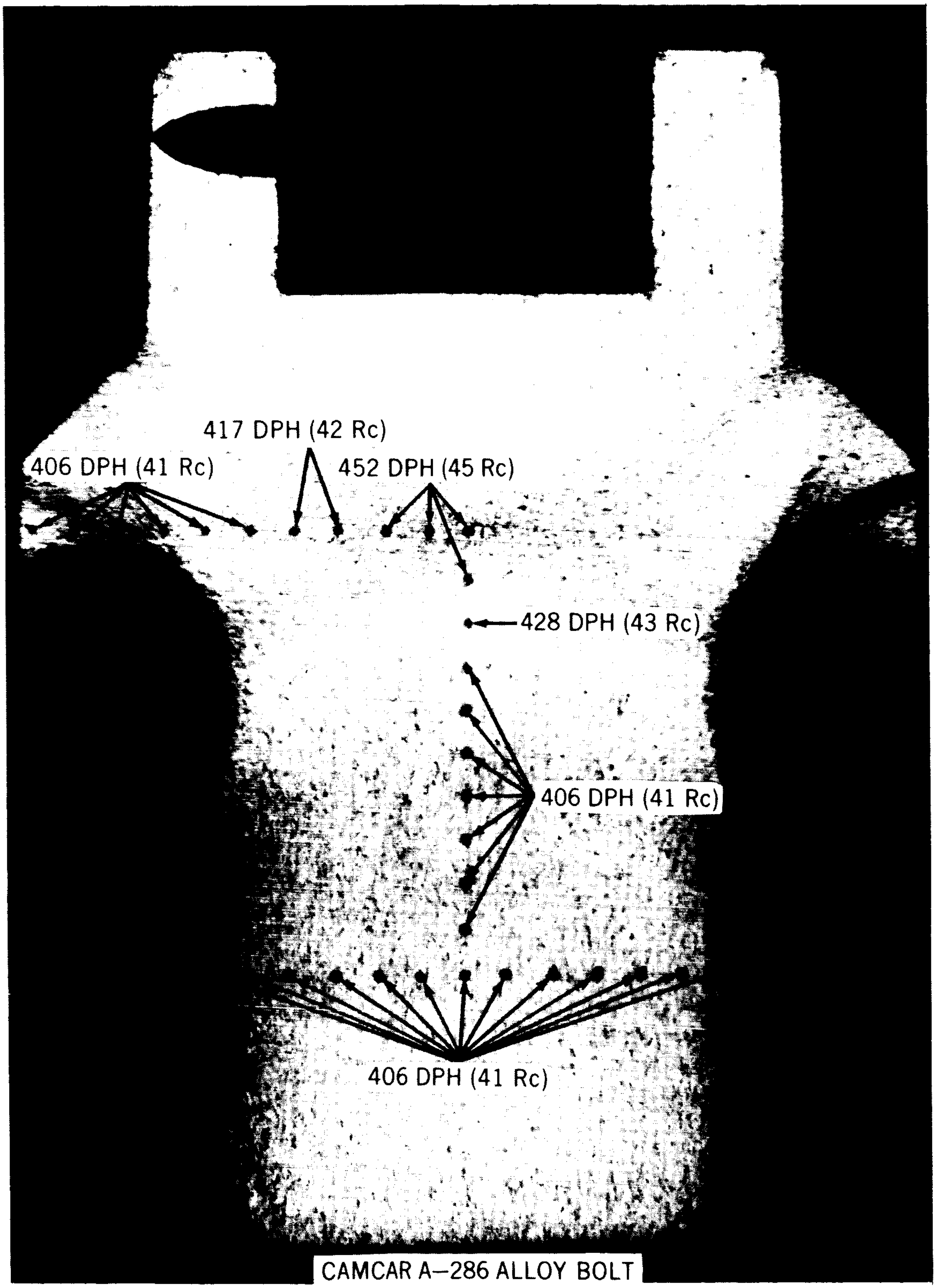


FIGURE 7—MACROSTRUCTURE OF BOLT HEAD SHOWING FLOW LINES AND HARDNESS VALUES

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LOW TEMPERATURE MECHANICAL PROPERTIES
OF HIGH STRENGTH A-286 BOLTS

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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