

PERFORMANCE CHARACTERISTICS OF A NEW WATER-ATOMIZED PREALLOYED POWDER (0.5 WEIGHT % MOLYBDENUM)

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ABSTRACT

A new prealloy material containing 0.50 w/o Mo was introduced recently. This medium hardenability material can be admixed with a variety of alloying ingredients to produce superior tensile properties. Results of admixing this prealloyed powder with nickel, copper, manganese, and graphite will be presented. In addition, quench and temper properties will also be discussed.

INTRODUCTION

Molybdenum prealloys containing 0.85 w/o and 1.50 w/o Mo have been commercially available since the late 1980s, (e.g. Ancorsteel 85 HP and Ancorsteel 150 HP). In response to requests from parts makers for a prealloy with a somewhat lower molybdenum content, a new grade containing 0.50 w/o Mo was introduced last year under the trade name of Ancorsteel 50 HP. The purpose of this paper is to present the results of limited studies to characterize the behavior of this powder in both straight graphite premixes and various so-called hybrid alloy premixes containing, in particular, admixed nickel.

The idea to focus attention on the use of admixed nickel with this particular powder was based on the fact that there are two nickel containing molybdenum prealloys of nominally the same 0.50 w/o Mo content, (e.g. Ancorsteel 2000 and Ancorsteel 4600V). Although these alloys were originally developed for powder forging applications, they have nevertheless found their way into a number of P/M applications as well. However, they are somewhat limited in the latter capacity by compressibility issues that derive from the presence of the prealloyed nickel. In comparison, nickel premixes of the straight molybdenum prealloys, including particularly the present 0.50 w/o Mo grade, are not similarly limited, (1). Thus, it was thought to be of general interest to give an indication of the properties that are obtainable with such premixes. In addition to nickel per se, the studies included determinations of the effects of the nickel in combination with modest additions of admixed copper and manganese.

EXPERIMENTAL PROCEDURE

Basically, three studies with differing objectives were conducted: 1) a study to characterize the Ancorsteel 50 HP as to powder and green properties; 2) a limited study to indicate its behavior in terms of sintered transverse rupture strength, (TRS), properties in simple carbon steel compositions; and lastly, 3) a fairly extensive study to assess its potential in alloy steel compositions with admixed nickel. The procedural details were as follows.

Powder and Green Properties of the Ancorsteel 50 HP - Comprehensive determinations of the powder and green properties of the new base powder were conducted. The green density determinations included measurements at 30, 40, and 50 tsi, (i.e. 415, 550, and 690 MPa respectively), with the powder in each of three conditions of lubrication: as-is, (i.e. die wall lubricated) and containing 0.5 and 1.0 w/o of admixed zinc stearate. The green strength determinations similarly included measurements at 30, 40, and 50 tsi but were otherwise limited to the indicated iterations with zinc stearate.

Ancorsteel 50 HP in Carbon Steel Compositions - A series of premixes adding graphite in increments of 0.2 w/o up to 0.8 w/o and lubricated with 0.75 w/o Acrawax C were used to assess the green and sintered TRS properties that are obtainable with the prealloy in simple carbon steel compositions. The specimens were compacted at 40 tsi, (550 MPa), and sintered at 2050 °F, (1120 °C), for 1/2 hour at temperature in a 75 v/o H₂, 25 v/o N₂, (i.e. synthetic DA), atmosphere.

Ancorsteel 50 HP in Nickel Containing Alloy Compositions - The compositions of the nickel containing alloy premixes that were included in the study are shown below in Table 1. The table also indicates the composition of a simple graphite premix that was used to reference the alloy premixes. Notice, in particular, the disparity in the graphite content indicated in the table for Premix 4. The additional carbon units needed to make up the difference in this case were contained in the manganese addition which was added in the form of a ferro alloy.

Table 1 - Compositions Of The Alloy And Carbon Steel Reference Premixes Studied.

Premix ID	Graphite (w/o)	Copper (w/o)	Manganese (w/o)	Nickel (w/o)	Acrawax C (w/o)	Ancorsteel 50 HP
1	0.60	--	--	--	0.75	Balance
2	0.60	--	--	2.0	0.75	Balance
3	0.60	1.0	--	2.0	0.75	Balance
4	0.55	--	1.0	2.0	0.75	Balance

The studies of these premixes were generally more extensive than those done with the aforementioned carbon steel compositions. In particular, they included determinations of the sintered TRS, dog-bone tensile and un-notched Charpy impact properties for a variety of process conditions. Most of the study was done with the specimens in the 2050 °F sintered condition at each of three compaction pressures including 30, 40, and 50 tsi. limited studies were also conducted at the 40 tsi compaction pressure of Premixes 1 and 4 in the 2350 °F, (1288 °C), sintered condition and of Premixes 3 and 4 in the quenched and tempered condition following initial sintering at each of 2050 and 2350 °F. The time at temperature in all of these cases was 1/2 hour and the sintering atmosphere was synthetic DA.

Quench and Tempering Details - The hardening treatment consisted of austenitizing the specimens for 1/2 hour at 1650 °F in an endothermic atmosphere at a carbon potential of 0.6 w/o followed by quenching in oil at 140-160 °F, (60-70 °C). Studies employing hardened TRS specimens were done initially to determine the tempering response of the alloys. These consisted of heating two series of single specimens under cover of a nitrogen atmosphere and determining the effects on their strengths and apparent hardnesses. One series was to various temperatures in the range of 300 to 1000 °F, (150 to 540 °C), for 1/2 hour at temperature; and the second series was at a 1000 °F for various times up to 4 hours. Subsequently, the findings were used to select the tempering conditions for the heat treated mechanical property determinations.

Testing Details - The powder, green and sintered transverse rupture, tensile, impact, and hardness properties of the premixes were determined employing standard ASTM procedures. With the exception of the tempering studies, the reported values were in all cases based on a minimum of three measurements and, in most cases, five measurements per condition. The powder and green properties included the apparent density, (ASTM B 212), the Hall flow rate, (ASTM B 213), the green density, (ASTM B 331), and the green strength, (ASTM B 312). The transverse rupture properties including the strength, (ASTM B 528), the % dimensional change, (ASTM B 610), and the sintered density, (ASTM B 331), were determined on standard 0.25 in., (~10 mm) bars.

The sintered tensile properties were based on as-pressed dog-bone specimens and the quenched and tempered properties, on machined round specimens, (ASTM E 8). The round specimens were polished parallel to the tensile axis to a 32 microinch RMS finish using metallurgical grade emery paper. Tensile testing was performed on an Instron machine at a crosshead speed of 0.05 cm/minute. The machine is equipped with a 1 in., (25 mm), extensometer and provides automated readouts of the 0.2% offset yield strength, ultimate tensile strength and % elongation values.

Impact testing in all conditions of sintering and heat treatment was at ambient temperature, (i.e. ~70 °F or 20 °C), using standard un-notched Charpy specimens, (ASTM E 23).

Apparent hardness determinations were made in connection with each of the various tests using the Rockwell B scale, (100 kgf load, 1/16" ball indenter) for the sintered condition and the Rockwell A scale, (60 kgf load, diamond indenter) for the heat treated condition.

Materials - The zinc stearate that was used in the green property premixes was from Mallinckrodt Chemical. The Acrawax C used in the balance of the studies was from Algroup Lonza. The graphite was Asbury Grade 3203 HSC. The nickel was International Nickel Grade Inco 123. The copper was Acupowder Grade 8081. The ferromanganese was F. D. Winter grade FEMN-325XD with a chemical analysis of 76.8 w/o Mn, 6.9 w/o C, balance Fe and impurities. The screen and chemical analyses of the Ancorsteel 50 HP were as follows.

Ancorsteel 50 HP - % Screen Analysis by Weight

+60	+80	+100	+140	+200	+230	+325	Pan
nil	4.0	5.7	16.1	18.7	12.6	18.9	24.0

Ancorsteel 50 HP - % Chemical Analysis by Weight

C	S	N	O	Mn	Cr	Ni	Cu	Mo
0.007	0.008	<0.001	0.095	0.097	0.033	0.036	0.062	0.48

RESULTS AND DISCUSSION

The results of the first two of the three studies that were conducted were reasonably straight forward and will be presented with minimal discussion. The third study, dealing with the effects of admixed nickel, was more comprehensive in scope and the resulting findings were correspondingly more complex.

Powder and Green Properties of the Ancorsteel 50 HP

The apparent density and Hall flow properties of the Ancorsteel 50 HP were 3.05 g/cm³ and 23 seconds / 50 g respectively. The green density variation of the powder as a function of compacting pressure and lubrication conditions is indicated in Table 2. As is typically observed with molding grade powders, these data showed that the green density of the Ancorsteel 50 HP increased with increasing compacting pressure and, in general, at first increased and then decreased with increasing lubricant content.

Table 2 - Ancorsteel 50 HP Compressibility Behavior

Green Density (g/cm³)			
Compacting Pressure (tsi / MPa)	Die Wall Lubricant	0.5 w/o Zinc Stearate	1.0 w/o Zinc Stearate
30 / 415	6.72	6.81	6.83
40 / 550	7.06	7.11	7.08
50 / 690	7.28	7.29	7.20

The green strength variation of the Ancorsteel 50 HP as a function of compacting pressure and lubrication conditions is shown in Table 3.

Table 3 - Ancorsteel 50 HP Green Strength Properties

Green Strength (psi / MPa)		
Compacting Pressure (tsi / MPa)	0.5 w/o Zinc Stearate	1.0 w/o Zinc Stearate
30 / 415	1450 / 10.0	1240 / 8.6
40 / 550	2180 / 15.0	1910 / 13.2
50 / 690	2690 / 18.5	2250 / 15.5

Here again, a review of the data will show that the green strength increased with increasing pressure but, unlike the green density, appeared to decrease monotonically with increasing lubricant content. The average decrease indicated by the data with increasing lubricant was about 15%.

Ancorsteel 50 HP in Carbon Steel Compositions

Table 4 lists the green and sintered TRS properties of the series of premixes that was made with increasing graphite contents to assess the potential of the Ancorsteel 50 HP in simple carbon steel compositions. Recall that the specimens in this case were pressed at 40 tsi and sintered at 2050°F.

.Table 4 - Green and Sintered TRS Properties of the Carbon Steel Compositions

Admixed Graphite (w/o)	Green Expansion (%)	Green Density (g/cm³)	Sintered Density (g/cm³)	Dimensional Change (%)	TRS (10³ psi / MPa)	Apparent Hardness (HRB)
0.2	+0.17	7.04	7.03	+0.06	82 / 565	29
0.4	+0.17	7.03	7.01	+0.11	97 / 668	53
0.6	+0.18	7.02	6.98	+0.17	117 / 806	65
0.8	+0.19	7.00	6.95	+0.22	125 / 861	72

As expected, these data showed that sintered strength and apparent hardness increased with increasing graphite content. In addition, they also showed concomitant increases in the green expansion and sintered dimensional change values and corresponding decreases in the green and sintered densities. Interestingly, the greatest effect of the graphite on density was on the sintered values which decreased at about twice the rate indicated by the green values.

Ancorsteel 50 HP in Nickel Containing Alloy Compositions

TRS and Impact Properties - The TRS and impact properties of the subject compositions are presented in Table 5. Notice that the table in this case lists data at two sintering temperatures for Premixes 1 and 4. Also, recall that Premix 1 in this series was a simple graphite mix that was included for reference purposes and contained no admixed nickel.

These data showed that each of the three admixed alloying elements had profound effects. The most significant effects relative to the reference premix were indicated by Premix 2. As will be recalled, Premix 2 differed from Premix 1 by the addition of 2 w/o of admixed nickel. The evident result of the addition was that each of the four properties listed in the table was positively affected. Accordingly, compared with Premix 1, Premix 2 exhibited the following improvements: a) improved compressibility as indicated by increased green densities; b) increased sinterability as indicated by negative versus positive dimensional change values; c) improved hardenability as indicated by higher strength values at lower sintered densities; and last, d) improved toughness as indicated by an increased impact resistance at a higher strength value.

The effects of adding 1 w/o of copper along with the admixed nickel as indicated by Premix 3 were somewhat mixed when compared with Premix 2 but were still generally positive compared with Premix 1. For example, in this case, the data showed the following for Premix 3: a) similar compressibility to Premix 2 and thus improved compressibility compared with Premix 1; b) reduced sinterability compared with Premix 2 but as shown by its generally smaller dimensional change values, better sinterability than Premix 1; c) significantly improved sintered strength as indicated by higher values at lower or similar sintered densities compared with both Premix 2 and Premix 1; and, d) in view of its higher strength, nearly equivalent toughness to Premix 2 and again, a much better result in this respect than with Premix 1.

The effects of adding 1 w/o of manganese as ferromanganese in combination with the admixed nickel as indicated by Premix 4 were largely negative in comparison with both Premixes 2 and 3 and only marginally positive in comparison with Premix 1. Accordingly, the data in this case

Table 5 - Transverse Rupture and Impact Properties of the Alloy Compositions

Premix ID	Compaction Pressure (tsi)	Green Density (g/cm ³)	Sintered Density (g/cm ³)	Dimensional Change (%)	TRS (10 ³ psi / MPa)	Impact Energy (ft·lbf / J)
2050 °F Sinter For 30 Minutes At Temperature In Synthetic DA						
1	30	6.78	6.73	+0.20	92 / 634	--
	40	7.03	6.98	+0.21	113 / 779	9.0 / 12.2
	50	7.15	7.11	+0.23	127 / 875	--
2	30	6.82	6.81	-0.08	123 / 847	--
	40	7.05	7.05	-0.02	147 / 1012	14.0 / 19.0
	50	7.16	7.18	-0.02	171 / 1178	--
3	30	6.81	6.77	+0.08	135 / 930	--
	40	7.05	7.00	+0.15	159 / 1095	12.0 / 16.3
	50	7.15	7.11	+0.18	178 / 1226	--
4	30	6.77	6.71	+0.22	114 / 785	--
	40	7.01	6.94	+0.27	137 / 943	11.0 / 14.9
	50	7.13	7.07	+0.33	142 / 978	--
2350 °F Sinter For 30 Minutes At Temperature In Synthetic DA						
1	40	7.03	7.04	-0.02	131 / 903	15.6 / 21.2
4	40	7.01	6.99	+0.03	185 / 1277	12.8 / 17.4

showed the following for Premix 4: a) both reduced compressibility and reduced sinterability relative to each of the other premixes; b) reduced sintered strengths versus Premixes 2 and 3 as indicated by lower values at higher densities as well as reduced toughness versus these same premixes as indicated by lower impact values at lower strengths. On the other hand, in comparison with Premix 1, Premix 4 showed markedly improved sintered strengths and slightly increased impact resistance as indicated by higher values at lower densities in both cases.

Finally, sintering Premixes 1 and 4 at 2350 °F versus 2050 °F led to significant property increases in both cases but appeared to have little effect on the relative differences between the premixes. Accordingly, as a cursory review of the relevant data will show, Premix 4 at the higher temperature continued to exhibit slightly inferior sinterability, substantially higher sintered strength and, in view of the higher strength, roughly equivalent toughness to Premix 1.

Tensile Properties - The tensile properties of the subject premixes are shown in Table 6. Here again, notice that the table lists data at two sintering temperatures for Premixes 1 and 4.

The data in this case generally reflected the foregoing findings but indicated two rather significant differences which tend to underscore the value of doing as complete an analysis of a particular composition as possible. As will be seen, these discrepancies had to do with the effects of the copper and manganese in Premixes 3 and 4 on sintered strength.

As previously, Premix 2, containing the straight nickel addition, exhibited significant improvements relative to Premix 1. These included: a) increased densities which were apparently again the result of accompanying increases in both compressibility and sinterability; b) substantially increased yield and ultimate strengths; and, c) increased apparent hardnesses. Unexpectedly, there was little effect of the nickel on ductility.

Table 6 - Tensile Properties of the Alloy Compositions

Premix ID	Compaction Pressure (tsi)	Sintered Density (g/cm ³)	Yield Strength (10 ³ psi / MPa)	Ultimate Strength (10 ³ psi / MPa)	Elong. in 1 in. (%)	App. Hard. (HRB)
2050 °F Sinter For 30 Minutes At Temperature In Synthetic DA						
1	30	6.70	35.2 / 242.8	49.9 / 344.1	2.4	52
	40	6.98	43.3 / 298.6	56.8 / 391.7	2.9	62
	50	7.12	44.8 / 309.0	59.8 / 412.4	3.0	70
2	30	6.79	47.0 / 324.1	64.8 / 446.9	2.0	74
	40	7.05	51.6 / 355.9	75.5 / 520.7	2.7	80
	50	7.19	54.9 / 378.6	79.8 / 550.3	3.3	84
3	30	6.77	47.7 / 329.0	65.6 / 452.4	2.0	74
	40	7.00	54.6 / 376.6	77.7 / 535.9	2.3	80
	50	7.14	56.5 / 390.3	86.6 / 597.2	2.6	84
4	30	6.70	54.7 / 377.2	70.2 / 484.1	1.1	84
	40	6.95	58.4 / 402.8	78.1 / 538.6	1.2	92
	50	7.09	61.2 / 422.1	81.4 / 561.4	1.3	94
2350 °F Sinter For 30 Minutes At Temperature In Synthetic DA						
1	30	6.75	40.1 / 276.6	53.9 / 371.7	3.4	55
	40	7.03	45.9 / 316.6	64.1 / 442.1	4.6	67
	50	7.18	49.0 / 337.9	70.1 / 483.4	5.4	71
4	30	6.75	62.4 / 430.3	78.7 / 542.8	1.0	90
	40	6.99	69.4 / 478.6	87.8 / 605.5	1.1	94
	50	7.13	74.8 / 515.9	88.4 / 609.7	1.3	101

As was earlier hinted, the tensile properties of Premix 3 which contained copper in addition to the nickel were unexpected. The comparable TRS data had indicated negative effects on sintered density but distinctly positive effects on strength. The present data indicated roughly the same negative effects on density but did not appear to corroborate the strength improvements. More specifically, compared with Premix 2, the data showed the following for Premix 3: a) decreased densities which paralleled but were not quite as great as those indicated in the TRS data; b) only slightly increased yield and ultimate strengths; c)

comparable ductilities; and, d) identical apparent hardnesses. To quantify matters, vis-à-vis the disparate strength indications in the two data sets, the ultimate strength increases that were indicated in the present data averaged just a little less than 3300 psi, (22.8 MPa). In contrast, the average strength increase indicated in the TRS data was upwards of 10,000 psi, (68 MPa).

Interestingly, the tensile results of Premix 4 which replaced the copper of Premix 3 with manganese were again partially in agreement and partially in conflict with the findings of the comparable TRS data. As above, there was reasonable agreement in the two data sets as to the effects on sintered density but significant disagreement regarding the effects on strength. However, as opposed to showing lower strength values than expected as was the case with Premix 3, the findings in this case were precisely the opposite. In particular, as may be recalled, the strength performance of Premix 4 in the TRS data was disappointingly poor. For example, when averaged over the three compaction conditions, it was less than 90% that of Premix 2. However, based on the present data, its tensile performance was exceptionally good. Accordingly, it averaged nearly 15% higher in yield strength than Premix 2 and about 5% higher in ultimate strength. As compared with Premix 2 in other respects, Premix 4 exhibited: a) lower densities, presumably due to concomitant decreases in both compressibility and sinterability; b) significantly lower but reasonably adequate elongation values; and, d) increased apparent hardnesses.

Finally, the effects on the tensile properties of Premixes 1 and 4 of sintering at 2350 °F versus 2050 °F appeared to be reasonably consistent with the indications of the earlier findings in this respect. For example, the sintered strength increases in the TRS data due to the higher sintering temperature were upwards of 15 % in both cases. In comparison, the present data similarly indicated yield and ultimate strength increases which ranged between 10 and 20% in both cases. The yield strength performance of Premix 4 at the higher sintering temperature was especially impressive, particularly in view of the totally lackluster TRS performance it earlier exhibited at the lower sintering temperature. Indeed, considering the indications of both data sets in this regard, the obvious implication is that manganese apparently offers significant potential as an alloying addition but requires strict attention to detail in processing, especially during sintering.

Quenched and Tempered Properties of the Nickel Containing Alloy Compositions

As will be explained, the quenched and tempered property determinations were specifically limited to Premixes 3 and 4. However, the general idea to include determinations of the heat treated properties of one or more of the present compositions in these studies was based primarily on the fact that the molybdenum of the Ancorsteel 50 HP base powder is first and foremost a potent hardenability agent, (2, 3). Thus, all of the compositions under study, even the straight graphite ones, are inherently hardenable and hence of potential interest for heat treated applications. The specific idea to conduct the determinations on Premixes 3 and 4 in particular was based on several considerations as follows.

First and simplest was the fact that these premixes were not only the two most highly alloyed compositions of the series adding nickel but of the study in general. Second, relative to Premix 3 in particular, there are in general five alloying elements that are known to produce significant precipitation hardening effects in low alloy steels. These include vanadium, niobium, chromium, molybdenum and copper, (4, 5, 6). However, as it turns out, none of these elements are widely used for such in P/M applications. The first three, of course, are oxidation prone and thus process challenged. The last two, on the other hand, are easy enough to process but are limited by the necessity to employ expensive secondary aging treatments to effect their benefits. For instance, molybdenum carbide precipitation, (i. e. Mo_{23}C_6), typically occurs in

relatively short times but requires temperatures in excess of about 800 °F, (427 °C), whereas epsilon copper precipitation requires long times, say up to 4 hours, and even higher temperatures of 1000 °F, (540 °C) or more, (5, 6). Thus, there is generally no interest in implementing such precipitation reactions when the same or greater strengthening effects can be obtained more economically in other ways. However, one obvious circumstance where this particular objection need not apply is where the necessary secondary treatments are potentially part and parcel of the overall processing such as in the present case. Thus, the interest in Premix 3 which, of course, contained both molybdenum and copper was not only to determine its properties in general but to examine the indicated precipitation effects as well.

The interest in Premix 4 which contained manganese in addition to the nickel was simpler. Accordingly, given the fact that manganese is probably best known in P/M applications for its hardenability effects, it would be ludicrous to include it in a survey study of the present kind and not examine its quenched and tempered properties, (7).

Tempering Studies - As will be recalled, the general plan in this case was to conduct tempering studies in advance of the mechanical property determinations. Thus, the results of the latter studies follow.

The effects of increasing tempering temperatures at a constant tempering time of 1/2 hour on the dimensional change and apparent hardness of quenched TRS specimens of the subject premixes are shown below in Figures 1 and 2. The specimens in this case were initially compacted at 40 tsi and sintered at 2050 °F.

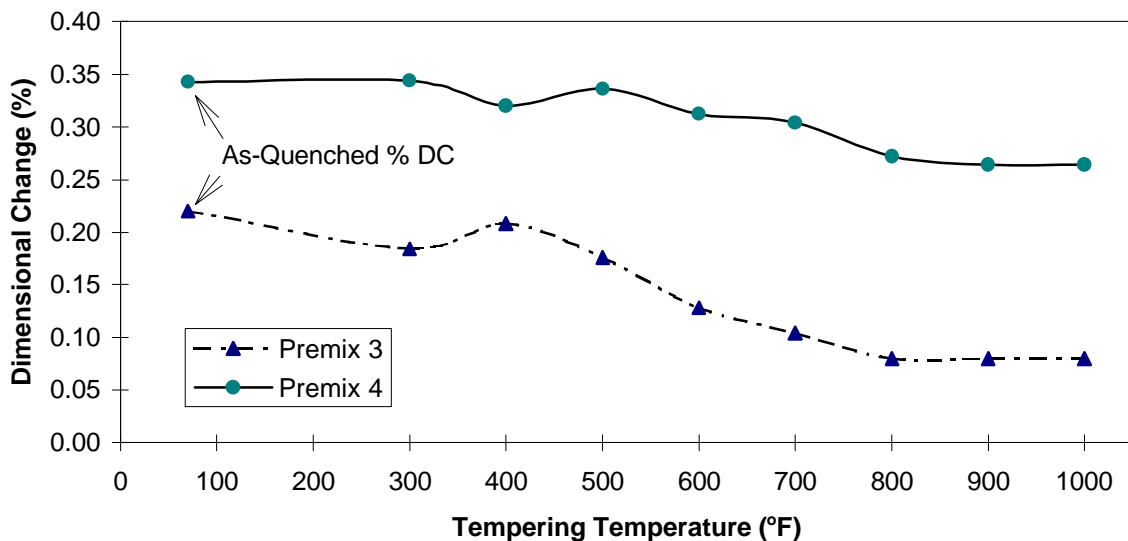


Figure 1 - Effects Of Tempering Temperature On The Dimensional Change Of Premixes 3 And 4.

In general, the combined indications of these figures are thought to include martensite tempering, secondary hardening and very possibly, retained austenite transformation in both premixes. The indications of martensite tempering are plainly evident in each figure. Accordingly, both the specific volume and hardness of as-quenched martensite are greater than those of tempered martensite, (8). Consequently, as generally indicated in the two figures, martensite tempering is typically manifest by simultaneous decreases in both properties.

The indications of secondary hardening in this case are predominantly in Figure 2 which specifically shows hardness minimums at 800 °F, (427 °C), for Premix 3 and at 900 °F, (482 °C), for Premix 4. As a matter of interest, the findings in Figure 1 also show that the dimensional change of both premixes leveled off at 800 °F and thus indicate that the martensite tempering reaction was essentially complete at this temperature. Hence, the relevant implication for the hardening behavior is that were it not for the onset of the indicated secondary hardening, the specimens would have continued to soften due to microstructural coarsening. In fact, there is actually some indication of this in the behavior of Premix 4 which, as indicated, continued to soften up to 900 °F.

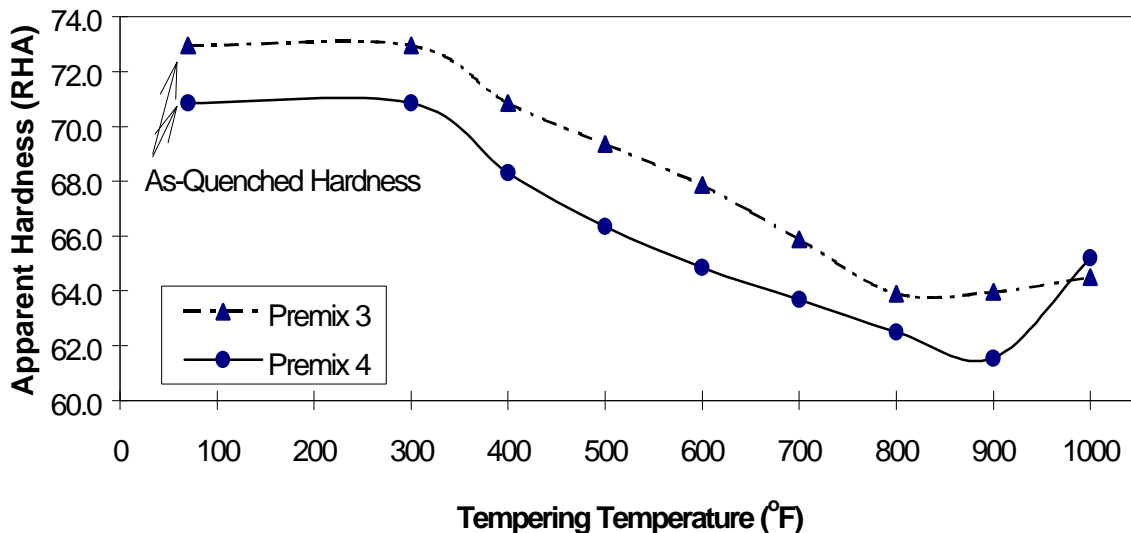


Figure 2 - Effects Of Tempering Temperature On The Apparent Hardness Of Premixes 3 And 4.

Finally, the indications of retained austenite transformation that were mentioned are in Figure 1 and while not entirely unequivocal, are nevertheless thought to warrant serious consideration. Accordingly, if martensite tempering is the only reaction that occurs in a particular temperature range, then the accompanying dimensional change variation within the range would be expected to be a monotonic decreasing one. The dimensional change findings in Figure 1, however, do not indicate monotonic decreasing trends in either premix for temperatures up to about 500 °F. Thus, it may be that some reaction in addition to martensite tempering is also occurring in this temperature range. Of the various known possibilities, transformation of retained austenite seems the most likely for the following three reasons. First, carbon, nickel, manganese and, to a lesser extent, copper are all known to lower the martensite start temperature, (9). Second, given the unlikelihood that any of the last three in this list would be completely homogenized by the sintering conditions that were employed and the fact that the nominal carbon content was otherwise high, its reasonable to suspect that the resulting martensite finish temperatures, especially in the vicinity of the interparticle boundaries, were substantially below ambient temperature. And finally, the specific volume of austenite is less than those of any of its transformation products, (10). Thus, its presence and eventual transformation would be accompanied by an increase in specimen dimensions.

Of course, efforts to confirm this speculation were beyond the scope of the study and consequently were not attempted. However, its of interest to note that if the speculation is correct, then limited tempering studies of the effects of either temperature or time at

temperature on the dimensional change behavior of compositions that are susceptible to the occurrence of retained austenite may provide a simple and efficient test to detect its presence.

The effects of tempering at 1000 °F for various times up to 4 hours were also determined. These results are shown below in Figures 3 and 4. Here again, the findings are interesting but necessarily speculative. In particular, they show subtle differences in the tempering responses of the two premixes which are apparently attributable to the underlying differences in composition and presumably reflect differences in the natures of the attendant secondary hardening reactions.

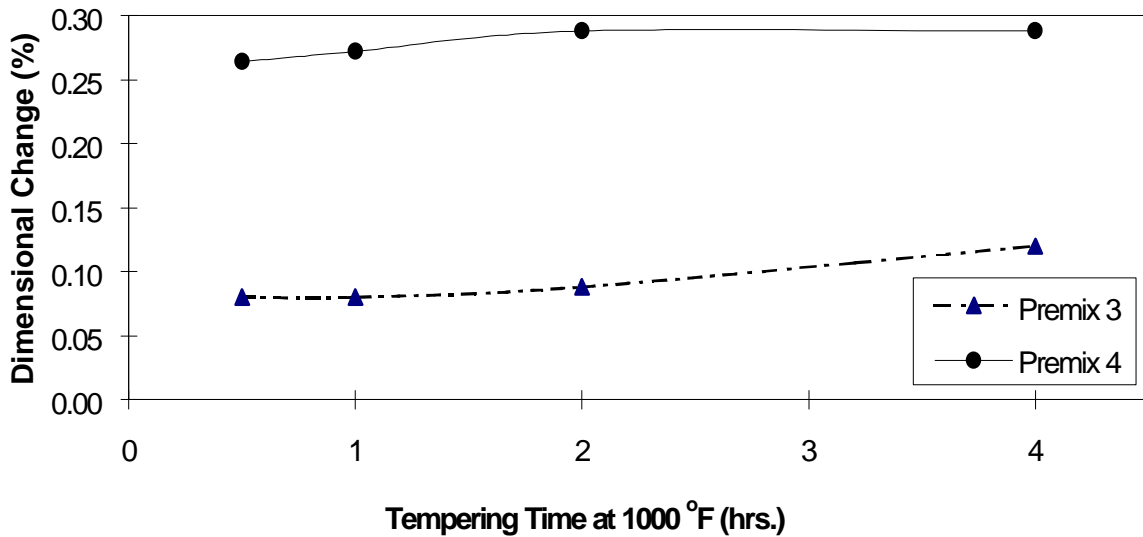


Figure 3 - Effects Of Tempering Time At 1000 °F On The Dimensional Change Of Premixes 3 And 4.

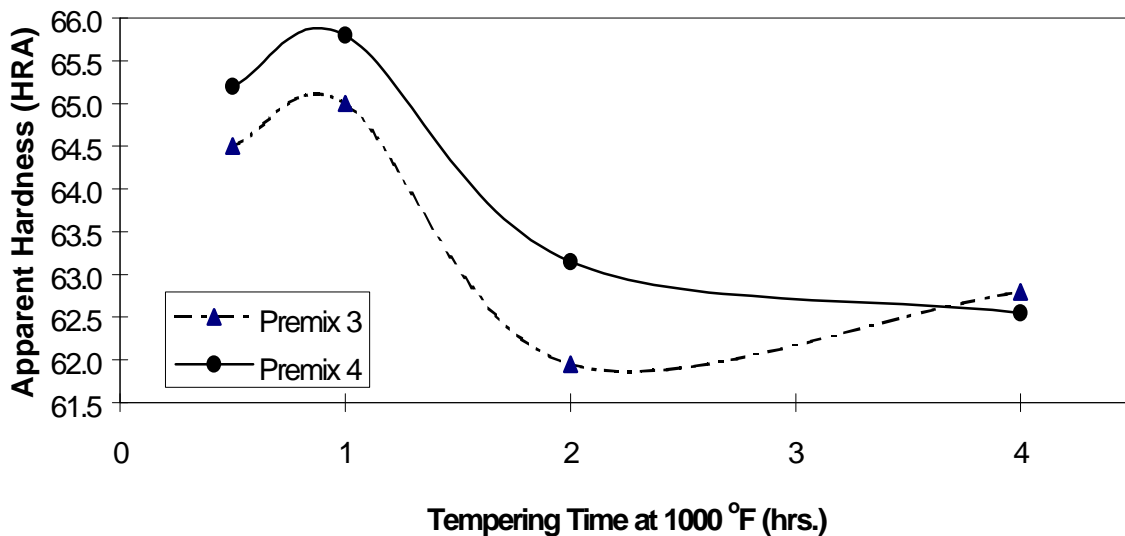


Figure 4 - Effects Of Tempering Time At 1000 °F On The Apparent Hardness Of Premixes 3 And 4.

Premix 3, of course, differs from Premix 4 by the presence of copper in addition to molybdenum. Thus, while the earlier indications of secondary hardening in Premix 4 can only be attributed to the precipitation of molybdenum carbide, the additional possibility exists that they were due to both molybdenum carbide and epsilon copper precipitation in Premix 3. However, the earlier findings were far from conclusive in this regard. For example, while the hardening responses of the two premixes were different, there was nothing specific in the differences to indicate the underlying cause. Thus, they could have been due to dual precipitation in Premix 3 or to any number of other causes including for example, kinetics or mode of precipitation or even random error to name but a few

In contrast, the present data appears to be considerably more indicative in these regards. Accordingly, Figure 3 shows that the specimens of both premixes grew slightly with time at temperature, presumably, as a consequence of lattice strain due to precipitation. Notice, however, that the specimens of Premix 4 stopped growing and leveled off after two hours at temperature while those of Premix 3 continued to grow throughout the entire four hours. At the same time, Figure 4 shows that coincident with these indications, the apparent hardness of the specimens of both premixes peaked in the first hour and then decreased to about the same extent in the second hour. Thereafter, the apparent hardness of Premix 4 leveled off in the last two hours while that of Premix 3 again increased. Of course, the latter increase is small and may be explainable as simply scatter in the data. However, the fact that the indicated hardness behaviors in both cases correlated with the indicated growth behaviors tends to obviate this explanation. Thus, it seems reasonable to speculate that the observed behaviors are indicative of: 1) the cessation of molybdenum carbide precipitation in both premixes followed by limited softening due to either one or both of overaging and microstructural coarsening; and, 2) the continuation or subsequent initiation of epsilon copper precipitation in Premix 3.

Quenched and Tempered Mechanical Properties - The quenched and tempered mechanical properties including the tensile and, in a few cases, the impact properties of Premixes 3 and 4 are presented in Table 7. As a cursory review of the table will show, the data also indicate the effects on properties of sintering at 2050 and 2350 °F and of various tempering treatments. The specimens in this case were all compacted at 40 tsi.

A review of the findings in this table showed three general trends as well as a number of interesting individual indications. These were essentially as follows. The first trend had to do with the performance of Premix 4 which again suffered apparently the same adverse effects of admixed manganese that were earlier shown to accompany its addition. Thus, the properties of Premix 4 were inferior to those of Premix 3 in virtually every case. Second, sintering at 2350 °F versus 2050 °F led to consistent increases in the strengths and apparent hardnesses of both premixes but had mixed effects on the ductilities of Premix 3 and no apparent effect on those of Premix 4. Actually, the ductility of Premix 3 generally increased with increase in the sintering temperature but, as reference to the data will show, exhibited a contrary result in this regard at the lowest tempering temperature. Finally, in the third trend shown by the data, increases in the tempering temperature and/or time generally led to decreases in the strength, apparent hardness and impact values of both premixes but had mixed effects on ductility. The effects on the ductility of Premix 3 were especially interesting. For sintering at 2050 °F, the data showed that the ductility first decreased and then increased with increasing temperature and time. For sintering at 2350 °F, they showed almost the same trend except for the aforementioned low result at the lowest tempering temperature. In addition, the findings also showed that while the strength properties that developed at the higher tempering temperatures were somewhat decreased relative to those at the lower temperatures, they were still quite good. Thus, the implication is that if ductility as well as strength is important, high tempering

temperatures may be applicable to develop useful combinations of the two that are not otherwise attainable.

Table 7 - Quenched And Tempered Properties Of Premixes 3 And 4

Premix ID	Tempering Conditions (°F) (hrs.)		Yield Strength (10 ³ psi / MPa)	Ultimate Strength (10 ³ psi / MPa)	Elong. in 1 in. (%)	App. Hard. (HRA)	Impact Energy (ft-lbf / J)
2050 °F Sinter For 30 Minutes At Temperature In Synthetic DA							
3	400	0.5	137 / 945	175 / 1207	1.1	71	11/ 14.5
	600	0.5	149 / 1028	155 / 1070	0.4	68	--
	1000	0.5	120 / 828	127 / 876	0.6	65	6.0/ 8.1
	1000	1.0	117 / 807	120 / 828	0.7	65	--
4	400	0.5	130 / 897	136 / 938	0.4	68	6.3/8.5
	600	0.5	137 / 945	141 / 972	0.5	65	--
	1000	0.5	112 / 772	120 / 828	0.4	65	4.0/5.4
	1000	1.0	117 / 807	120 / 828	0.4	66	--
2350 °F Sinter For 30 Minutes At Temperature In Synthetic DA							
3	400	0.5	181 / 1248	188 / 1297	0.4	72	--
	600	0.5	165 / 1138	172 / 1186	0.5	70	--
	1000	0.5	130 / 897	139 / 959	1.0	67	--
	1000	1.0	126 / 869	137 / 945	1.2	66	--
4	400	0.5	147 / 1014	153 / 1055	0.4	71	--
	600	0.5	147 / 1014	157 / 1083	0.5	72	--
	1000	0.5	125 / 862	130 / 897	0.4	67	--
	1000	1.0	103 / 897	128 / 883	0.4	67	--

SUMMARY AND CONCLUSIONS

Data were presented to characterize the performance of a new water atomized base powder. The powder contains 0.50 w/o of prealloyed molybdenum and was recently commercialized under the trade name of Ancorsteel 50 HP. The data were generated in three studies with differing objectives as follows. The first study had the aim to determine the powder and green properties of the new powder. The second study was conducted to indicate its sintered behavior in terms of the TRS properties of simple graphite containing premixes. The third study comprised a more comprehensive assessment of its properties in a series of hybrid alloy premixes containing principally 0.6 and 2.0 w/o of admixed graphite and nickel and otherwise variously adding 1 w/o of either admixed copper or manganese. This investigation included determinations of the mechanical properties of each of the alloy premixes along with those of a simple graphite containing composition as a reference premix in the as-sintered condition and of the copper and manganese containing premixes in heat treated condition. Tempering studies were conducted in advance of the heat treated property determinations.

The powder and green property study generally showed the new powder to be characterized by excellent compressibility and otherwise to be reasonably typical in terms of its apparent density, flow and green strength properties. The study to examine the response of the new powder to sintering in simple carbon steel compositions again showed it to be essentially average in terms of the relevant TRS properties.

The studies to indicate the new powder's potential in alloy compositions with admixed nickel showed a number of interesting possibilities. The admixed nickel led to significant increases in compressibility and sinterability. The resulting sintered densities, especially at the higher compaction pressures, far exceeded those that are known to be possible with similar contents of prealloyed nickel, (e.g. as in Ancorsteel 4600V). The accompanying mechanical property improvements were likewise significant.

Modest additions of copper or manganese in addition to the nickel led to further sintered strength improvements without significant adverse effects to either ductility or toughness. Interestingly, in the as-sintered condition, the copper addition had the greatest effect in improving the transverse rupture strength whereas the manganese addition had the greatest effect in improving the yield and ultimate strengths.

The comparisons of the heat treated properties of these two premixes were also informative as to the possibilities with the new base powder. The initial tempering studies showed significant secondary hardening at the higher tempering temperatures in both cases. The hardening was evidently due primarily to molybdenum carbide precipitation and may have been assisted by epsilon copper precipitation in the copper modified composition. In addition to determining the effects of a variety of tempering conditions, the subsequent mechanical property determinations were also done for two sintering temperatures. In contrast with the findings in the as-sintered condition, the resultant mechanical properties of the copper modified premix were now better than those of the one with the manganese. The best properties in terms of strength and ductility in both cases were developed at the highest sintering temperature and the lowest tempering temperature. Nevertheless, potentially interesting combinations of strength and ductility were also observed at the higher tempering temperatures, especially in the case of the copper modified premix.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Messrs. R. Fitzpatrick and W. R. Bentcliff for their help in specimen preparation and testing. Thanks are also due to Mr. Dennis Creed of the PresMet Corporation for his help in heat treating the quenched and tempered tensile and impact specimens.

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