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TESTING PROGRAM AND TEST RESULTS

OBTAINED ON

**THREE HEATS OF
ARMCO 22-13-5
ELECTROSLAG REMELT ALLOY**

MASTER

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December 1, 1971

Mr. Robert Gale, Purchasing
Aerojet Nuclear System Company
P. O. Box 15847
Sacramento, California 95801

Dear Mr. Gale:

Per our agreement on Purchase Order N-00536, I am sending you details of the testing program and test results obtained on three heats of Armco 22-13-5 electro-slag remelt alloy. The testing program intended to determine the forgeability of this alloy for the Nerva project was outlined in my letter to Mr. D. F. Johns, Jr., Purchasing, dated October 29, 1970.

Details on the testing program are as follows:

1. A one-half slice, approximately 3" thick, was received from each of three heats of 17.5" octagon Armco 22-13-5 (ESR) alloy. Armco heat numbers 316401, 316397, and 316396 were assigned Wyman-Gordon analyses numbers Z6539, Z6540, and Z6541, respectively.

The three slices were machined on both transverse and longitudinal planes, etched with a ferric chloride solution for macro examination and visually inspected. Photographs showing the macrostructures of each slice in both planes are presented as Figures 1 through 3. On visual examination, the test slices appeared sound and no abnormal conditions were noted. A variation in macro grain size was noted and this condition is apparent in the photomicrographs. In Figure 3, the slice from analysis Z3941, two .078" diameter drill holes can be noted. These holes were drilled for ultrasonic inspection purposes.

2. The three test slices were sectioned as indicated in Figure 4. The following were obtained:

Two as-received microspecimens, two tensile coupons, a chemistry sample, and five 4" x 4" sections for forging.

3. Microstructures of the as-received material, surface and center locations are shown in Figures 5 through 7. ASTM grain size ratings for each location are also reported. In the center location of the slice from analysis Z6540 (Figures 5 and 8) some localized micro "segregation" was noted. The "segregation" appears to be primarily located from mid-radius to the center of the billet. This condition was not noted in the other two heats of material.
4. The chemical analysis of the three heats of material as reported by Armco, and also as determined by Wyman-Gordon is reported in Table I.
5. Duplicate tensile test coupons from the billets obtained from the three heats of material as indicated in Figure 4. All coupons were annealed at 1950°F for 1.5 hours at heat and fan cooled. Test properties are reported in Table II.
6. Fifteen 4" x 4" x 3" thick sections, five from each heat, were prepared for upsetting (Figure 9). Section orientation was maintained throughout the forging and testing processes. This precaution was taken to eliminate random orientation of tensile specimens. Sections from each heat were forged, using a 1500-ton hydraulic press, from ~ 3" to .75" thick in one operation at the following temperatures: 2100°F, 2150°F, 2200°F, 2250°F, and 2275°F. All samples were air cooled from the forging press. All sections were forged without any difficulty. Upsets were cleaned by grit blasting, then visually inspected and photographed (Figures 10 through 12). No cracking was noted on the die contact surfaces. On the outside diameter bulge surfaces, some minor cracking was noted on the upsets forged at 2250°F and 2275°F.
7. All upset sections were heat treated in one furnace load at 1950°F for 1.5 hours at heat and fan cooled.

Duplicate room temperature tensile tests were cut from each upset. Test results are reported in Tables III through V. Also reported are Rockwell "B" hardness values obtained from the heat treated sections. A review of the test data showed that all tensile values exceed the minimum requirements of the proposed specification, AMS 5764, for this alloy. Yield and ultimate tensile strengths for analyses Z6539 and Z6541 were comparable and were approximately 3 to 5 KSI higher than analysis Z-6540. Ultimate tensile strength decreased slightly with increased forging temperature. Elongations and reduction of areas were uniform for all tests regardless of material heats or forging temperatures. A

comparison of tensile properties obtained from the as-received material and the fifteen upsets showed a significant improvement in tensile strength in the upset material. Compare values in Table II with values in Tables III through V.

8. A microspecimen was cut from the center portion of each heat treated upset and prepared for examination. Structures are shown in Figures 13 and 15. ASTM grain size ratings are reported in Table VI. In general, the recrystallized grain sizes of all upsets were relatively fine (approximately ASTM 7-8). All upsets forged at 2100°F and 2150°F showed uniform recrystallization throughout the areas examined. In two heats of material, analysis Z6540 and Z6541, some stringers of unrecrystallized grains and/or areas of grain growth were observed in the sections upset forged at 2200°F. This condition became more predominant with increasing forge temperatures, e.g., 2250°F and 2275°F. In the third heat of material, analysis Z6539, a few areas of unrecrystallized grains and/or areas of grain growth were observed in the 2250°F and 2275°F upset sections.

Forging did not appreciably alter the "segregated" condition observed in heat 316397, analysis A6540, with the exception of causing it to be highly directional. This condition can be seen in the microstructures of upset number 2 and number 3, forged at 2150°F and 2200°F respectively (Figure 14). The microspecimen from the 2150°F upset was reprepared and lightly etched (Figure 16). Compare "segregation" in as-received condition (Figure 8) with Figure 16. The exact nature of this condition and its effect on the final product is not known. It did not appear to adversely affect forgeability.

Based on the data generated in this forgeability study, a maximum forging temperature of 2150°F is suggested for processing this material. Higher forging temperatures, e.g., 2200-2275°F, appear to promote non-uniform grain recrystallization, a tendency towards surface rupturing, and a decrease in tensile ultimate strength.

December 1, 1971

The 2150°F forging temperature selected for processing Armco's 22-13-5 and the data generated in the report is submitted for ANSC approval.

Very truly yours

WYMAN-GORDON COMPANY

Joseph R. Long
Research and Development

JRL:abl
Enclosures

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TABLE I

Chemical Analysis of Armco 22-13-5 (ESR)
Billet Material

WG Number	Heat Number	Analysis Source	C	Mn	P	S	Si	Cr	Ni	V	Mo	Cb	N
Z6539	316401	WG	.048	4.32	.027	.003	.73	21.60	12.45	.13	2.39	.17	.312
		Armco	.050	5.03	.030	.003	.55	21.50	12.57	.15	2.18	.21	.29
Z6540	316397	WG	.060	4.18	.017	.005	.61	21.80	12.20	.15	2.38	.21	.268
		Armco	.064	4.77	.025	.004	.50	21.27	12.32	.19	2.24	.23	.26
Z6541	316396	WG	.054	4.59	.023	.004	.70	22.10	12.40	.12	2.39	.20	.312
		Armco	.055	5.38	.027	.004	.53	21.88	12.65	.19	2.20	.19	.30
Proposed AMS 5764 Specification Requirement			.06 max.	4.00 6.00	.040 max.	.030 max.	1.0 max.	20.50 23.50	11.50 13.50	.10 .30	1.50 3.00	.10 .30	.20 .40

TABLE II

Room Temperature Tensile Properties of
Armco 22-13-5 (ESR) Billet Material
Test Coupons Annealed at 1950°F ~ 1.5 Hours at Heat, Fan Cooled

<u>WG Number</u>	<u>Heat Number</u>	<u>0.2% Y.S. (KSI)</u>	<u>U.T.S. (KSI)</u>	<u>El.%</u>	<u>R.A.%</u>
Z6539	316401	52.0	112.4	46.0	58.7
		51.8	108.2	49.0	58.7
Z6540	316397	52.0	112.0	48.0	68.2
		52.0	112.0	48.0	68.2
Z6541	316396	52.0	114.6	49.0	65.5
		52.0	114.6	49.0	66.4

TABLE III

Room Temperature Tensile Properties of
 Armco 22-13-5 (ESR) Billet Material
 Forged at Indicated Temperatures from ~ 3" to .75" Thick
 Also Reported are Rockwell "B" Hardness Values

WG Analysis Z6539, Heat #316401

Annealed at 1950°F - 1.5 Hours, Fan Cooled

<u>Section Number</u>	<u>Forge Temp. (°F)</u>	<u>0.2% Y.S. (KSI)</u>	<u>U.T.S. (KSI)</u>	<u>El.%</u>	<u>R.A.%</u>	<u>Rockwell "B"</u>
1	2100	61.8 62.6	123.6 121.0	47.0 46.0	67.9 68.8	93
2	2150	63.2 64.0	121.0 121.4	45.5 44.5	66.4 66.0	90
3	2200	62.0 61.2	118.2 116.8	45.0 45.5	66.4 65.0	91
4	2250	60.6 61.4	117.2 115.4	47.0 45.0	67.4 66.0	93
5	2275	60.2 60.0	115.4 115.0	45.0 48.0	66.0 67.9	91

AMS 5764 Proposed
 Specification
 Requirement:

55.0 100.0 35.0 55.0

TABLE IV

Room Temperature Tensile Properties of
 Armco 22-13-5 (ESR) Billet Material
 Forged at Indicated Temperatures from ~ 3" to .75" Thick
 Also Reported are Rockwell "B" Hardness Values

WG Analysis Z6540, Heat #316397

Annealed at 1950°F - 1.5 Hours, Fan Cooled

<u>Section Number</u>	<u>Forge Temp. (°F)</u>	<u>0.2% Y.S. (KSI)</u>	<u>U.T.S. (KSI)</u>	<u>El.%</u>	<u>R.A.%</u>	<u>Rockwell "B"</u>
1	2100	55.6 55.0	116.6 116.6	47.0 47.0	68.2 68.8	94.0
2	2150	57.6 58.0	115.0 115.4	46.5 46.0	69.1 68.2	92.0
3	2200	60.2 58.0	114.2 113.2	45.0 45.0	67.9 66.4	91.5
4	2250	62.0 60.4	110.0 109.4	47.0 45.0	72.5 71.3	94.6
5	2275	62.0 64.0	109.0 114.0	45.0 44.0	66.9 68.2	95.0
AMS 5764 Proposed Specification Requirement:		55.0	100.0	35.0	55.0	

TABLE V

Room Temperature Tensile Properties of
 Armco 22-13-5 (ESR) Billet Material
 Forged at Indicated Temperatures from ~ 3" to .75" Thick
 Also Reported are Rockwell "B" Hardness Values

WG Analysis Z6541, Heat #316396

Annealed at 1950°F - 1.5 Hours, Fan Cooled

<u>Section Number</u>	<u>Forge Temp. (°F)</u>	<u>0.2% Y.S. (KSI)</u>	<u>U.T.S. (KSI)</u>	<u>El.%</u>	<u>R.A.%</u>	<u>Rockwell "B"</u>
1	2100	61.6 62.0	120.0 122.4	45.0 45.0	70.3 69.1	96.0
2	2150	63.0 63.0	120.0 122.0	45.0 45.0	66.9 66.0	96.0
3	2200	64.0 64.0	118.0 118.0	45.0 45.0	65.0 66.0	94.5
4	2250	62.8 62.2	120.0 117.8	45.0 45.0	65.0 65.0	92.5
5	2275	64.0 66.0	115.4 118.0	44.0 41.0	64.5 66.0	95.0
AMS 5764 Proposed Specification Requirement:		55.0	100.0	35.0	55.0	

TABLE VI

ASTM Grain Size Rating on Microspecimens from 22-13-5 Alloy
 Forged from ~ 3" to .75" Thick at Indicated Temperature
 Material Annealed at 1950°F - 1.5 Hours at Heat, Fan Cooled

WG Analysis Number	Section Number	Forge Temp. (°F)	ASTM Grain Size Rating		
			Pred.	ALA	Remarks
Z6539	1	2100	8	5	Uniform
	2	2150	8	5	Uniform
	3	2200	8	5	Uniform
	4	2250	7.5	4	One Unrecrystallized Area
	5	2275	7	4	Few Stringers of Unrecrystallized Areas
Z6540	1	2100	8	6	Uniform
	2	2150	8	6	Uniform
	3	2200	8	6	Few Stringers of Unrecrystallized Areas
	4	2250	8		~ 5% Stringers of Unrecrystallized Areas
	5	2275	(60% 8)		~ 40% Stringers of Unrecrystallized Areas
Z6541	1	2100	8	6	Uniform
	2	2150	8	6	Uniform
	3	2200	7.5		Few Stringers of Unrecrystallized Areas
	4	2250	(50% 7.5)		~ 50% Stringers of Unrecrystallized Areas
	5	2275	(50% 7.5)		~ 50% Stringers of Unrecrystallized Areas

Figure 1
 Transverse and longitudinal views showing macrostructure
 of Armco 22-13-5 alloy, heat number 316401
 Note large unrecrystallized grains

Neg. 15244

Figure 2
 Transverse and longitudinal views showing macrostructure
 of Armco 22-13-5 alloy, heat number 316397
 Note relatively fine and uniform grain structure

Neg. 15245

Figure 3

Transverse and longitudinal views showing macrostructure
of Armco 22-13-5 alloy, heat number 316396

Note areas of relatively large grain size

Drill holes in longitudinal plane view were for sonic inspection purposes

Neg. 15246

Figure 4
 Sketch of Armco 22-13-5 alloy test slice showing cut-up plan
 for as-received microstructure, chemistry sample, tensile specimens,
 and 4" x 4" x 3" thick sections for forgeability study
 Neg. 15247

Surface X100
ASTM Grain Size - Predominantly 9, ~ 40% unrecrystallized

Center X100
ASTM Grain Size - Predominantly 5, ~ 40% unrecrystallized

Figure 5
Wyman-Gordon Analysis Z6539, Heat 316401
Microstructures and ASTM grain size rating of
as-received Armco 22-13-5 (ESR) alloy, surface and center locations
Neg. 15248

Surface X100
ASTM Grain Size Rating (~40% 2) (~60% 6) As large as 0

Center X100
ASTM Grain Size Rating (~30% 2) (~70% 7) As large as 1

Figure 6
Wyman-Gordon Analysis Z6540, Heat 316397
Microstructures and ASTM grain size rating of as-received
Armco 22-13-5 (ESR) alloy, surface and center locations
Note micro "segregation" in center location
Neg. 15249

Surface X100
ASTM Grain Size Rating - Predominantly 9, as Large as 4

Center X100
ASTM Grain Size Rating - Predominantly 5, as Large as 3

Figure 7
Wyman-Gordon Analysis Z6541, Heat 316396
Microstructures and ASTM grain size rating of as-received
Armco 22-13-5 (ESR) alloy, surface and center locations
Neg. 15250

Figure 8
X500

Microstructure of "segregation" found in the center of
analysis Z6540 - as-received condition
is shown here at a higher magnification

Specimen was electropolished and lightly etched with
50 HCl, 30 H₂O, 20 HF, and 10 HNO₃

Neg. 15251

Figure 9
Sections from three heats of Armco 22-13-5 alloy
prepared for upsetting at 2100°F to 2275°F temperature range
Neg. 15252

Figure 10
Sections from Armco heat number 316401 upset from ~ 3" to .75"
at 2100°F, 2150°F, 2200°F, 2250°F, and 2275°F -
bottom section to top progressively.
Note tendency for minor bulge cracking on top two sections,
2250°F and 2275°F forge temperature.

Neg. 15253

Figure 11
Sections from Armco heat number 316397 upset from $\sim 3"$ to $.75"$
at 2100°F , 2150°F , 2200°F , 2250°F , and 2275°F -
bottom section to top progressively.
Note tendency for minor bulge cracking on top two sections,
 2250°F and 2275°F forge temperature.

Neg. 15254

Figure 12
Sections from Armco heat number 316396 upset from $\sim 3"$ to $.75"$
at 2100°F , 2150°F , 2200°F , 2250°F , and 2275°F ,
bottom section to top progressively.

Note tendency for minor bulge cracking on top two sections,
 2250°F and 2275°F forge temperature.

Neg. 15255

2100°F

2150°F

2200°F

2250°F

2275°F

Figure 13
 All photos X100
 Wyman-Gordon Analysis Z6539, Heat 316401
 Microstructures from sections upset ~ 3" to .75"
 at indicated temperatures

Neg. 15256

2100°F

2150°F

2200°F

2250°F

2275°F

Figure 14
All photos X100
Wyman-Gordon Analysis Z6540, Heat 316397
Microstructures from sections upset ~ 3" to .75"
at indicated temperatures

Neg. 15257

2100°F

2150°F

2200°F

2250°F

2275°F

Figure 15
All photos X100
Wyman-Gordon Analysis Z6541, Heat 316396
Microstructures from sections upset ~ 3" to .75"
at indicated temperatures

Neg. 15258

Figure 16
X500

Microstructure of "segregation" found in the upset forged at 2150°F
Compare with segregation in as-received condition (Figure 8)
Neg. 15259