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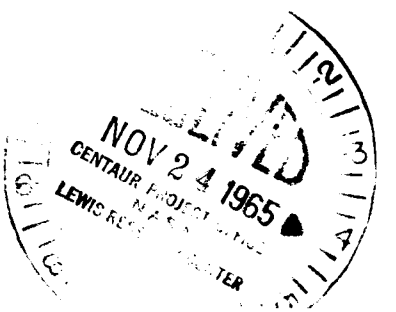

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MECHANICAL PROPERTIES OF HASTELLOY SHEET ALLOY R - 235 AT CRYOGENIC TEMPERATURES

MRG-300

March 19, 1962

Prepared by: J. Christian

Senior Engineering Mettalurgist

GENERAL DYNAMICS / CONVAIR

MRG-300

19 March 1962

SUBJECT: Mechanical Properties of Hastelloy Sheet Alloy R-235 at Cryogenic Temperatures

19454

ABSTRACT: Hastelloy alloy R-235 is a nickel base alloy developed for high temperature (to 1750°F) service. It was the purpose of this investigation to determine the applicability of this alloy for structural uses at cryogenic temperatures. Parent metal and welded tensile properties and toughness, as determined by notched (K_t = 6.3) tensile strengths and notched/unnotched tensile ratios, were evaluated at 78°, -100°, -320° and -423°F. The alloy was tested in the annealed and two aged conditions.

The data indicate that the R-235 alloy remains as tough at cryogenic temperatures (to -423°F) as it is at room temperature for the conditions tested. This alloy does have a rather low yield strength to density ratio as compared to other high strength sheet materials (e.g. 60% C.R., 301 S.S., 2014-T6 Al., Ti-5Al-2.5Sn), however may find application if service conditions range from very low (to -423°F) to quite high (1750°F) temperatures.

Prepared by Jack Christian
J. Christian
Senior Engineering Metallurgist

Approved by A Hurlich
A. Hurlich
Research Group Engineer
Materials Research Group

AH:JC:jn

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19 March 1962

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SUBJECT: Mechanical Properties of Hastelloy Sheet Alloy R-235 at Cryogenic Temperatures

INTRODUCTION:

There are several proposed vehicles, such as recoverable boosters, powered re-entry vehicles, etc., which require structural materials with high strengths and adequate toughness over the temperature range of -423°F to + 1600-1800°F. These temperatures are encountered in service due to the proposed use of liquid oxygen (b.p. of -297°F) and liquid hydrogen (b.p. of -423°F) as propellants and due to the frictional heating during atmospheric re-entry. It was the purpose of this investigation to determine if Hastelloy R-235 alloy, which has good high temperature properties (to +1750°F), may be used for structural applications at cryogenic temperatures.

R-235 is a vacuum melted nickel base alloy which contains aluminum and titanium for precipitation hardening. It is the presence of the Ni_3 (Al-Ti) precipitates which account for the alloys high temperature strength. The alloy is readily available in many forms (sheet, plate, wire, bar, tubing and forging stock) and can be easily fabricated (machined, formed, and resistance and fusion welded). R-235 possesses good high temperature oxidation resistance, resists over-aging at elevated temperatures, and may be easily heat treated.

MATERIALS:

A sheet of 0.015 inch thick R-235 alloy was supplied by Haynes - Stellite Company to perform the test work. The chemical analysis and physical properties of this material are given in Table 1. The alloy was tested in the as-received (annealed - 2150°F, A. C.) and two aged conditions.

PROCEDURE:

Blanks for tensile specimens, 9" x 1½", were identified and sheared. Panels of the alloy were inert-arc fusion welded on production equipment, identified, and sheared into tensile blanks. Some of the tensile blanks were aged in the Materials Research Group heat-treating laboratory. Two different aging treatments were employed. One group, including welded blanks, was aged at 1450°F for 24 hours and air cooled. Other specimen blanks were aged at 1600°F for 20

minutes followed by air cooling. Smooth and welded specimens were machined per MMG-D-1 and notched specimens per MRG-D-10, Notch "A". Notched specimens were inspected and measured by an optical comparator. Tests were performed at 78°F (room temperature), -100°F (by immersion in a bath of a dry ice-alcohol mixture), -320°F (immersion in liquid nitrogen) and -423°F (immersion in liquid hydrogen). Strain rates were 0.001 in/in/min. until 0.2% offset yield and 0.15"/min until failure. Total elongations on smooth and welded specimens were determined over a 2" gauge length. Strain measurements were made by use of extensometers and continuous stress-strain recorders.

RESULTS AND DISCUSSION:

The tensile, weld tensile and notched tensile properties of R-235 alloy at 78, -100, -320 and -423°F are given in Tables 2 through 4. Table 2 gives the properties of the alloy in the as-received condition. There is a continuous increase in the parent metal yield and tensile strengths, weld tensile strength, and notched tensile strength with decrease in temperature from 78°F to -423°F. The yield/density (about 200,000 in lbs/lb) and strength/density (about 400,000 in lbs/lb) ratios at 78°F are quite low as compared with other high strength sheet alloys such as 60% C.R. 301 S.S., 2014-T6 aluminum and Ti-5Al-2.5 Sn which have yield/density ratios of about 600,000 in lbs/lb. Elongations of parent metal and welded specimens were nearly the same at all testing temperatures. Weld joint efficiency decreased from 96% at 78°F to 84% at -423°F. Notched tensile strengths increased at about the same rate as smooth tensile strengths with decrease in testing temperature. Therefore, notched/unnotched tensile ratios remained about the same from 78° to -423°F. The notched/unnotched tensile strength ratios were quite low, from 0.77 to 0.85. It is not presently understood why the annealed or solution treated conditions of certain nickel and aluminum base alloys have lower notched/unnotched tensile strength ratios than do the aged conditions of the same alloys. This type of behavior has been noted before in Rene' 41 and 2024 Al. (Ref. Reports MRG-164 and -190). However, the notched test data indicate that the annealed material is as tough at cryogenic temperatures as it is at room temperature.

Table 3 gives the data obtained on the R-235 alloy in the 1450°F, 24 hr. A.C. aged condition and Table 4 give the data on the 1600°F, 20 min., A.C. aged material. These two aging treatments are recommended for this sheet R-235 alloy. The yield, tensile, weld tensile and notched tensile strengths increase with decrease in testing temperature. Joint efficiencies are nearly 100% at all testing temperatures. Notched/unnotched tensile strength ratios increase with decrease in temperature indicating that the resistance to brittle fracture at cryogenic temperatures is as great as or greater than at room temperature. The yield and tensile strength of the 1450°F aged material

are 5-10% higher than for the material aged at 1600°F.

Based on the data obtained in the present investigation it is believed that R-235 sheet alloy retains adequate toughness for structural applications at cryogenic temperatures (to -423°F) in either the annealed or aged (1450°F or 1600°F) conditions. Because of the low strength/density ratio, the R-235 alloy would probably be limited to only those applications where service conditions would range from very low (e.g. -423°F) to quite high (1750°F) temperatures.

TABLE I

Chemical Analysis and Properties of Hastelloy Alloy R-235*

0.015" Sheet: Heat RV-7478: as Received

Element	Composition %	Typical Composition** %
Cr	15.48	14 - 17
Fe	9.98	9 - 11
C	0.12	0.16 max.
Si	0.32	1.00 max.
Co	0.39	2.50 max.
Mn	0.02	1.00 max.
Mo	5.58	4.5 - 6.5
P	0.001	
S	0.006	
Al	1.80	1.75 - 2.25
Ti	2.61	2.25 - 2.75
B	0.004	
Ni	Bal.	Bal.

Properties at Room Temperature

F_{ty} (0.2% offset) - 61,425 psi
F_{tu} 113,485 psi
Elong. (over 2") - 34.0 %

*Certified Report from Haynes Stellite Company, dated 17 May 1960
**"Hastelloy Alloy R-235" Haynes Stellite Company, March 1958

TABLE 2

Mechanical Properties of Hastelloy Alloy B-235

0.015" Sheet; Heat RV-7478; as Received

Test Temp.(°F)	Direction	F_{ty}(Ksi)	F_{tu}(Ksi)	Elong.(%)	Notched (K_t=6.3) Tensile Strength(Ksi)	Notched/Unnotched Tensile Ratios	Weld* F_{tu}(Ksi)	Weld Elong.%	Joint Efficiency (%)
78	Long.	65.0	116	32.0	92.7		113	26.0	
78	Long.	65.0	113	30.0	97.1		108	23.0	
78	Long.	67.0	107	21.5	95.8		102	17.5	
	Avg.	65.7	112	27.8	95.2	0.85	108	22.2	96
78	Trans.	60.0	115	33.5	96.5				
78	Trans.	60.0	117	37.0	98.7				
	Avg.	60.0	116	35.3	97.6	0.84			
-100	Long.	73.4	126	30.0	105		115	20.0	
-100	Long.	——	129	30.5	106		114	20.0	
-100	Long.	73.1	127	32.0	106		112	19.0	
	Avg.	73.3	127	30.8	106	0.83	114	19.7	90
-100	Trans.	69.0	132	40.0	105				
-100	Trans.	68.4	133	43.0	105				
	Avg.	68.7	133	41.5	105	0.79			
-320	Long.	84.0	155	40.5	122		118	23.0	
-320	Long.	86.0	147	30.0	124		140	24.5	
-320	Long.	87.2	152	34.0	125		140	25.5	
	Avg.	85.7	151	34.8	123	0.81	133	24.3	88
-320	Trans.	74.2	156	42.5	122				
-320	Trans.	80.7	156	42.0	118				
	Avg.	77.5	156	42.3	120	0.77			
-423	Long.	94.9	174	32.0	136		141	16.5	
-423	Long.	97.5	168	32.5	138		140	15.0	
-423	Long.	92.8	170	36.0	147		149	21.5	
	Avg.	95.1	171	33.5	140	0.82	143	17.7	84
-423	Trans.	84.7	163	32.5	143				
-423	Trans.	87.4	168	36.0	132				
	Avg.	86.1	166	34.3	138	0.83			

*Inert-arc fusion welded, no post treatment.

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TABLE 3

Mechanical Properties of Hastelloy Alloy R-235

0.015" Sheet; Heat RV-7478, Aged 1450°, 24 hr., A.C.

Test Temp.(°F)	Direction	F_{ty}(Ksi)	F_{tu}(Ksi)	Elong.(%)	Notched(K_t=6.3) Tensile Strength(Ksi)	Notched/Unnotched Tensile Ratio	Weld* F_{tu}(Ksi)	Weld Elong.(%)	Joint Efficiency (%)
78	Long.	115	171	20.0	146		154	7.5	
78	Long.	119	172	16.5	148		173	19.0	
78	Long	119	171	17.5	151		165	11.5	
	Avg.	118	171	18.0	148	0.87	164	12.7	96
78	Trans.	119	163	10.5	147				
78	Trans.	118	162	10.5	147				
	Avg.	119	163	10.5	147	0.90			
-100	Long.	125	184	17.0	156		150	9.0	
-100	Long.	124	182	16.0	155		150	9.0	
-100	Long.	123	185	22.0	152				
	Avg.	124	184	18.3	154	0.84	154	8.0	84
-320	Long.	138	186	10.5	169		169	5.0	
-320	Long.	138	195	13.0	162		174	6.0	
-320	Long.	137	187	11.5	167		199	9.0	
	Avg.	138	189	11.7	166	0.88	181	6.7	96
-320	Trans.	137	171	6.5	167	0.98			
-320	Trans.	136	173	7.0	168	0.98			
	Avg.	137	172	7.0	168				
-423	Long.	147	189	9.0	183		193	9.5	
	Long.	141	190	9.5	178		189	8.0	
	Long.	143	185	8.5	189		178	5.5	
	Avg.	144	188	9.0	183	0.97	187	7.7	99
-423	Trans.	—	163	—	185				
	Trans.	149	171	4.0	189				
	Avg.	149	167	4.0	187	1.12			

*Inert-arc fusion welded, aged at 1450°F, 24 hr., A. C.

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TABLE 4

Mechanical Properties of Hastelloy Alloy B-235

0.015" Sheet; Heat RV-7478; Aged 1600°F, 20 min., A.C.

Test Temp. (°F)	Direction	Fty (Ksi)	Ftu (Ksi)	Elong. (%)	Notched (K_t=6.3) Tensile Strength (Ksi)	Notched/Unnotched Tensile Ratio	Weld* Ftu (Ksi)	Weld Elong. (%)	Joint Efficiency (%)
78	Long.	103	158	19.5	137		153	20.0	
78	Long.	104	160	19.5	137		162	19.5	
78	Long.	111	164	19.0	139		168	20.5	
	Avg.	106	161	19.3	138	0.86	161	20.0	100
78	Trans.	109	156	13.5	140				
78	Trans.	107	155	13.0	142				
	Avg.	108	156	13.3	141	0.90			
-100	Long.	115	172	18.0	137		171	15.0	
-100	Long.	116	175	19.0	149		178	20.5	
-100	Long.	115	180	18.0	146		182	19.0	
	Avg.	115	176	18.3	144	0.82	177	18.2	100
-320	Long.	126	171	9.5	159				
-320	Long.	128	172	9.5	160				
-320	Long.	130	182	10.5	158				
	Avg.	128	175	9.8	159	0.91			
-320	Trans.	131	183	10.5	162		183	12.5	
-320	Trans.	130	183	12.5	165		177	12.0	
	Avg.	131	183	11.5	164	0.90	189	15.0	
							183	13.2	100
-423	Long.	138	184	10.0	171		204	14.5	
-423	Long.	141	188	10.5	176		189	9.0	
	Long.	153	178	7.5	167		199	10.5	
	Avg.	144	183	9.3	171	0.93	197	11.3	100
-423	Trans.	146	172	4.5	174				
	Trans.	138	172	4.5	178				
	Avg.	142	172	4.5	176	1.02			

*Inert-arc fusion welded, aged 1600°F, 20 min., A.C.

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