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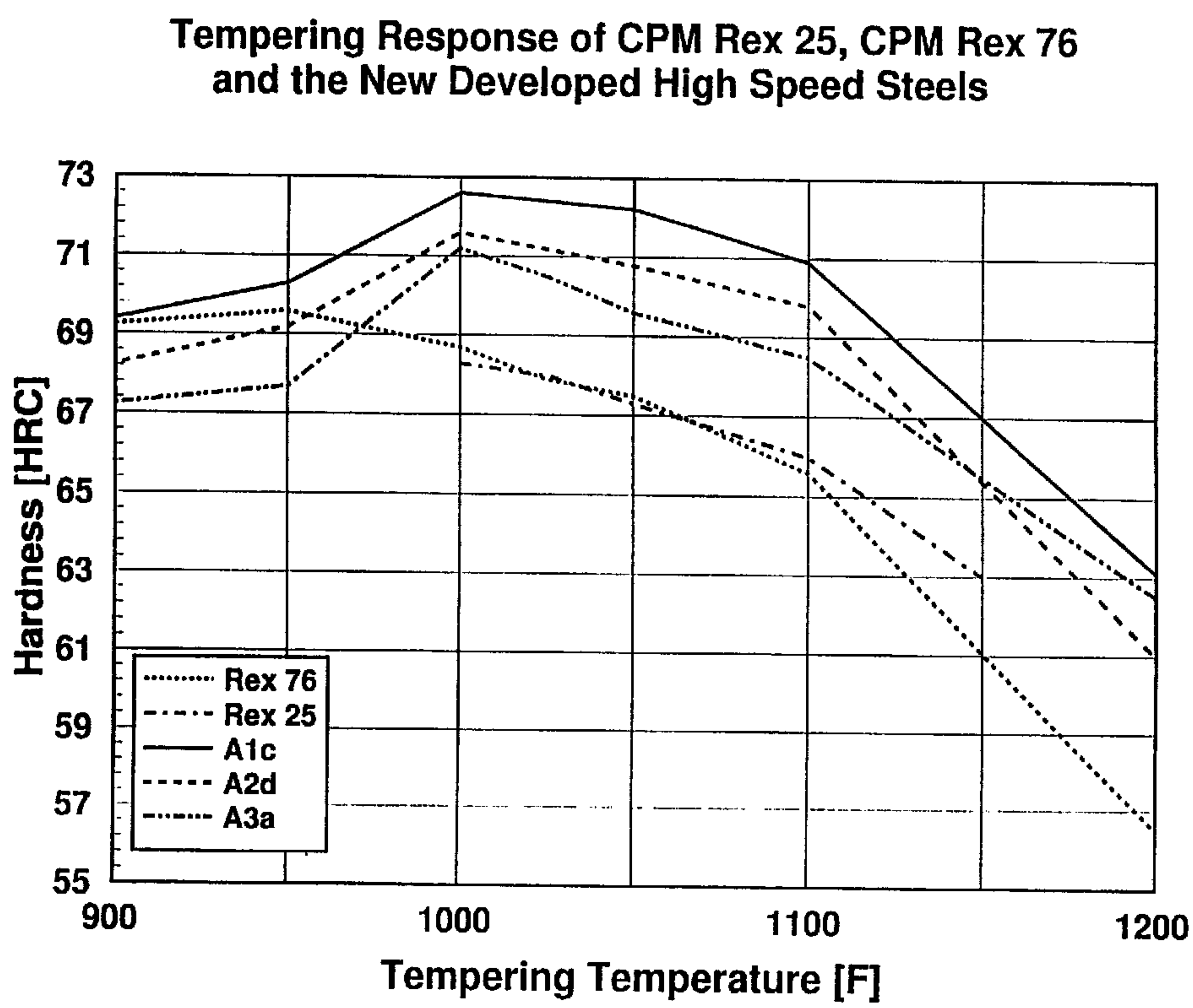
(72) Inventeurs/Inventors:
WOJCIESZYNSKI, ANDRZEJ L., US;
STASKO, WILLIAM, US

(73) Propriétaire/Owner:
CRUCIBLE MATERIALS CORPORATION, US

(74) Agent: RICHES, MCKENZIE & HERBERT LLP

(54) Titre : OBJET EN ACIER RAPIDE TRES HAUTE DURETE PRODUIT A PARTIR DE LA METALLURGIE DES POUDRES
(54) Title: HIGH HARDNESS POWDER METALLURGY HIGH-SPEED STEEL ARTICLE



Comparison of the tempering response of CPM Rex 25, CPM Rex 76 and new high speed steels.

(57) Abrégé/Abstract:
A powder-metallurgy produced high-speed steel article having a combination of high hardness and wear resistance, particularly at elevated temperatures. This combination of properties is achieved by the combination of W, Mo, V, and Co. The article is particularly suitable for use in the manufacture of gear cutting tools, such as hobs, and surface coatings.

ABSTRACT OF THE DISCLOSURE

A powder-metallurgy produced high-speed steel article having a combination of high hardness and wear resistance, particularly at elevated temperatures. This combination of properties is achieved by the combination of W, Mo, V, and Co. The article is particularly suitable for use in the manufacture of gear cutting tools, such as hobs, and surface coatings.

HIGH HARDNESS POWDER METALLURGY HIGH-SPEED STEEL ARTICLE

BACKGROUND OF THE INVENTION

The invention relates to a powder-metallurgy produced high-speed steel article characterized by high hardness and wear resistance, particularly at elevated temperatures, suitable for use in the manufacture of gear cutting tools, such as hobs and other tooling applications requiring very high wear resistance.

In tooling applications requiring high hardness and wear resistance where the tool during use is subjected to elevated temperatures exceeding about 1000°F and up to for example 1200°F, it is typical to employ carbide material for the manufacture of these tools. Carbide material, however, has the significant disadvantage of being difficult to machine to the desired tooling configurations, particularly intricate cutting surfaces, and is characterized by relatively poor toughness, which renders the tool made therefrom susceptible to cracking and chipping during use. In these applications, it is desirable to employ high speed steels, rather than carbide materials, because high speed steels are easier to machine to the desired tooling configuration and exhibit much higher toughness than carbide materials. High speed steels have not been used in these applications, however, because they do not exhibit the necessary hardness, and thus wear resistance, at the elevated temperatures in which conventional carbide tools are employed.

It is accordingly an object of the present invention to provide a powder metallurgy produced high-speed steel article useful for the production of gear cutting tools, such as hobs and other tooling applications requiring high wear resistance. The material shall be capable of attaining and maintaining high hardness at the elevated temperatures anticipated in carbide cutting tool applications and yet have the benefit of high-speed steels from the standpoint of toughness and machinability.

SUMMARY OF THE INVENTION

The invention relates generally to a powder metallurgy produced high-speed steel article of compacted high-speed steel powder particles. The steel consists essentially of, in weight percent, 2.4 to 3.9 carbon, up to 0.8 manganese, up to 0.8 silicon, 3.75 to 4.75 chromium, 9.0 to 11.5 tungsten, 4.75 to 10.75 molybdenum, 4.0 to 10.0 vanadium, and 8.5 to 16.0 cobalt, with 2.0 to 4.0 niobium being selectively present, and the balance iron and incidental impurities.

The following are preferred and more preferred high-speed steel compositions, in weight percent, in accordance with the invention:

Composition	Alloy No. 1		Alloy No. 2		Alloy No. 3	
	Preferred	More Preferred	Preferred	More Preferred	Preferred	More Preferred
C	2.60-3.50	3.00-3.30	2.40-3.20	2.90-3.10	2.90-3.90	3.20-3.60
Mn	Max. 0.8	Max. 0.5	Max. 0.8	Max. 0.5	Max. 0.8	Max. 0.5
Si	Max. 0.8	Max. 0.5	Max. 0.8	Max. 0.5	Max. 0.8	Max. 0.5
Cr	3.75-4.75	4.2-4.6	3.75-4.50	3.90-4.20	3.75-4.50	3.90-4.20
W	9.0-11.5	10.5-11	9.75-10.75	10-10.5	9.50-11.00	10.00-10.50
Mo	9.50-10.75	10.00-10.50	6.75-8.25	7.25-7.75	4.75-6.00	5.00-5.50
V	4.0-6.0	5-5.5	5.0-7.0	6-6.5	8.50-10.00	9.00-9.50
Nb	2.0-4.0	2.8-3.2	-	-	-	-
Co	14.00-16.00	14.50-15.00	13.00-15.00	14-14.5	8.50-10.00	9.00-9.50

The article in accordance with the invention may have a minimum hardness of 70 R_c in the as-quenched and tempered condition and preferably a minimum hardness of 61 R_c after tempering at 1200°F. Preferably, the minimum hardness in the as-quenched and tempered condition may be 72 R_c. Preferably, the hardness after tempering at 1200°F may be 63 R_c.

The article in accordance with the invention may be in the form a gear cutting tool, such as a hob, or a surface coating on a substrate.

In a further aspect, the present invention provides a powder metallurgy produced high-speed steel article of compacted high speed steel prealloyed powder particles having an improved combination of wear resistance and toughness, consisting essentially of, in weight percent, 2.4 to 3.9 carbon, up to 0.8 manganese, up to 0.8 silicon, 3.75 to 4.75 chromium, 9.0 to 11.5 tungsten, 4.75 to 10.75 molybdenum, 4.0 to 10.0 vanadium, and 8.5 to 16.0 cobalt, and balance iron and incidental impurities.

In a still further aspect, the present invention provides a powder metallurgy produced high-speed steel article of compacted high speed steel prealloyed powder particles having an improved combination of wear resistance and toughness, consisting essentially of, in weight percent, 2.4 to 3.9 carbon, up to 0.8 manganese, up to 0.8 silicon, 3.75 to 4.75 chromium, 9.0 to 11.5 tungsten, 4.75 to 10.75 molybdenum, 4.0 to 10.0 vanadium, 2.0 to 4.0 niobium and 8.5 to 16.0 cobalt, and balance iron and incidental impurities.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a graph showing the tempering response of alloys in accordance with the invention compared to conventional powder-metallurgy produced alloys; and

Figure 2 is a graph showing the hot hardness of alloys in accordance with the invention compared to conventional powder-metallurgy product alloys.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

By way of demonstration of the invention, powder metallurgy produced articles for testing were produced with the allow compositions, in eight percent, set forth in Table 1.

Alloy	C	Mn	Si	Cr	W	Mo	V	Nb	Co	Ti	Al	P	S	O	N
Rex 76	1.52	0.32	0.32	3.79	9.72	5.31	3.14	-	8.22	-	-	0.015	0.059	0.009	0.031
Rex 25	1.78	0.33	0.43	3.94	12.6	6.52	5.1	0.02	0.34	0.004	-	0.017	0.062	-	0.046
M25a	1.93	0.33	0.43	3.94	12.6	6.52	5.1	0.02	0.34	0.004	-	0.017	0.062	-	0.046
M25b	2.03	0.33	0.43	3.94	12.6	6.52	5.1	0.02	0.34	0.004	-	0.017	0.062	-	0.046
M2511a	1.89	0.26	0.76	4.2	11.91	10.95	5.01	-	-	-	-	-	-	0.005	0.03
M2511b	2.19	0.26	0.76	4.2	11.91	10.95	5.01	-	-	-	-	-	-	0.005	0.03
M2511c	2.34	0.26	0.76	4.2	11.91	10.95	5.01	-	-	-	-	-	-	0.005	0.03
M2511d	2.44	0.26	0.76	4.2	11.91	10.95	5.01	-	-	-	-	-	-	0.005	0.03
M766a	2.23	0.47	0.38	3.88	10.01	5.1	6.07	-	9.11	-	-	0.01	0.006	0.029	0.05
M766b	2.33	0.47	0.38	3.88	10.01	5.1	6.07	-	9.11	-	-	0.01	0.006	0.029	0.05
M766c	2.53	0.47	0.38	3.88	10.01	5.1	6.07	-	9.11	-	-	0.01	0.006	0.029	0.05
M769a	2.97	0.47	0.35	3.94	10.19	5.2	9.12	-	9.17	-	-	0.01	0.005	0.011	0.039
M769b	3.12	0.47	0.35	3.94	10.19	5.2	9.12	-	9.17	-	-	0.01	0.005	0.011	0.039
E1a	2.24	0.42	0.50	3.96	12.15	6.75	5.04	2.59	5.99	-	-	0.01	0.004	0.009	0.041
E1b	2.39	0.42	0.50	3.96	12.15	6.75	5.04	2.59	5.99	-	-	0.01	0.004	0.009	0.041
E2a	1.80	0.42	0.51	4.04	6.11	9.86	3.07	1.97	11.96	-	0.52	0.01	0.006	0.009	0.021
E2b	1.95	0.42	0.51	4.04	6.11	9.86	3.07	1.97	11.96	-	0.52	0.01	0.006	0.009	0.021
E3a	2.19	0.42	0.51	3.98	4.96	10.10	4.90	2.53	7.83	-	-	0.01	0.005	0.008	0.042
E3b	2.34	0.42	0.51	3.98	4.96	10.10	4.90	2.53	7.83	-	-	0.01	0.005	0.008	0.042
E4a	2.34	0.42	0.50	4.00	5.00	10.22	4.01	2.45	7.85	0.51	0.71	0.01	0.005	0.009	0.044
E4b	2.39	0.42	0.50	4.00	5.00	10.22	4.01	2.45	7.85	0.51	0.71	0.01	0.005	0.009	0.044
E6a	3.04	0.58	0.67	4.00	10.04	6.00	9.98	-	17.81	-	-	0.01	0.011	0.01	0.035
E6b	3.54	0.58	0.67	4.00	10.04	6.00	9.98	-	17.81	-	-	0.01	0.011	0.01	0.035
E7	2.46	0.56	0.56	4.04	9.06	10.11	4.47	2.50	14.69	-	-	0.01	0.013	0.008	0.017
A1a	2.66	0.56	0.56	4.04	9.06	10.11	4.47	2.50	14.69	-	-	0.01	0.013	0.008	0.017
A1b	2.96	0.56	0.56	4.04	9.06	10.11	4.47	2.50	14.69	-	-	0.01	0.013	0.008	0.017
A1c	3.02	0.44	0.44	4.41	10.99	10.2	5.22	3.08	14.96	-	-	0.016	0.014	0.01	0.021
A1d	3.27	0.44	0.44	4.41	10.99	10.2	5.22	3.08	14.96	-	-	0.016	0.014	0.01	0.021
A2a	2.44	0.58	0.54	3.90	10.05	7.59	5.31	-	13.97	-	-	0.01	0.011	0.009	0.017
A2b	2.59	0.58	0.54	3.90	10.05	7.59	5.31	-	13.97	-	-	0.01	0.011	0.009	0.017
A2c	2.74	0.58	0.54	3.90	10.05	7.59	5.31	-	13.97	-	-	0.01	0.011	0.009	0.017
A2d	2.82	0.43	0.42	3.98	10.43	7.44	6.35	-	14.15	-	-	0.008	0.012	0.011	0.024
A2e	3.07	0.43	0.42	3.98	10.43	7.44	6.35	-	14.15	-	-	0.008	0.012	0.011	0.024
A3a	3.37	0.47	0.35	3.94	10.19	5.2	9.12	-	9.17	-	-	0.01	0.005	0.011	0.039
A3b	3.47	0.47	0.35	3.94	10.19	5.2	9.12	-	9.17	-	-	0.01	0.005	0.011	0.039
A3c	3.57	0.47	0.35	3.94	10.19	5.2	9.12	-	9.17	-	-	0.01	0.005	0.011	0.039

The articles for testing, the compositions of which are set forth in Table 1, were produced by conventional powder metallurgy practices including the production of prealloyed powder by nitrogen gas atomization followed by consolidation to full density by hot isostatic compacting.

The samples of Table 1 were austenitized, quenched in oil, and tempered four times, each time for two hours, at the temperatures shown in Table 2. They were then tested to measure hardness after tempering at these temperatures. Wear resistance was determined, as reported in Table 3, by pin abrasion testing and cross-cylinder testing. Bend fracture strength and Charpy C-notch impact toughness were determined on longitudinal and transverse specimens after heat treatment using the hardening and tempering temperatures given in Table 3.

Alloy	Tempering Response* - Hardness Rc							
	Aust. °F	950°F	1000°F	1025°F	1050°F	1100°F	1150°F	1200°F
Rex 76	2200	66.9	68.9	-	66.5	65.9	-	57.0
Rex 25	2250	67.8	67.8	-	66.1	64.4	-	55.7
M25a	2225	68.4	68.5	-	66.7	65.2	-	56.6
M25b	2225	67.4	68.4	-	67.8	65.7	-	57.2
M2511a	2250	69.1	68.8	68.1	-	-	63.2	-
M2511b	2250	66.7	69.2	69.7	-	-	66.4	-
M2511c	2225	65.7	68.6	69.2	-	-	66.6	-
M2511d	2225	64.2	67.5	68.7	-	-	65.3	-
M766a	2200	70.0	70.2	-	68.7	66.8	-	57.1
M766b	2200	69.7	70.1	-	69.2	67.5	-	58.2
M766c	2175	69.3	69.8	-	-	-	-	-
M769a	2200	70.2	69.8	-	67.9	66.4	-	56.2
M769b	2175	70.2	70.0	-	-	-	-	-
E1a	2200	69.3	68.2	-	67.2	62.2	-	52.4
E1b	2200	69.3	69.4	-	67.4	62.9	-	55.8
E2b	2200	70.4	69.8	-	68.1	63.9	-	55.6
E3a	2200	68.9	67.5	-	65.4	61.4	-	53.9
E3b	2200	69.2	68.2	-	66.4	64.9	-	53.9
E4a	2200	69.1	68.9	-	67.6	62.2	-	54.9
E4b	2200	69.0	69.9	-	67.2	63.9	-	55.0
E6a	2225	70.1	68.9	-	67.8	66.1	-	60.6
E6b	2225	71.7	70.7	-	69.5	67.1	-	59.3
E7	2225	72.2	70.3	-	70.4	67.6	-	57.5
A1a	2240	71.7	72.3	-	70.8	68.9	-	62.5
A1b	2225	68.9	71.3	-	71.1	70.0	-	63.8
A1c	2200	70.3	72.6	-	72.2	70.9	-	63.1
A1d	2200	70	72.3	-	72.6	70.9	-	63.8
A2a	2225	71.8	71.0	-	70.8	68.5	-	60.9
A2b	2200	69.5	71.4	-	71.0	68.8	-	60.3
A2c	2200	67.5	70.9	-	70.6	68.8	-	60.3
A2d	2200	69.2	71.6	-	70.8	69.9	-	62.3
A2e	2200	69.4	71.4	-	71.4	69.3	-	62.6
A3a	2240	67.7	71.2	-	69.6	68.5	-	62.5
A3b	2240	66.2	69.2	-	70.2	68.9	-	62.5
A3c	2240	68.7	70.2	-	70.0	68.1	-	62.6

* Hardness after tempering 4 x 2 hours at the given temperature.

[redacted]

Alloy	Heat Treat. Aust./Temp. (°F/°F)	C-Notch Energy (ft. lbs.)		BFS (ksi)		Pin Abrasion (mg)	Cr. Cyl. 10^{10} psi
		Long.	Trans.	Long.	Trans.		
REX 76	2175/1025	11	6.5	576	390	38.3	42
REX 25	2250/1025	9.5		531			
E6a	2250/1025	4.7	3.7	360	300		
E6b	2240/1025	2.7	2.2	253	228	9.3	104
E7	2225/1025	3.8	3.5	321	154	15	71
A1c	2200/1025	1.7	1.6	196	158.0	2.2	73
A2a	2200/1025	2.6	2.6	294	218	4.9	77
A2d	2200/1025	2.0	1.7	219	163	2.9	81
A3a	2225/1025	3.8	3.3	292	231	2.1	102

Alloys A1a through A1d, A2a through A2e, and A3a through A3c are alloy compositions in accordance with the invention. As may be seen from the tempering response data set forth in Table 2 and graphically presented in Figure 1, alloys of the series A1, A2, and A3 in accordance with the invention exhibited superior hardness at tempering temperatures up to 1200°F relative to the existing commercial alloys. Likewise, as shown in Table 3, samples A1c, A2a, A2d, and A3a in accordance with the invention also exhibited excellent wear resistance as determined by the pin abrasion and cross-cylinder test results. Of these invention alloys, alloys A1 exhibited optimum combination of the tempering response and wear resistance. Alloys A2 exhibited slightly lower hardness after tempering at 1200°F, but somewhat improved toughness and bend fracture strength than alloys A1. All of the invention alloys, however, as shown in Table 3 and Figure 1, exhibited improved combinations of tempering response, toughness and wear resistance over the existing commercial alloys.

[redacted]

Alloy	Test Temperature (°F)							
	75	950	1000	1050	1100	1150	1200	1300
REX 76	67.5	60	59.5	59	58	52.5	46.5	-
A1c	73.5	-	64.5	-	63	-	57.5	39
A2d	72	-	63	-	60	-	56	38.5
A2e	72	-	62.5	-	60	-	56	39
A3a	71.5	-	61	-	58.5	-	53	33.5

Table 4 and Figure 2 indicate the hot hardness values for alloys A1c, A2d, A2c, and A3a, in accordance with the invention, compared to the existing commercial alloy (REX 76). As may be seen from this data, all of the alloys in accordance with the invention exhibited improved hot hardness at elevated temperatures up to 1300°F, compared to the existing commercial alloy.

All compositions set forth in the specification are in weight percent, unless otherwise indicated.

WHAT IS CLAIMED IS:

1. A powder metallurgy produced high-speed steel article of compacted high speed steel prealloyed powder particles having an improved combination of wear resistance and toughness, consisting essentially of, in weight percent, 2.4 to 3.9 carbon, up to 0.8 manganese, up to 0.8 silicon, 3.75 to 4.75 chromium, 9.0 to 11.5 tungsten, 4.75 to 10.75 molybdenum, 4.0 to 10.0 vanadium, and 8.5 to 16.0 cobalt, and balance iron and incidental impurities.

2. A powder metallurgy produced high-speed steel article of compacted high speed steel prealloyed powder particles having an improved combination of wear resistance and toughness, consisting essentially of, in weight percent, 2.4 to 3.9 carbon, up to 0.8 manganese, up to 0.8 silicon, 3.75 to 4.75 chromium, 9.0 to 11.5 tungsten, 4.75 to 10.75 molybdenum, 4.0 to 10.0 vanadium, 2.0 to 4.0 niobium and 8.5 to 16.0 cobalt, and balance iron and incidental impurities.

3. The article of claim 2 having 2.6 to 3.5 carbon, 3.75 to 4.75 chromium, 9.0 to 11.5 tungsten, 9.5 to 10.75 molybdenum, 4.0 to 6.0 vanadium, 2 to 4 niobium and 14.0 to 16.0 cobalt.

4. The article of claim 3 having in weight percent 3.0 to 3.3 carbon, 0.5 maximum manganese, 0.5 maximum silicon, 4.2 to 4.6 chromium, 10.5 to 11.0 tungsten, 10.0 to 10.5 molybdenum, 5.0 to 5.5 vanadium, 2.8 to 3.2 niobium, and 14.5 to 15.0 cobalt.

5. The article of claim 1 or claim 2 having in weight percent 2.4 to 3.2 carbon, 3.75 to 4.5 chromium, 9.75 to 10.75 tungsten, 6.75 to 8.25 molybdenum, 5.0 to 7.0 vanadium, and 13.0 to 15.0 cobalt.

6. The article of claim 5, having in weight percent 2.9 to 3.10 carbon, 0.5

maximum manganese, 0.5 maximum silicon, 3.9 to 4.2 chromium, 10.0 to 10.5 tungsten, 7.25 to 7.75 molybdenum, 6.0 to 6.5 vanadium, and 14.0 to 14.5 cobalt.

7. The article of claim 1 or claim 2, having in weight percent 2.9 to 3.9 carbon, 3.75 to 4.5 chromium, 9.5 to 11.0 tungsten, 4.75 to 6.0 molybdenum, 8.5 to 10.0 vanadium, and 8.5 to 10.0 cobalt.

8. The article of claim 7, having in weight percent 3.2 to 3.6 carbon, 0.5 maximum manganese, 0.5 maximum silicon, 3.9 to 4.2 chromium, 10.0 to 10.5 tungsten, 5 to 5.5 molybdenum, 9.0 to 9.5 vanadium and 9.0 to 9.5 cobalt.

9. The article of any one of claims 1 to 8 having a minimum hardness of 70 R_c in the as-quenched and tempered condition.

10. The article of any one of claims 1 to 8 having a minimum hardness of 70 R_c in the as-quenched condition and a 61 R_c in the as-quenched and tempered condition when tempered at 1200° F.

11. The article of claim 9, wherein said minimum hardness is 72 R_c.

12. The article of claim 10, wherein said minimum hardness after tempering at 1200° F. is 63 R_c.

13. The article of claim 9 in the form of a gear cutting tool.

14. The article of claim 10 in the form of a gear cutting tool.

15. The article of claim 9 in the form of a surface coating on a substrate.

16. The article of claim 10 in the form of a surface coating on a substrate

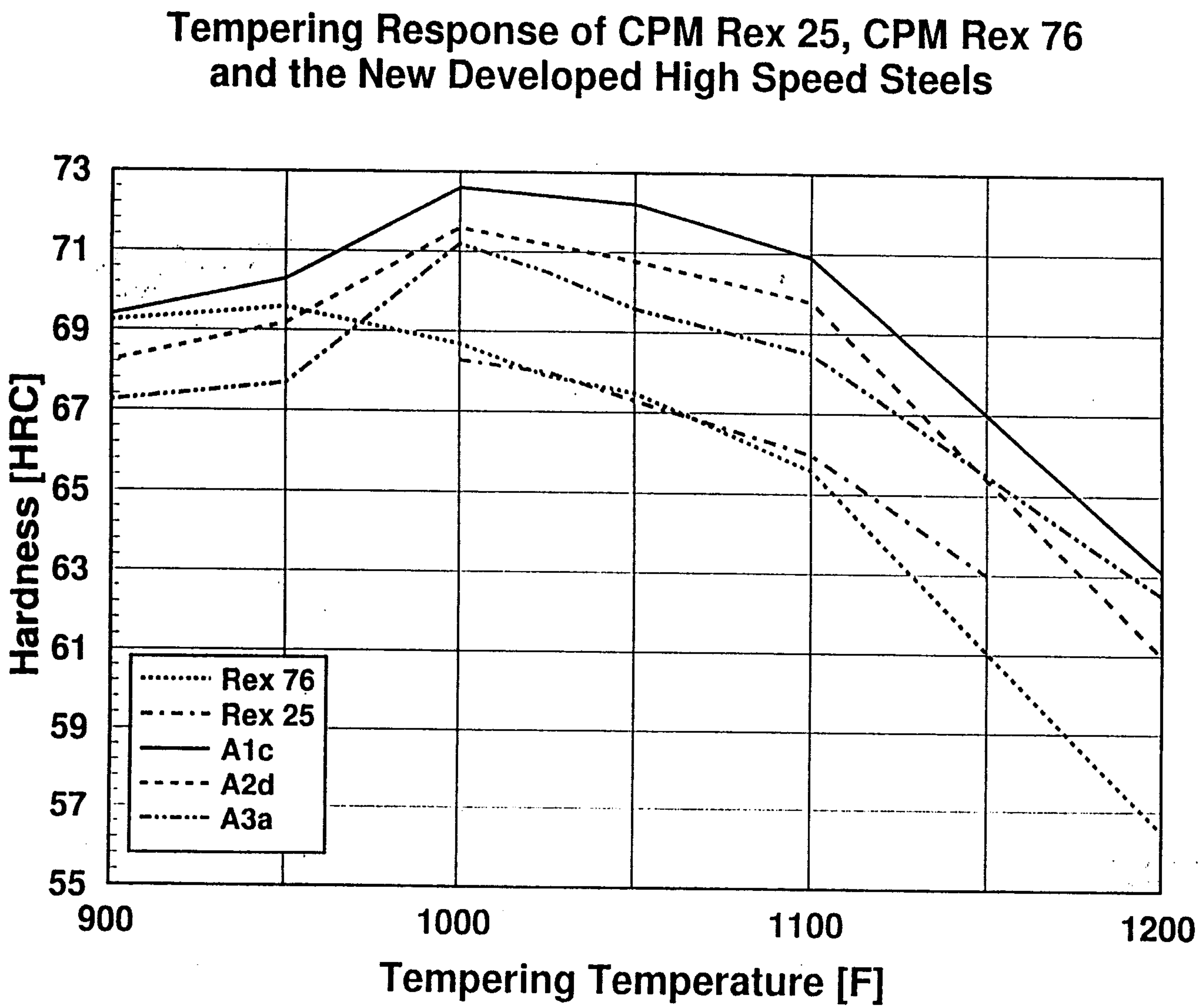


Figure 1. Comparison of the tempering response of CPM Rex 25, CPM Rex 76 and new high speed steels.

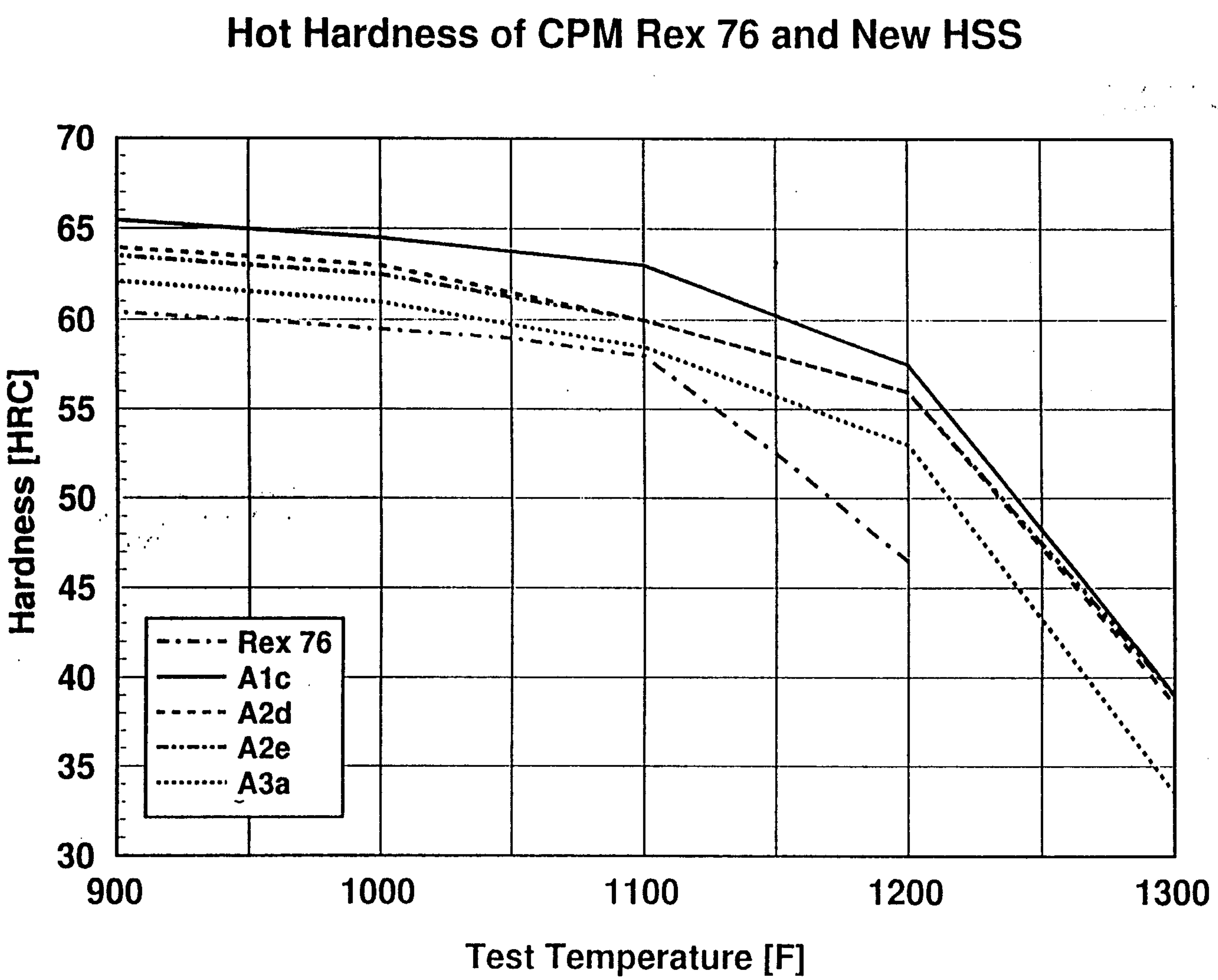
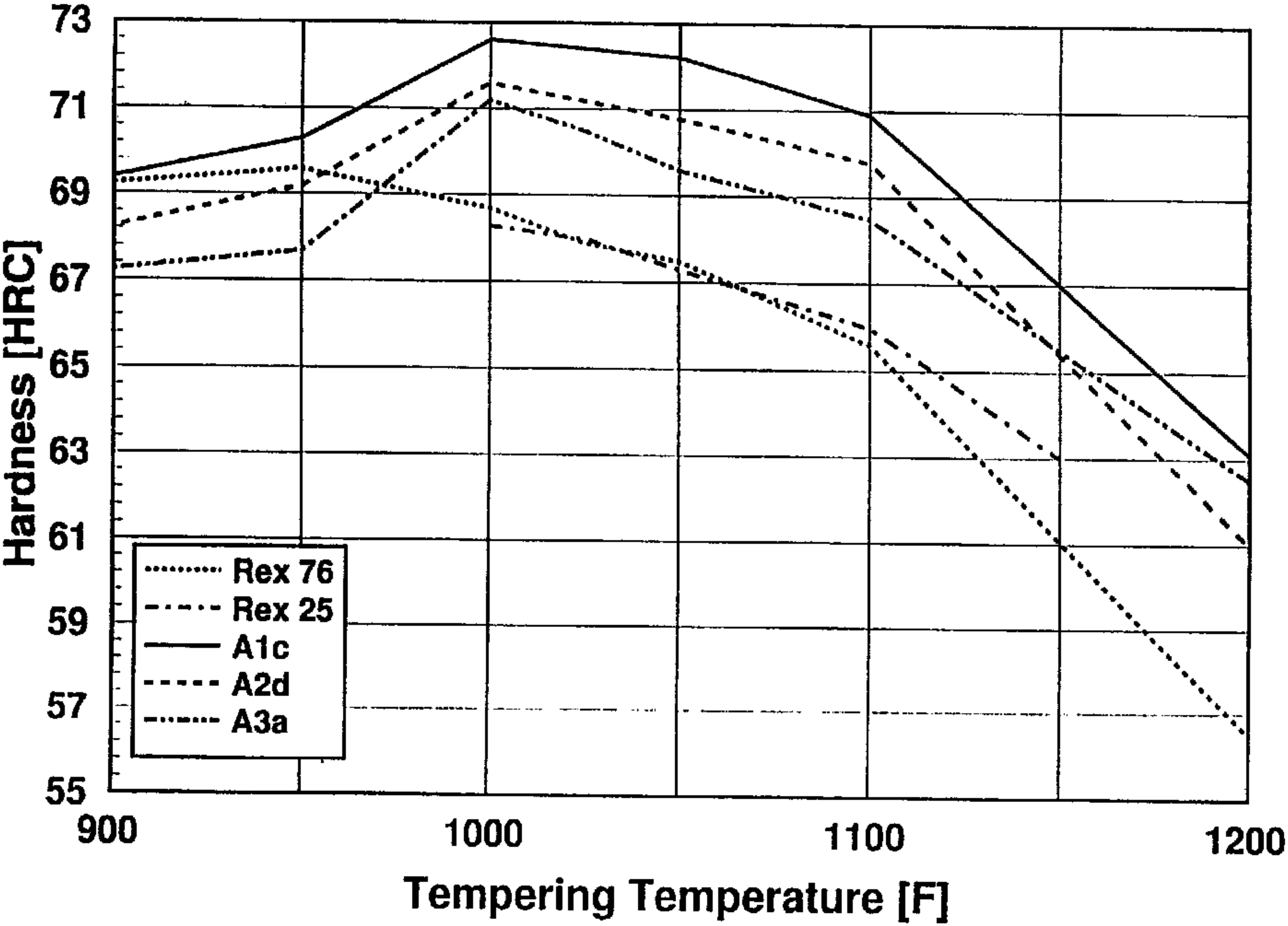


Figure 2. Comparison of hot hardness of CPM Rex 76 and several new high speed steels made to the chemistries A1, A2 and A3.

Tempering Response of CPM Rex 25, CPM Rex 76 and the New Developed High Speed Steels



Comparison of the tempering response of CPM Rex 25, CPM Rex 76 and new high speed steels.