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A New High Performance, Cost Effective, Carburizing Grade Alloy Steel

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A NEW CARBURIZING GRADE ALLOY STEEL has been developed. This alloy utilizes nickel, chromium, and vanadium to provide a steel with high levels of hardenability, toughness, and fatigue resistance. Its nominal composition is:

C	Mn	Si	Ni	Cr	V
0.19	0.55	0.20	1.80	0.60	0.12

This paper describes the properties of this Ni-Cr-V alloy determined in laboratory tests and commercial application evaluations and compares these properties to those of other standard high performance carburizing grades.

LABORATORY EXPERIMENTS

COMPOSITIONS - Several standard carburizing grade alloys were tested for comparison with the Ni-Cr-V material. The compositions of these materials are listed in Table I. The nickel content of the alloys ranged from 0.18% (i.e., residual level) to 3.65%.

PROCESSING - One group of alloys was melted as 70 pound air-induction-melted heats. These heats were forged at 2150°F to 1-1/4-inch square bars. Hardenability specimens were sectioned from these bars. Three-inch lengths from these bars were subsequently upset forged at 2000°F to 1/2-inch thick sections to simulate a commercial forging operation. Blanks for impact specimens were sectioned from these upset sections.

A second group of alloys was melted as 250 pound air-induction-melted heats. These heats were forged to 1-3/4-inch diameter round bars. Hardenability and impact specimens were sectioned from these bars. Component tests were also conducted with this group of heats; these tests are described later.

HARDENABILITY - The Jominy hardenability data for these laboratory heats are illustrated in Figures 1 and 2. The Jominy bars were normalized at 1700°F and end quenched from 1700°F

ABSTRACT

A 1.8 Ni-0.60 Cr-0.12 V alloy steel has been developed for use in carburizing applications. Hardenability, strength, toughness, and fatigue tests have been conducted on this material. Comparisons were made with the properties of several standard nickel alloy steels including 4620, 4320, 3310, and 4815 which show that the Ni-Cr-V alloy performs at least as well as the 1.8% Ni grades (4620, 4320) and approaches, and in some instances equals or exceeds, the 3.5% Ni grades (3310, 4815). The Ni-Cr-V alloy can provide a cost effective substitute for these more costly high nickel grades.

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Table I - Compositions of Laboratory Heats

Grade	Heat Size (lbs)	C	Mn	Si	P	S	Ni	Cr	Mo	V	Pb
6118	70	0.19	0.63	0.29	0.015	0.020	0.18	0.62	0.06	0.12	-
4718	70	0.18	0.84	0.30	0.015	0.019	1.05	0.49	0.34	-	-
4620	70	0.20	0.58	0.25	0.011	0.019	1.85	0.15	0.25	-	-
4620	250	0.18	0.58	0.29	0.014	0.019	1.85	0.20	0.23	-	-
4320	250	0.20	0.59	0.30	0.008	0.019	1.80	0.50	0.23	-	-
Ni-Cr-V	70	0.18	0.55	0.22	0.010	0.016	1.85	0.56	0.03	0.12	-
Ni-Cr-V	250	0.20	0.64	0.28	0.010	0.017	1.80	0.66	0.07	0.13	-
4815	250	0.16	0.54	0.28	0.008	0.015	3.50	0.19	0.22	-	-
3310	70	0.12	0.48	0.24	0.015	0.020	3.35	1.45	0.04	-	-
33L10	70	0.10	0.50	0.20	0.015	0.021	3.30	1.45	0.04	-	0.15
33L10	250	0.12	0.57	0.30	0.008	0.017	3.65	1.65	0.07	-	0.22

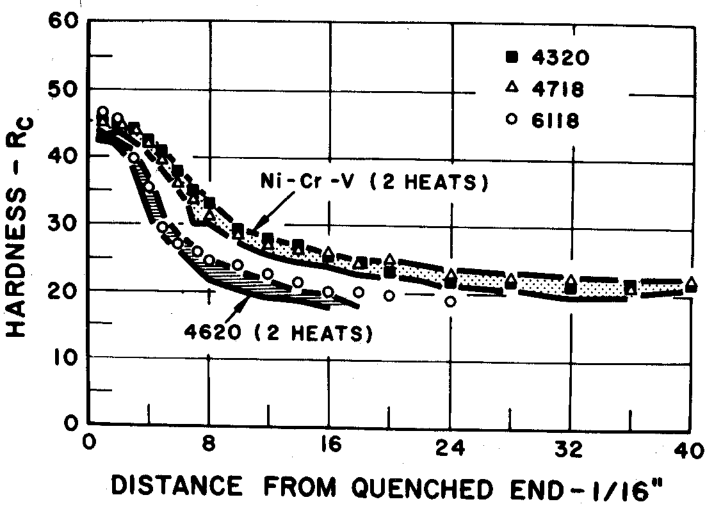

Fig. 1 - Jominy hardenability of 6118, 4620, 4718, 4320, and Ni-Cr-V laboratory heats

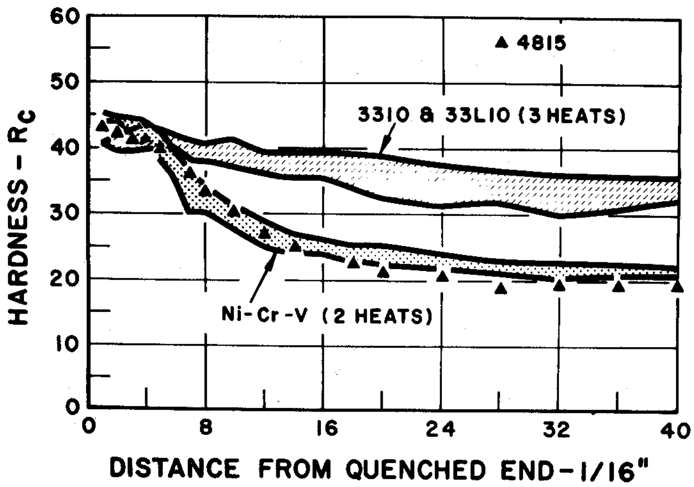

Fig. 2 - Jominy hardenability of 4815, 3310, 33L10, and Ni-Cr-V laboratory heats

with the exception of the higher nickel alloys (4815, 3310, 33L10) which were end quenched from 1550°F. The hardenability of the Ni-Cr-V heats is observed to be greater than that of the 6118 and 4620 heats tested, very similar to that of the 4718, 4320, and 4815 materials, and less than that of the 3310 and 33L10 alloys.

CARBURIZED IMPACT TOUGHNESS - To evaluate the toughness of these materials in the carburized condition, unnotched Charpy impact specimens were employed; these samples were ground to finish size, carburized, and tested in the unnotched condition. Carburizing was done in a batch-type furnace using endothermic gas, dew point controlled with 1/2 to 2% methane being added at appropriate times during the carburizing cycle. The specimens were quenched into 140°F agitated oil. Three carburizing cycles were used as described in Table II. Effective case depths (to R_c 50) of approximately 0.055 inch were obtained with these treatments.

The results of the impact tests conducted at +70°F are illustrated in Figure 3. In general, greater toughness values were obtained with the lower (0.85%) carbon potential cycles B and C than with the 0.95% carbon potential cycle A. Little difference was noted between the direct quench (B) and reheat (C) cycles for all of the steels except the highest nickel grades (4815, 3310, 33L10) where the reheat cycle generally resulted in somewhat higher toughness values than did the direct quench cycle.

Surface hardness readings taken on the carburized impact specimens are listed in

Table III. Values ranged from 56-63 R_c with the > 3.0% Ni steels (4815, 3310, 33L10), generally exhibiting the lower hardnesses (56-60 R_c).

Toughness tests were also conducted at -40°F. Figure 4 illustrates the effect of test temperature on the toughness of the samples carburized with the reheat cycle C. The lower Ni steels 6118 and 4718 exhibit the lowest toughness values and little dependence on temperature over the range tested. The higher Ni steels 4620, 4320, Ni-Cr-V, and 3310 exhibit higher, virtually identical toughness values; some dependence on test temperature is noted. The 4815 material exhibited the highest levels of toughness at both test temperatures; this material also exhibited the lowest surface hardness (58 R_c) for cycle C as indicated in Table III.

Figures 3 and 4 indicate a trend of increasing toughness with increasing nickel content, particularly when nickel is increased from the 0.18% (6118)-1.05% (4718) range to the ≥ 1.80% range. Figures 5 and 6 illustrate this trend more directly. The 1.8% Ni steels (4620, 4320, and Ni-Cr-V) exhibit toughness levels higher than the lower Ni grades 6118 (0.18%) and 4718 (1.05%). The levels of toughness in the 1.8% Ni steels (4620, 4320, Ni-Cr-V) are similar to one another and are also very comparable to the 3.5% Ni grade 3310 (and 33L10). The 4815 (3.5% Ni) material exhibits the greatest toughness. Referring to Figure 3, the superiority of 4815 is evident in the 0.85% carbon potential cycles, particularly the reheat cycle C; with the 0.95% carbon potential cycle (A), however, its toughness is quite similar to the 1.8% Ni steels and to 3310. With the lower carbon potential, it is also noted that surface hardness was low (57-58 R_c) which may contribute to the greater toughness values observed.

CORE IMPACT TOUGHNESS - Conventional Charpy V-notch samples were obtained from the second group of alloys and given a pseudo-carburizing treatment duplicating the thermal history of carburizing cycle B. The results of tests conducted at +70 and -40°F are illustrated in Figure 7. The toughness values for the materials tested (4620, 4320, Ni-Cr-V, 4815, and 33L10) did not exhibit significant differences and were very similar to one another.

COMPONENT TESTS

A heavy-duty gear component was forged from the 1-3/4-inch diameter bars of the second group of alloys (4620, 4815, 33L10, and Ni-Cr-V). These components were carburized using a reheat cycle similar to cycle C used in the laboratory experiments. The components were subjected to fatigue and impact tests designed to simulate in-service loading.

Table II - Carburizing Cycles

Cycle A	—	1650°F (8 Hours) → Oil Quench → Temper, 325°F (1 Hour) ∿ 0.95% Carbon Potential
Cycle B	—	1700°F (7 Hours) → Oil Quench → Temper, 325°F (1 Hour) ∿ 0.85% Carbon Potential
Cycle C	—	Same as Cycle B Plus a Reheat Hardening Cycle

Grade	Reheat Temperature, °F (1 Hour)
6118	1575
4718, 4320, 4815	1550
4620, Ni-Cr-V	1525
3310, 33L10	1500

Oil Quench and Temper, 325°F (1 Hour)

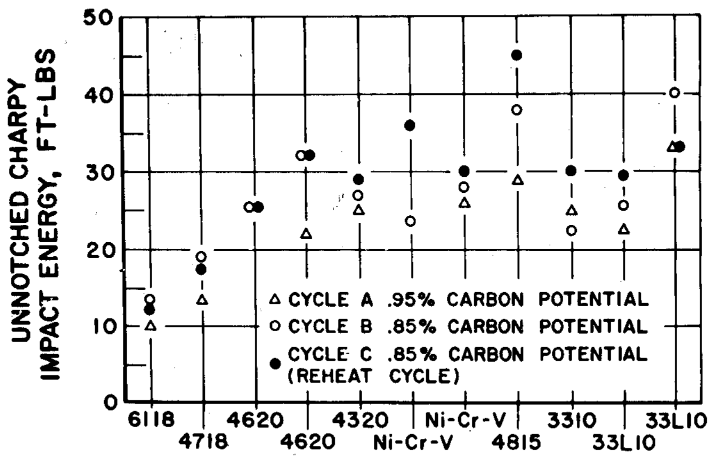

Fig. 3 - Toughness of carburized unnotched Charpy samples (+70°F) for various carburizing cycles

The results of the fatigue tests are illustrated in Figure 8. The data show the Ni-Cr-V and 4815 materials to be similar and to exhibit better fatigue resistance than the 4620 and 33L10 materials.

Impact tests were also conducted on these components; the number of impact blows to failure (at a constant energy level) was measured. These data are illustrated in Figure 9. In this test, which can also be considered a low cycle impact fatigue test, the Ni-Cr-V material exhibited the best behavior with the 4620 being next followed by the 4815 and 33L10 materials.

COMMERCIAL EXPERIENCE

Based on the laboratory results and the gear component test results, the Ni-Cr-V alloy was chosen by the component manufacturer for use in a gear which had previously been produced using 4620 and 33L10. Fifteen commercial heats totaling 2700 tons have been successfully used in that application.

HARDENABILITY - The range of Jominy hardness values obtained for the 15 commercial heats of the Ni-Cr-V alloy is compared to the H-bands for 4620, 4815, and 3310 in Figures

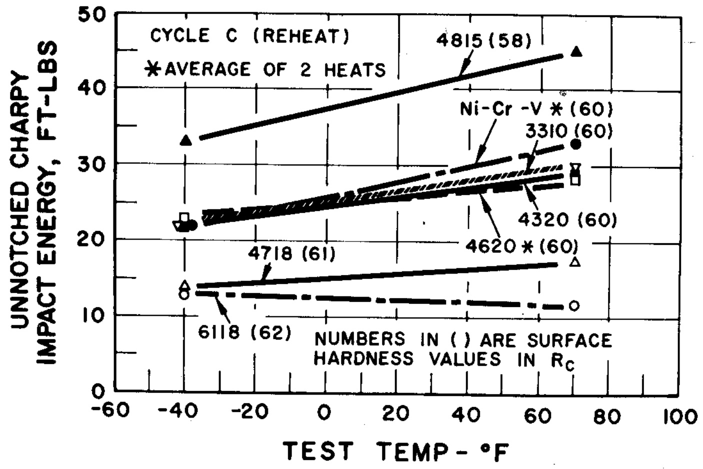

Fig. 4 - Toughness of carburized unnotched Charpy samples at +70 and -40°F

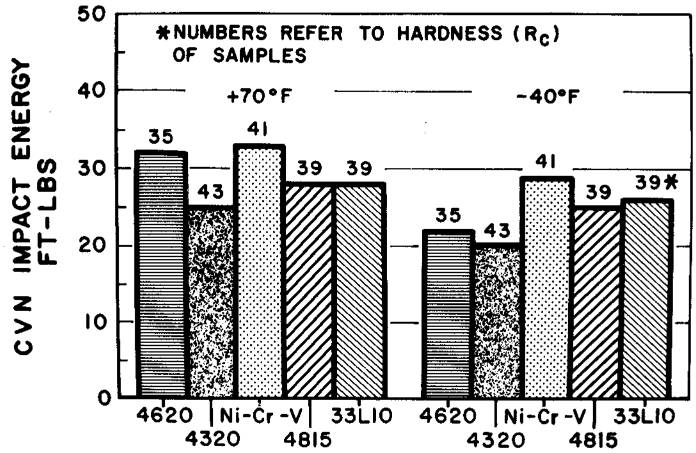

Fig. 7 - Core toughness

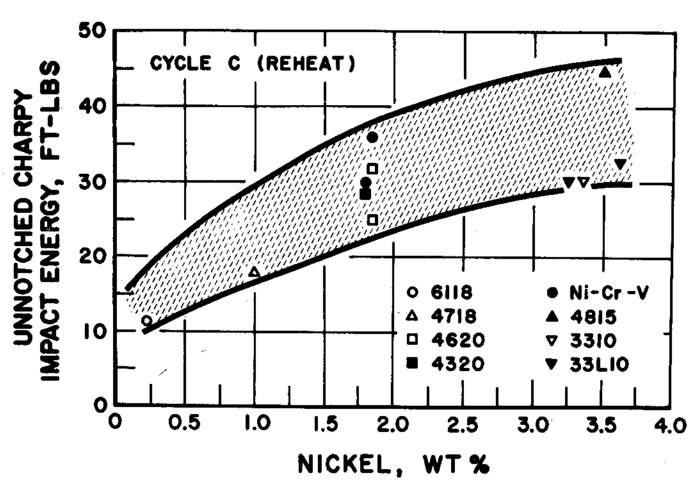

Fig. 5 - Effect of nickel content on carburized impact toughness at +70°F

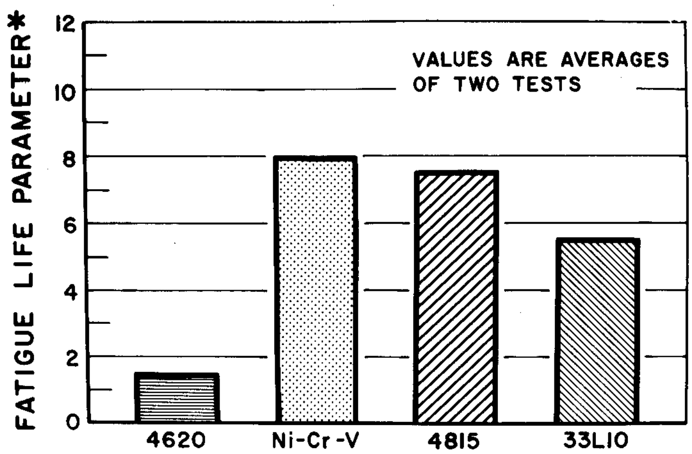

Fig. 8 - Component fatigue test results

* The "Fatigue Life Parameter" is directly related to the number of fatigue cycles sustained by the sample

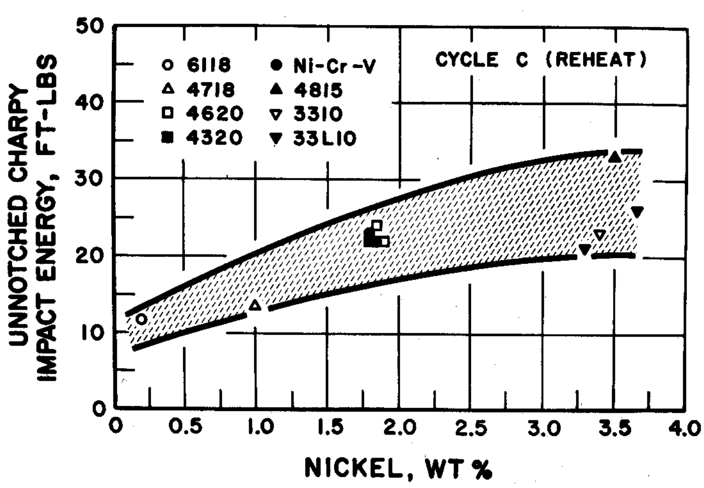

Fig. 6 - Effect of nickel content on carburized impact toughness at -40°F

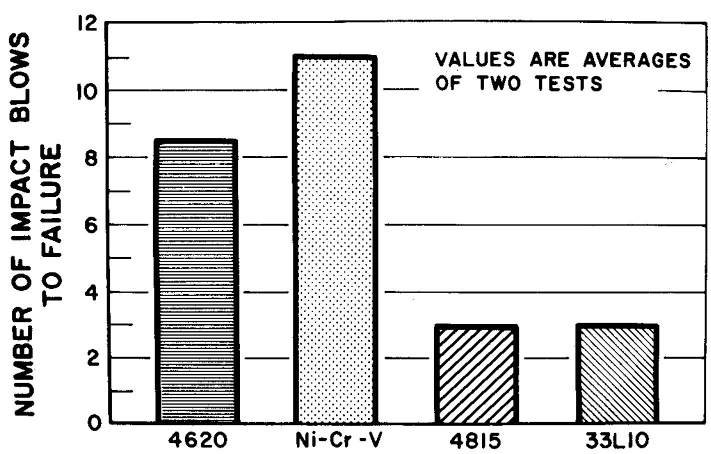

Fig. 9 - Component impact test results

10, 11, and 12, respectively. The commercial Ni-Cr-V alloys exhibit hardenability which is generally equal to or greater than 4620, equal to 4815, and equal to or less than 3310. The chemistry ranges for these 15 heats are listed in Table IV.

PSEUDOCARBURIZED PROPERTIES - Core properties were developed on commercially melted materials (4620, Ni-Cr-V, 33L10). Compositions of these three materials are listed in Table V. Table VI lists the results of tensile and impact tests conducted on pseudocarburized samples. The Ni-Cr-V alloy exhibits strengths similar to 4620 and 33L10, ductility equal to 33L10 and superior to 4620, and toughness levels greater than those of both the 4620 and 33L10 materials tested.

CARBURIZED IMPACT AND FATIGUE - Carburized unnotched Charpy impact specimens were also tested for these three commercial heats; results are listed in Table VII. Depending on carburizing cycle and test temperature, the Ni-Cr-V material exhibited toughness levels greater and less than those of the 4620 material and similar to or less than those of the 33L10 material. R. R. Moore rotating beam fatigue tests were conducted on carburized specimens of 4620 and Ni-Cr-V; the fatigue endurance limits determined from these tests

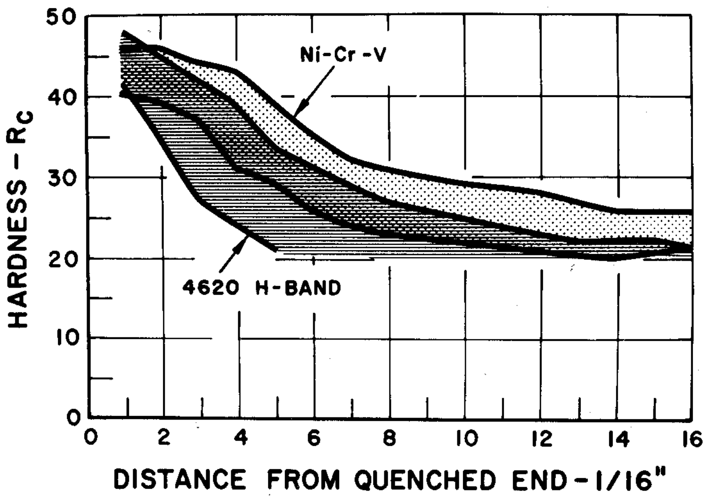

Fig. 10 - Hardenability range for 15 commercial heats of Ni-Cr-V compared to the 4620 H-band

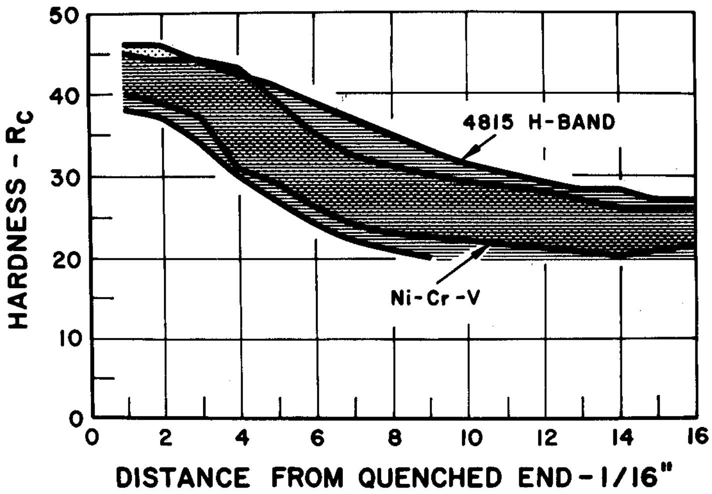

Fig. 11 - Hardenability range for 15 commercial heats of Ni-Cr-V compared to the 4815 H-band

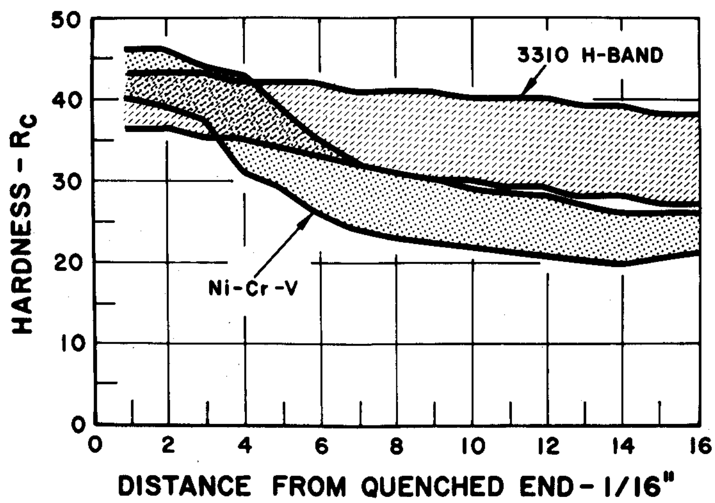

Fig. 12 - Hardenability range for 15 commercial heats of Ni-Cr-V compared to the 3310 H-band

Table III - Surface Hardness of Carburized Impact Specimens

	Surface Hardness (R_C)		
Grade	Cycle A, 0.95% C	Cycle B, 0.85% C	Cycle C, 0.85% C (Reheat)
6118	63	61	62
4718	62	61	61
4620	61	59	60
4320	61	59	60
Ni-Cr-V	61	60	60
4815	60	57	58
3310	56	59	60
33L10	57	58	59

Table IV - Chemistry Ranges for Commercial Ni-Cr-V Heats

	C	Mn	Si	P	S	Ni	Cr	Mo	Cu	V
*	0.16 / 0.21	0.54 / 0.69	0.17 / 0.29	0.004 / 0.008	0.016 / 0.025	1.63 / 1.77	0.58 / 0.71	0.03 / 0.06	0.09 / 0.20	0.11 / 0.13
**	0.16 / 0.21	0.40 / 0.70	0.15 / 0.30	0.035 max	0.040 max	1.65 / 2.00	0.45 / 0.75	-	-	0.10 / 0.15

* Actual Ranges for 15 Heats

** Melt Ranges

Table V - Compositions of Commercial Heats

Grade	C	Mn	Si	P	S	Ni	Cr	Mo	Cu	V	Pb
4620	0.18	0.55	0.24	< 0.008	0.024	1.75	0.14	0.24	0.14	< 0.01	-
Ni-Cr-V	0.17	0.63	0.27	< 0.008	0.023	1.65	0.63	0.04	0.20	0.11	-
33L10	0.13	0.52	0.25	< 0.008	0.017	3.13	1.23	0.07	0.29	< 0.01	0.20

Table VI - Pseudocarburized Properties of Commercial Heats

Grade	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction in Area	CVN Impact Energy (ft-lbs) +70°F	CVN Impact Energy (ft-lbs) -40°F
4620	150.3	211.4	12.5	38.9	36	17
Ni-Cr-V	147.3	200.5	15.0	56.6	47	36
33L10	142.9	187.3	15.0	55.5	32	30

Pseudocarburized Using Thermal History of Cycle B

Table VII - Carburized Impact Properties of Commercial Heats

	Unnotched Charpy Impact Energy (ft-lbs)					
	Cycle A		Cycle B		Cycle C	
Grade	+70°F	-40°F	+70°F	-40°F	+70°F	-40°F
4620	19	19	28	19	23	20
Ni-Cr-V	26	13	22	11	30	20
33L10	28	22	38	31	33	24

Table VIII - Carburized Fatigue Properties of Commercial Heats

	Endurance Limit (ksi)	
Grade	Cycle A	Cycle B
4620	140	150
Ni-Cr-V	145	157.5

are listed in Table VIII. The two materials exhibited similar values for both of the carburizing cycles employed.

POTENTIAL APPLICATIONS

The Ni-Cr-V alloy has demonstrated its ability to perform at a level comparable to other high nickel carburizing grade alloys. The Ni-Cr-V alloy can therefore be considered as a cost effective equivalent material for applications in which 4620 and 4320 are used or contemplated. Even greater cost savings may be realized if the Ni-Cr-V material can be substituted in applications where the higher nickel 4815 or 3310 grades are used or contemplated.

SUMMARY

A carburizing grade alloy steel with the following nominal composition has been developed:

C	Mn	Si	Ni	Cr	V
0.19	0.55	0.20	1.80	0.60	0.12

Laboratory experiments have demonstrated that this alloy has hardenability and toughness levels at least comparable to the 1.80% nickel steels 4620 and 4320. In addition, its properties approach those of the 3.5% nickel steels 3310 and 4815. Fatigue and impact tests on a forged and carburized component indicated that the Ni-Cr-V alloy could substitute for 4620, 33L10, and possibly 4815 in that application. Because of the performance exhibited by the Ni-Cr-V alloy in these component tests, this material has replaced 4620 and 33L10 in this application; 15 commercial heats have been successfully produced and used.

In addition to providing a high level of performance typical of higher nickel steels, the Ni-Cr-V alloy offers a potential cost effective substitute for these standard higher nickel alloy steels.