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PROCESS SPECIFICATION FOR TYPE 46XX POWDER-FORGED WEAPON COMPONENTS PHASE I - INTERIM TECHNICAL REPORT

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MARCH 1985

U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
FIRE CONTROL AND SMALL CALIBER WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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18. SUPPLEMENTARY NOTES

This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army material.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Powder metallurgy
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The open literature was searched for information on the processing and properties of powder-forged (P/F) 46XX and 10XX steels. Mechanical-property graphs were constructed which compared the reported P/F material properties to equivalent AISI wrought grades. Areas where additional testing is needed to complement the existing data were identified, and a testing program was outlined. The data will be used to develop a military specification for powder-forged weapon components. The literature was also searched for appropriate nondestructive test methods and inspection procedures to be included in the specification to

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20. Abstract (con't.)

ensure forged material quality. Thirty small-caliber weapon components were evaluated for the technical feasibility of manufacturing by powder forging. This evaluation identified four primary and several secondary candidates. A detailed cost analysis was performed on the ten most promising candidates to determine the economic feasibility of manufacturing by powder forging. This analysis revealed that powder forging would be uneconomical for some components, while for others, cost savings up to $30.00 per part could be achieved.

FORWARD

This contract was funded under the U. S. Army's Manufacturing Methods and Technology Program as part of project 6838324. Dr. J. W. Burlingame was the Armament Research and Development Center's project engineer for this contract.

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INTRODUCTION

The frequently predicted and much publicized emergence of powder forging (P/F) as a major metal-forming process has not yet occurred. Many explanations have been offered, but the major barrier to acceptance and adoption is the absence of a widely-used standard property specification that would allow substitution for conventional wrought steels.

Over a decade ago, the Department of Defense initiated a series of programs concerned with powder forging of highly-stressed weapon and vehicular components.[1-4] An outcome of this effort was military specification MIL-F-45961 on pre-alloyed-steel powder forgings. This specification is narrow in scope because only one carbon level (4640) and one heat-treated hardness level (R_C 30-33) were covered. It was therefore decided to sponsor the present program to develop an expanded specification that would include three carbon levels (tentatively 4620, 4640 and 4660) with two deformation levels and three hardness levels for each carbon level. Such a specification would be more suitable for currently produced, small-caliber weapon components. It should be noted that the weapon system for which the original specification was written is no longer being produced.

Phase I of the program consisted of the following five parts:

1. Review and critically evaluate the published and unpublished data on processing/property relationships for P/F 46XX and 10XX steels.

2. Outline the properties and processing information that require further study to develop the desired specification for P/F 46XX and a subsequent specification for P/F 10XX.

3. Review the literature for appropriate destructive and nondestructive test and inspection methods to be included in the specifications to ensure forged material quality and conformance to property requirements.

4. Determine the feasibility of manufacturing weapon components by powder forging from a group of thirty weapon-component drawings selected by ARDC. The components were selected from two currently produced, small-caliber weapons.

5. Select the most promising weapon components in both 46XX and 10XX steel and run a detailed cost analysis on each. Compare these to cost estimates for the same parts made by conventional means.

REVIEW AND EVALUATION OF EXISTING DATA ON P/F 46XX AND P/F 10XX

Literature Search

A thorough and extensive search of the open literature was performed. Using Dialog Information Services the following commercially-available, metals- and engineering-information databases were searched:

NTIS - 1964-1984	WORLD ALUMINUM ABSTRACTS - 1968-1984
COMPENDEX - 1970-1983	WELDSEARCH - 1967-1983
INSPEC - 1969-1976	STANDARDS AND SPECIFICATIONS - OCT 1983
INSPEC - 1977-1984	NONFERROUS METAL ABSTRACTS - 1961-1983 DEC
METADEX - 1966-1984	ENGINEERING MEETINGS - 1983

In addition, a systematic search of the SPS Technologies Corporate Technical Library and MPIF Library, Princeton, New Jersey was conducted. A table of references was constructed from the papers collected; frequently cited works not already obtained were ordered. Finally, an ad hoc committee consisting of twelve experts from the government, MPIF, metal-powder producers and powder-metal (P/M) parts manufacturers was formed in an effort to obtain additional data from unpublished studies.

In all, 120 references were obtained and critiqued; the complete bibliography is included as Appendix A. There was considerable duplication of data among the 120 references; furthermore, some references contained data that was not applicable (that is, low density, properties on actual components rather than specimens). As a result, only 50% of the compiled papers were used in the review that follows, and these are separately referenced.

Graphs on hardenability, tensile properties, impact properties, transition temperatures, fatigue properties and fracture toughness were constructed to determine the status of the existing data and to identify areas where data were lacking.

Properties of 46XX P/F Steels

Hardenability:

Eight published papers[6-13] plus three unpublished studies[14-16] contained hardenability data on P/F 4620. These data are plotted in Figure 1 along with the wrought AISI 4620 hardenability band.[5] Both P/F and wrought 4620 have virtually the same hardenability.

Five published papers[10,12,13,17,18] plus two unpublished studies[15,16] contained hardenability data on P/F 4640. As shown in Figure 2, the P/F 4640 data fall within the lower half or below the wrought AISI 4640 hardenability band and indicate a shallower than expected hardenability starting around the J5 or J6 distance.

There were no published data on the hardenability of P/F 4660; unpublished data from the Hoeganaes Corporation[15] is presented in Figure 3. Since there is no wrought AISI 4660, AISI 4063 was used for comparison. Cracking may account for the low hardness near the quenched end, but otherwise the hardenabilities of P/F 4660 and AISI 4063 are equivalent.

Tensile

The tensile properties--ultimate, yield strength, elongation and reduction of area--for P/F 4620 are presented in Figure 4. Five references[6,19-22] contained data which extended over a hardness range from R_C 20-36. The properties of wrought AISI 4620[5,23] are comparable. Two British publications[7,8] did not report hardness or tempering temperature; their data are presented in Figure 5 as strength vs. elongation. The strength/ductility relationship for P/F 4620 is inferior to that for AISI 4620. This has been reported previously.[20,24]

Twelve publications[1,2,17,18,20,25-31] contained tensile data on P/F 4640. These data are shown in Figures 6a and 6b. Despite the considerable scatter, the comparison between P/F and wrought 4640 is quite good.

Only one paper[20] contained tensile data on P/F 4660. Table 1 shows that ductility for the P/F steel is extremely poor in comparison to AISI 4063.

Table 1. Tensile Properties of P/F 4660 and AISI 4063[23]

Material	Ultimate Tensile Strength (ksi)	.2% Yield Strength (ksi)	Elongation (%)	Reduction of Area (%)
		Tempered-300°C		
4063	295	260	8.0	30
4660	276	211	3.5	3
		Tempered-400°C		
4063	240	220	10.0	40
4660	199	177	5.0	10
		Tempered-600°C		
4063	155	140	16.0	50
4660	144	120	5.5	15

Impact (Charpy V-Notch)

Five papers[1,11,12,22,32] reported impact properties for P/F 4620; these data are shown in Figure 7 along with wrought AISI 4620 data. Generally, the P/F material is inferior to wrought in both shelf energy and transition temperature. However, processing has a substantial effect on property level. Increasing the sintering temperature from 2050°F to 2300°F effectively doubles the impact energy. Flow has a similar effect.

Ten papers[1,12,18,20,25,30,31,33-35] reported impact properties for P/F 4640. As with P/F 4620, the P/F 4640 shows substantially lower impact energy than its wrought equivalent (Figure 8). However, the gap between P/F and wrought is less for the .40% carbon material than for the .20% carbon material.

One paper[20] reported impact properties for P/F 4660. In the normalized condition, P/F 4660 has an impact energy of 10 ft.-lbs., which compares favorably with the 12 ft.-lbs. exhibited by AISI 4063.

It should be noted that all the results presented were determined in the longitudinal direction. Many authors have shown that P/F steels are inferior to wrought steels in the longitudinal direction but superior in the transverse direction.

Fatigue

Fatigue data for P/F 46XX were found in eleven papers[1,7,8,20,21,30,33-37] for carbon contents from 0.20% to 0.50% (Figure 9). The ratio of endurance limit to ultimate tensile strength ranged from 0.34 to 0.59 (with one at 0.28) which compares very favorably with wrought steel. Inclusion content appears to be the most important variable affecting fatigue performance (Figure 10).[35] Surface treatment (carburizing, nitrocarburizing) also has a profound effect on fatigue (Figure 11),[2,33] which is most pronounced when a low carbon material is treated.

Fracture Toughness

A number of investigators have expressed concern that impact testing (specifically, Charpy V-notch) is too severe a test for powder-forged steels and is not a true property test for this material. Investigation of the literature uncovered six papers[27,32,38-41] that dealt with fracture toughness of P/F 46XX. Figure 12 compares the fracture toughness of P/F 46XX steels with wrought low alloy steels.[42] Only in rare cases did the P/F results fall inside the wrought steel band. Processing variables that were noted to improve impact energy (such as lower oxygen content, increased flow, and increased sintering and forging temperatures) also improved fracture toughness. The high fracture toughness, low yield strength material fell well outside the wrought steel band; it may be that the larger specimen size required for these tests created a problem.

Tempering Response

The response of P/F 46XX steels to tempering temperature was found in twelve papers.[6,10,12,18,27,29,30,32,33,39,43,44] There was some scatter, but overall the tempering response of P/F and wrought 46XX steels is the same (Figure 13).

Properties of 10XX P/F Steels

Hardenability

Only one paper[8] contained hardenability data on P/F carbon steels. Figure 14 shows the hardenability of a 0.47% carbon powder-forged steel vs. a wrought AISI 1045 steel. In this case, the hardenability of the powder-forged material is slightly greater than the wrought.

Tensile

Tensile properties for P/F 10XX were found for two heat-treated conditions: as-forged (normalized)[20,30,46-49,60] and quenched and tempered.[8,37,43,48,50-52] Normalized properties were comparable to those exhibited by wrought carbon steels (Figure 15). Quench and tempered properties were significantly lower than those exhibited by wrought carbon steels (Figure 16).

Impact (Charpy V-Notch)

Nine papers[20,25,30,43,46,47,50,53,54] contained impact data for P/F carbon steels. Except for very low carbon contents (that is, 0.05%), the impact energy was a small fraction (25%) of that exhibited by wrought carbon steels, regardless of the heat-treated condition. Moyer[50] pointed out that, because of the very low manganese content in these steels, thin carbides form at the grain boundaries which drastically reduce impact strength.

Fatigue

The fatigue properties of powder-forged carbon steels[8,43,52] compare favorably with their wrought counterparts (Figure 17). The ratio of endurance limit to ultimate tensile strength exhibited by the P/F carbon steels (.33 to .40) is similar to that exhibited by wrought carbon steels. Usmani's[52] extensive study on the effects of surface treatment on fatigue behavior found a slight improvement with medium carbon steels but a significant one with low carbon or carburizing steels (Figure 18).

Fracture Toughness

Only one paper[51] contained fracture toughness data for P/F 10XX steels. The author suggested that the low manganese content may contribute to the poor fracture toughness of powder-forged carbon steels.

Processing/Property Relationships

One of the objectives for this program was to analyze the existing data for processing/property relationships, use statistical analysis to establish quantitative relationships, and ultimately to write a specification that would dictate a specific processing route for making powder-forged parts. After a careful review of the results of the literature search, it became apparent that such an approach was infeasible. The existing data was not as extensive as anticipated. The disparity in powder compositions (Tables 2 and 4) and processing variables (Tables 3 and 5) used in the referenced works makes establishing quantitative relationships a nearly impossible task. In addition, the overwhelming opinion of industry representatives is that the desired specification should focus on performance (final properties and quality) and not unduly restrict the development of better, more cost-effective processing alternatives that presently are not foreseen.

Thus, the specification to be developed will cover only the properties required of the powder and the forgings. This will effectively set the process controls needed but will allow powder-metal parts manufacturers sufficient flexibility in processing. In addition, a "first article" provision for initial part qualification is being considered for inclusion in the specification. Such a provision would qualify a manufacturer's process; subsequent processing changes would necessitate requalification.

Table 2. Compositions of 46XX Powders Used in Referenced Studies

Reference	Principal Author	Weight Percent				
		Ni	Mo	Mn	Cr	Si
1	Lally	1.90	0.50	0.20	--	--
2	Lally	1.25	0.38	0.25	--	--
6	Nokita	1.75- 1.90	0.45- 0.55	0.30- 0.40	--	--
7	Steed	2.39	0.59	0.42	0.05	0.03
8	Brown	1.80	0.47	0.23	0.05	0.03
	Brown	2.26	0.59	0.42	0.04	0.02
9	Hanejko	1.80	0.50	0.20	--	--
10	Smith	1.82	0.52	0.20	--	--
11	Moyer	1.91	0.50	0.26	--	0.027
12	Antes	1.76	0.46	0.15	0.08	0.033
17	Husby	1.73	0.44	0.17	0.08	0.02
18	Husby	1.82	0.47	0.17	0.08	0.02
19	Mackiewicz	1.25- 1.90	0.38- 0.50	0.20- 0.25	--	--
20	Cundill	1.70	0.42	0.12	--	0.03
22	Moyer	1.80	0.50	--	--	--
26	Crowson	1.77	0.48	0.23	0.05	0.07
27	Crowson	1.45	0.62	0.19	0.07	0.02
	Crowson	1.77	0.48	0.23	0.05	0.07
	Crowson	1.74	0.26	0.40	0.04	0.28
	Crowson	1.74	0.23	0.51	0.10	0.42
28	Bargainnier	2.03	0.55	0.04	--	0.01
29	Knopp	2.00	0.50	0.20	--	--
30	Bockstiegel	1.87	0.49	0.27	0.02	0.01
31	Lindskog	1.86	0.51	0.24	0.04	--
32	Eldis	1.81	0.58	0.12	--	--
33	Saritas	1.95	0.57	0.35	0.09	--
34	Krantz	1.83	0.51	0.18	--	--
35	Brown	1.86	0.42	0.20	0.05	0.02
	Brown	1.70	0.47	0.01	0.01	0.04
	Brown	1.97	0.52	0.03	0.05	0.01
	Brown	1.80	0.47	0.25	0.10	0.02
36	Amato	2.03	0.70	--	--	--
37	Brown	1.86	0.42	0.20	0.05	--
38	Dower	1.70	0.51	0.12	--	0.015
39	Pilliar	1.83	0.51	0.18	--	--
40	Pilliar	1.68	0.52	0.20	--	0.023
	Pilliar	2.09	0.61	0.22	--	0.01
41	Bratina	1.68	0.50	0.20	--	--
43	Pietrocini	1.75- 1.90	0.45- 0.55	0.30- 0.40	--	--
48	Cull	2.00	0.50	--	--	--
53	Huppman	1.80- 2.20	0.45- 0.55	0.25- 0.35	--	--
54	Ferguson	1.75- 1.90	0.45- 0.55	0.30- 0.40	--	--

Table 3. Processing Variables Used in Referenced 46XX Studies

		Sintering			Forging					
Reference	Principal Author	Temperature (°C)	Time (min.)	Atmosphere*	Temperature (°C)	Mode	Pressure (tsi)	Die Temperature (°C)	Amount of Flow	Oensity
1	Lally	982/1120/ 1315	--	Hydrogen or O.A.	760	Repress	20,30,40	204	-(0.24-0.45) -(0.16-0.20)	99.5+%
2	Lally	1120	60	Hydrogen	870,980, 1090	--	40	150,230,315	--	99.1-99.5% 99.0-99.9% 99.9-100%
6	Nokita	1050	60	O.A.	1000	Repress	100	--	-0.27	99.5%
7	Steed	1120	40	Controlled	1080	Repress	--	250	--	Full
8	8rown	1125	20	Endo	--	--	--	--	0	--
9	Hanejko	1120	30	D.A.	980	Plane Strain	50	--	-1.12	7.83 gm/cm^3
10	Smith	1120	--	Endo	925	--	75	--	-0.92	7.85 gm/cm^3
11	Moyer	1120	60	D.A.	982	Plane Strain	--	--	-0.92	1% Porosity
12	Antes	1120	60	O.A.	980-1040	Upset/ Repress	30	260	-1.14/ -0.21	Full
17	Husby	1120	15-20	O.A.	926-1149	Upset	--	--	-1.16/ -1.61	>99.1%
18	Husby	1120	15-20 x 2	O.A.	926-1149	Upset	--	--	-1.16/ -1.61	99.1- 99.89%
19	Mackiewicz	1120	60	Hydrogen	870,980, 1090	--	--	150,230,315	--	99.0-100%
20	Cundill	1050	30	Hydrogen	1000-1100	Repress	25	--	-0.29	7.85 gm/cm^3
21	Ferguson	1120	--	--	982	Plane Strain	--	--	-0.35/ -1.20	--
22	Moyer	1120-1260	--	--	980,1120	Upset	--	--	--	99.9%

Table 3. (Continued)

Reference	Principal Author	Sintering			Forging					
		Temperature (^{o}C)	Time (min.)	Atmosphere*	Temperature (^{o}C)	Mode	Pressure (tsi)	Oie Temperature (^{o}C)	Amount of Flow	Density
25	Crowson	1040/1200	10-60	Hydrogen, CH_4	1040/1200	Repress	--	350,400	--	99.0-99.6%
26	Crowson	1038/1315	10-90	Vac./Argon/ Hydrogen	1038/1315	--	40	149,232	-0.22	--
27	Crowson	1120	60	99% Hydro- gen, 1% CH_4	1000,1100, 1200	Upset, Repress	20,40	300,350	--	99.2-99.9%
28	Barganinnier	1150	40	Endo	815-1150	Repress	80	--	--	97.5-99.5%
29	Knopp	1093	15	Hydrogen	1093	Repress	--	--	-0.14/-0.17	98.0%
30	Bockstiegel	1050	20	O.A.	1050	Repress	36-43.5	--	-0.19	Full
31	Lindskog	1100-1200	30-60	O.A.	1100-1200	Repress	--	--	--	--
32	Eldis	1230/1120	30	Hydrogen/ Endo	982	Plane Strain	75	204	-0.92	--
33	Saritas	--	--	--	--	Repress	--	--	-0.22	Full
34	Krantz	1204	30	Hydrogen	1010	Repress	--	315	-0.41	Complete
35	Brown	1120	40	--	--	Repress	--	--	--	--
36	Amato	1150	30	Hydrogen	800-850	Repress	72.5	--	--	99.0%
37	Brown	--	--	--	--	--	--	--	--	--
38	Oower	1100/1200	60	90% Argon 10% Hydrogen	950,1150	Repress, Upset	--	200	-0.24 -0.41	99.6-99.9%
39	Pilliar	1050-1100	--	Vac.	--	Upset	--	--	-1.38	Full

Table 3. (Continued)

		Sintering			Forging					
Reference	Principal Author	Temperature (^{o}C)	Time (min.)	Atmosphere*	Temperature (^{o}C)	Mode	Pressure (tsi)	Die Temperature (^{o}C)	Amount of Flow	Density
40	Pilliar	1010,1200	30	Hydrogen	815-875	Repress	--	--	--	99.8%
41	Bratina	1200	30	Hydrogen	1010	--	--	--	--	--
43	Pietrocini	1120	20	--	982	Repress	--	--	--	98.0%
48	Cull	1100	--	--	--	--	--	--	--	--
53	Huppman	--	--	--	--	--	--	--	--	--

* D.A. = disassociated ammonia
Endo = endothermic
CH_4 = methane
Vac. = vacuum

Table 4. Composition of 10XX Powders Used in Referenced Studies

Reference	Principal Author	Weight Percent									
		Ni	Mo	Mn	Cr	Si	Cu	C	S	P	O_2
8	Brown	--	--	0.08	--	0.03	--	--	0.016	0.008	--
20	Cundill	---Atomized Iron---									
30	Bockstiegel	0.02	0.0	0.05	0.02	0.01	--	0.01	--	--	0.07
43	Pietrocini	---1050---									
46	Ishimara	---AHC 100.29 and A. O. Smith 300M---									
47	Hoffman	0.02	--	0.05	0.005	0.01	0.005	0.01	0.004	0.004	--
48	Cull	--	--	0.003	--	0.018	--	0.02	--	0.12	--
49	Leheup	---Mannesmann WP150 and ASC -100.29---									
50	Moyer	---Ancorsteel 1000---									
51	Bastia	0.07	0.02	0.05	0.04	0.05	0.10	0.40	0.09	0.006	--
52	Usmani	--	--	0.1	--	--	--	0.46	0.013	0.010	0.027
54	Ferguson	--	--	0.30	--	0.10	0.30	0.30	--	0.02	--

Table 5. Processing Variables Used in Referenced 10XX Studies

Reference	Principal Author	Sintering Temperature (°C)	Time (min.)	Forging Atmosphere*	Temperature (°C)	Mode	Pressure (tsi)	Oie Temperature (°C)	Amount of Flow	Oensity gm/cm³
8	Brown	--	--	--	--	--	--	--	--	6.90-7.70
20	Cundill	1050	30	Hydrogen	1100	Repress	25.0	--	-0.29	--
30	Bockstiegel	1100	20	O.A.	1050	Repress	43.5	--	--	Full
43	Pietrocini	1120	20	--	980	--	--	Pre-heated	--	7.72
46	Ishimara	1120	30	--	900	--	--	--	--	7.80
47	Hoffman	1280	--	D.A.	1000	Repress	--	--	--	>7.70
48	Cull	--	--	--	1100	--	--	--	--	--
49	Leheup	--	--	--	--	--	--	--	--	--
50	Moyer	1120	30	O.A.	R.T.	Plane Strain	--	R.T.	-1.20 max.	5.60/7.83
51	Bastia	--	--	--	--	--	--	--	--	--
52	Usmani	--	--	--	1150	--	44.5	--	--	--
54	Ferguson	1120	30	O.A.	980	Repress/ Plane Strain	--	260	-0.25/-1.09	Full

* O.A. = disassociated ammonia
R.T. = room temperature

OUTLINE THE PROPERTIES AND PROCESSING INFORMATION THAT REQUIRE FURTHER STUDY

Table 6 summarizes the results of the literature search and indicates areas where data are lacking. The properties of powder-forged 4620 and 4640 are documented fairly well; data for powder-forged 1020 and 1040 are less complete; almost no data exist for 4660 and 1060. Overall, the open literature was not as entensive as anticipated. There may be considerable data contained in unpublished works which could not be obtained. The data collected show that hardenability, tensile and fatigue properties of powder-forged 46XX and 10XX steels are very similar to those of wrought steel and demonstrate the feasibility of powder forging as a practical, alternative manufacturing technology. However, in some areas the properties of powder-forged steels have been notably inferior to wrought steels, specifically fracture toughness and impact properties. However, these data may not be representative of P/F components made from today's better powders and improved processing techniques.

The ultimate objective is to establish minimum property values at a 95% confidence level for powder-forged 46XX and 10XX. Clearly, considerable testing is required to fill the obvious gaps in the data. Unfortunately, considerable testing is necessary also in some areas where existing data are relatively abundant. The data are useful for making qualitative comparisons, but to integrate the existing data to establish minimum property values is made difficult by the lack of a common denominator. Researchers used different powder types and compositions; in some cases, important processing information and actual density were not reported. In addition, powder quality has improved somewhat over the years so that properties reported in earlier studies may not be representative of today's newer, cleaner powders. Thus, an extensive testing program is recommended to develop the desired specification.

The principal variables to be used in generating property data are carbon content, deformation level, and hardness:

46XX Test Plan

Carbon Contents

The carbon contents (classes) will be 4620, 4640 and 4660.

Two compositions of powder will be prepared for each class:

a. minimum carbon with minimum alloying elements, and
b. maximum carbon with minimum alloying elements.

The former composition will be used to yield minimum tensile properties and hardenability; the latter will be used to yield minimum impact properties.

Table 6. Summary of Literature Search

Property	Number of References to Powder-Forged							
	4620	4640	4660	46XX	1020	1040	1060	10XX
Hardenability	11	7	1		0	1	0	
Tensile	7	12	1					14*
Impact	5	10	1					9
Fatigue				12				3
Fracture Toughness				6	1			

* 7 presented normalized data and 7 presented were quenched and tempered data.

Deformation Level

The desired specification should contain requirements for different grades of forgings since the various weapon components will have different performance requirements. Therefore, four rather than two different but standard processing routes will be used to establish the grade levels. Sintering temperature and amount of lateral flow will be varied as shown below:

Grade	Processing	
1	2300^{o}F sinter with considerable lateral flow	(31%)
2	2050^{o}F sinter with considerable lateral flow	(31%)
3	2050^{o}F sinter with limited lateral flow	(14%)
4	2050^{o}F sinter with a hot repress	(<1%)

Hardness

Each class/grade combination will be evaluated in two or three heat-treated conditions (low, intermediate and high hardness levels). There will be two conditions for classes 4620 and 4662 and three conditions for class 4640.

10XX Test Plan

A similar test plan will be followed for 10XX powder-forged material except that fewer combinations will be considered.

Carbon Contents

Two carbon levels corresponding to 1040 and 1060 will be evaluated; 1020 will be omitted because this material is not specified for any of the weapon components.

Deformation Level

Only two deformation levels will be considered, corresponding to grades 2 and 4 above. High sintering temperatures and small changes in lateral flow do not affect property levels significantly in these materials.

Hardness

Analysis of 10XX candidate weapon components shows that two heat-treatment conditions are typically used: normalized and carbonitrided. As-forged properties represent the normalized condition. A mock-carburizing heat treatment will be used to produce specimens that will be representative of the core of carbonitrided components.

Recommended Tests for Property Comparison Data

For both powder-forged 46XX and 10XX, testing will include room-temperature tensile, Charpy V-notch impact at room temperature and at -65^{O}F, Rockwell hardness, density and Jominy end quench. The literature review showed that the impact properties of P/F carbon steels are affected adversely by the presence ofgrain boundary carbides. While there is a definite need for remedies to this problem, such work is beyond the scope of the recommended test plan and would be best addressed by a separate study.

Fatigue requirements will not be included in the eventual specification. Fatigue data from the literature review (R. R. Moore specimens) indicate that the ratio of endurance limit to tensile strength for powder-forged 46XX and 10XX is comparable to that of their wrought equivalents. Further, tests on actual components showed that powder-forged parts (connecting rods, roller bearings) had better fatigue properties due to their finer surface finish. With this in mind, specifying minimum property requirements for tensile and impact strength, as well as the requirements on actual components in the areas of microstructure, density and defects should be sufficient to guarantee satisfactory fatigue performance. However, limited fatigue testing to verify Phase I results will be conducted. The fatigue properties of one class (4640) will be evaluated as a function of grade and hardness.

Fracture toughness testing is not considered necessary since plane strain conditions are not attained in the small components involved in small-caliber weapons.

LITERATURE REVIEW ON TEST METHODS AND INSPECTION PROCEDURES

Powder

The quality of a powder-forged component is largely determined by the quality of the starting material. Powder properties must be controlled to maintain a consistent product and ensure reproducibility. There are three types of characterization used to define the powder population:[55] particle morphology (which includes size, shape and size distribution), microstructure and chemical composition.

Particle Morphology

Particle size can have a significant effect on the properties of the green compact, sintered preform and forged component. Most P/M powders are -80 mesh (177μm); coarser powders (-60 and -40 mesh) are used only in times of shortage. Excessive amounts of coarse particles can degrade the properties of powder forgings because the frequency of large inclusions increases.[56]

An irregular particle shape is required for apparent density and green strength. Too irregular a shape can cause agglomerates and lead to low apparent density and high flow times.

Molding-grade water-atomized steel powders normally show a bimodal size distribution. Excessive shifts in either direction can cause problems with apparent density, compressibility and green strength. In addition, excessive amounts of fines (-325 mesh/45μm) can degrade the dynamic properties of powder-forged components because of the increased number of small network-type inclusions which result.[57]

Microstructure

Water atomization gives very high cooling rates which produce a very fine martensitic microstructure. To make the powder soft and compressible, it must be annealed. Annealing is also required to reduce the oxygen content. The resulting microstructure consists of fine ferrite. Examination of the powder's microstructure is an indirect method to check the annealing operation.

Chemical Composition

Control of chemical composition is extremely important to maintain a consistent product. For typical 46XX powder, controls are maintained over the following elements:

a. Nickel (1.75% minimum) and molybdenum (0.5% minimum) are necessary for hardenability and strengthening.

b. Manganese contributes to hardenability but low levels promote compressibility and low oxygen content.

c. Phosphorous must be kept to a minimum or compressibility suffers.

d. Sulfur must be kept low to minimize the number of sulfide inclusions.

e. Silicon content must be minimized to ensure low oxygen content in the final forging.

f. Oxygen content is kept reasonably low; subsequent processing can reduce the oxygen content to even lower levels.

For the proposed specification, requirements on chemical composition and particle size distribution should be sufficient.

Requirements for apparent density, flow rate, green density and green strength are important for powder to be used for conventional powder-metal components (pressed and sintered). Fabricators of forged components may want to use a low apparent-density powder or a low green-strength powder, and as long as forged properties can be maintained, they should not be unduly restricted. However, requirements can be imposed which are not difficult to achieve and which will further define powder quality.

Inspection of Powder-Forged Components

Surface inspection for cracks, oxides and porosity is performed primarily by liquid-penetrant and magnetic-particle techniques. Testing for subsurface defects still relies, for the most part, on production sampling owing to the high added cost for X-ray or ultrasonic inspection. While ultrasonic velocity and resonant frequency measurements have begun to see increased use, specifically to estimate tensile properties in sintered and powder-forged parts,[49,58] the only recent innovation in nondestructive testing (NDT) has been the development of a magnetic bridge sorting technique.[59] The method compares eddy currents developed within a forging, as it passes through a coil carrying alternating current, with those produced in a reference sample. The technique has been used to check core hardness, surface decarburization, surface oxide penetration and porosity. It has not, however, seen widespread use.

For the proposed specification, NDT requirements should focus on surface inspection techniques; these will be evaluated in Phase II.

Destructive quality-assurance testing of forged components or identically-processed test coupons is done using sampling procedures such as those in MIL-STD-105D. Standard testing includes chemical analysis, mechanical properties tensile and impact), Rockwell hardness, density and surface decarburization. Automated procedures that utilize quantitative analysis equipment have begun to replace manual point-counting techniques for determining plain iron contamination and nonmetallic inclusion level.

Inspection requirements will be established based on current industry practice and the results of the Phase II test program. Hardenability requirements will be established as well, owing to the fact that the hardenability of powder-forged steels cannot be accurately calculated on the basis of chemical composition.

FEASIBILITY OF PRODUCING WEAPON COMPONENTS BY POWDER FORGING

Thirty drawings of weapon components from the M240 and M242 small-caliber machine guns were reviewed and evaluated to assess the feasibility of manufacturing the parts by powder forging. This study was conducted primarily by Deformation Control Technology (DCT), a consulting firm with extensive experience in the areas of preform design and forging deformation limitations for powder forging. A copy of their report is included as Appendix B. Their results are summarized below.

The parts selected by ARDC are listed in Table 7. Seven components were judged impractical for powder-forging from a manufacturing standpoint: back buffer plate, block front, tripping lever, housing cap damper, cluster gear, firing pin and safety catch. Their complex shapes do not lend themselves to powder forging.

The remaining parts were then evaluated from an economic standpoint to select the most promising components for a detailed cost analysis. This evaluation included a determination of the powder-forged shape from the standpoints of achieving net surfaces where possible, adding any necessary material in the form of a forging envelope, calculating metal removal volumes per type of finish machining operation, and ranking the parts according to these criteria. A numerical rating was calculated for each part; a high rating indicates a high chance of successfully implementing powder forging.

Table 7. List of Thirty Weapon Components Selected by ARDC

Part	Current Wrought Material	Condition
	Alloy Steel	
Cap, Housing, Damper	4130	R_C 31-36
Sprocket, Feed, Aft	4130	R_C 36-40
Gear, Worm Shaft	4130	R_C 36-40
Sprocket, Drive	4130	Mod. Comm. Part
Latch, Feed Handle	4130	R_C 38-43
Spur Gear, Clutch	4140	R_C 35-40
Dog, Clutch	4340	R_C 50-53
Clutch, Feed Shaft	4340	R_C 43-46
Gear-Bevel, Motor Gearbox	4340	R_C 36-40
Cluster Gear	4340	R_C 36-40
Pinion, Bevel	4340	R_C 36-40
Pin, Firing	4340	Forged, R_C 44-46
Carrier, Bolt	4340	Forged, R_C 50-53
Arm, Chain Sear	4340 MOD	R_C 53-56
Gear, Clutch	4340	R_C 39-42
Catch, Safety	4140	Hot Rolled
Bolt, Breech	8650	R_C 47-51
Link, Piston Extension	8650	R_C 47-51
Lever, Locking	9310H	$<$ BHN 245
Sear	9310H	R_A 80
	Carbon Steel	
Guide Sleeve	10L35	Cold Drawn
Back Buffer Plate	10L35	Normalized
Threaded Machine Plug	10L35/ 1045	Hot Finish
Extractor Block	12L35	Cold Finish
Block Front	1060	Forged
Feed Pawl (#1182/6180)	1060	Spheroidized/ Carbonitride
Feed Pawl (#1182/6188)	1060	Spheroidized/ Carbonitride
Tripping Level	1060	R_A 72-75
Catch	1060	Spheroidized/ Carbonitride
Extractor Spacer	12L14	Cold Finished

From this part of the study it was concluded:

P/F 46XX

Of the twenty components currently manufactured from wrought low alloy steels, there are four primary candidates and several secondary candidates for powder forging:

Part	Rating
Primary	
Aft Feed Sprocket	5.402
Bevel Pinion	4.548
Drive Sprocket	4.343
Bevel Gear	3.169
Secondary	
Feeder Latch Handle	1.735
Bolt Carrier	1.499
Clutch Spur Gear	1.306
Feed Shaft Clutch	1.139
Breech Bolt	1.137

P/F 10XX

Of the ten components currently manufactured from wrought carbon steels, there are no primary candidates and only three that show any promise at all for powder forging:

Part	Rating
Secondary	
Threaded Machine Plug	2.443*
	0.322**
Catch	0.640
Feed Pawl	0.593
(P/N 11826180)	

* versus machining
** versus forging

COST ANALYSIS FOR FEASIBLE COMPONENTS

Cost estimating was hampered for three reasons:

1. The Army was unable to furnish cost information for parts produced by current production routes.

2. Cost information and actual manufacturing methods could not be obtained from current parts manufacturers.

3. Drawings could not be sent out for quotations owing to the nature of the parts.

The approach taken was to develop manufacturing methods and cost information based on SPS Technologies' manufacturing capabilities and facility rates. Estimating the cost of manufacturing the parts both ways (conventional vs. powder forging) at SPS gives a more accurate assessment of the potential advantages offered by powder forging.

A DCT computer program was used to estimate the cost to make the forgings; the DCT report "Feasibility of Producing Small Weapon Components by Powder Forging" was used as a guide to determine finish machining requirements.

Conventional manufacturing methods were chosen based on SPS manufacturing capabilities; where alternative methods appeared feasible, they were noted.

Facility hour rates currently in operation at SPS were used; these rates should be typical of any large production facility.

Tooling is normally government property and is not amortized against production. Thus, tooling costs were excluded from the analysis.

Machining operations common to both manufacturing methods were eliminated from the analysis; this resulted in the development of cost differentials rather than quantitative cost estimates.

Cost analyses were conducted for lot sizes of 1000, 5000 and 10,000 pieces. A summary of the cost analysis is presented in Table 8 for ten parts selected as candidates for powder forging. A short explanation on costing each of the parts is given below:

P/F 10XX:

1. Thread Machine Plug for M240 Machine Gun (P/N 11826223) - Cost analysis revealed a marginal advantage for powder forging in the 1000-piece range. This would decrease rapidly with increased lot size. The powder-forged method was compared to a shear-forge-turn diameter-drill hole route of manufacture.

2. Catch for M240 Machine Gun (P/N 11826125) - Cost analysis revealed a moderate advantage for powder forging. The powder-forged method was compared to a shear-forge-trim-grind-machine profile-machine ends route of maufacture. Almost 60% of the cost differential arises from the "machine profile" operation, which requires slow machining to maintain location relative to the 4.03 mm diameter hole.

3. <u>Feed Pawl for M240 Machine Gun (P/N 11826180)</u> - SPS would forge this part on a hot press resulting in a semi-finished profile. Some additional machining, specifically milling the 1.75 mm x 45^{0} break, would be required to obtain the same net shape produced by powder forging. However, the extra machining cost would be more than offset by the cost of pressing and sintering the powder-forged preform. Thus, this part would be more costly to produce by powder forging.

P/F 46XX

1. <u>Aft Feed Sprocket for M242 Cannon (P/N 12524153)</u> - Cost analysis revealed a moderate advantage for powder forging. The powder-forged method was compared to a machine blank-grind cut-off end-step ream and chamfer-machine teeth route of manufacture. Alternative manufacturing routes such as bar shaping and blanking from sheet stock would reduce the powder forging advantage; quantitative estimates were not prepared as SPS does not have the capability for performing these operations.

2. <u>Drive Sprocket for M242 Cannon (P/N 12524393)</u> - Parts with sockets and splines are generally considered prime candidates for P/M techniques; the cost analysis bears this out. The powder-forged method was compared to a two-hob and machine method.

It should be noted that this part is an "altered item" and as such may be considerably less expensive to manufacture (due to high volume of the parent part from Emerson Electric).

3. <u>Bevel Gear for M242 Cannon (P/N 12524457)</u> - The method of manufacture for a wrought-steel product would parallel the drive sprocket. Both products have an internal spline which would be hobbed and an external sprocket or gear form which would be cut. Since the number of teeth on the bevel gear is 33 as opposed to twelve on the drive sprocket, the amount of machining time would be greater. Thus, powder forging offers a significant cost advantage.

4. <u>Bevel Pinion for M242 Cannon (P/N 12524456)</u> - This part falls into the category of the drive sprocket and bevel gear since it has two gear-type forms. The powder-forging cost advantage falls between the above two parts because of the number of teeth on the external gear.

5. <u>Latch Feeder Handle for M242 Cannon (P/N 12524228)</u> - The powder-forged method was compared to both a 100% machining method and a shear-preform-forge-trim-bend-and-drill method. For conventional manufacture, the 1000-piece quantity was less expensive with the 100% machining method while the 5,000- and 10,000-piece quantities were less expensive with the forged method due to the set-up hours required. Powder forging offered a slight cost advantage over both.

6. <u>Breech Bolt (P/N 11826041) and Locking Lever (P/N 11826041) for M240 Machine Gun</u> - The net surfaces which could be achieved by powder forging are relatively simple and inexpensive to achieve by machining when compared with overall part cost. Also, due to the interdependency of the dimensional requirements, it is quite probable that locating certain characteristics would consume more set-up time than would machining a surface and locating from that surface. Thus, powder forging offers no cost advantage for these two parts.

Table 8. Cost Estimates for Selected Weapon Components

Part	$ Saving/Powder-Forged Part vs. Wrought		
	1,000 Pieces	5,000 Pieces	10,000 Pieces
Threaded Machine Plug	0.44	None	None
Catch	10.05	9.32	9.32
Feed Pawl	None	None	None
Aft Feed Sprocket	11.94	10.95	10.95
Bevel Pinion	23.23	23.23	23.23
Drive Sprocket	18.48	18.48	18.48
Bevel Gear	30.52	30.52	30.52
Latch, Feeder Handle	3.88	2.09	2.09
Breech Bolt	None	None	None
Locking Lever	None	None	None

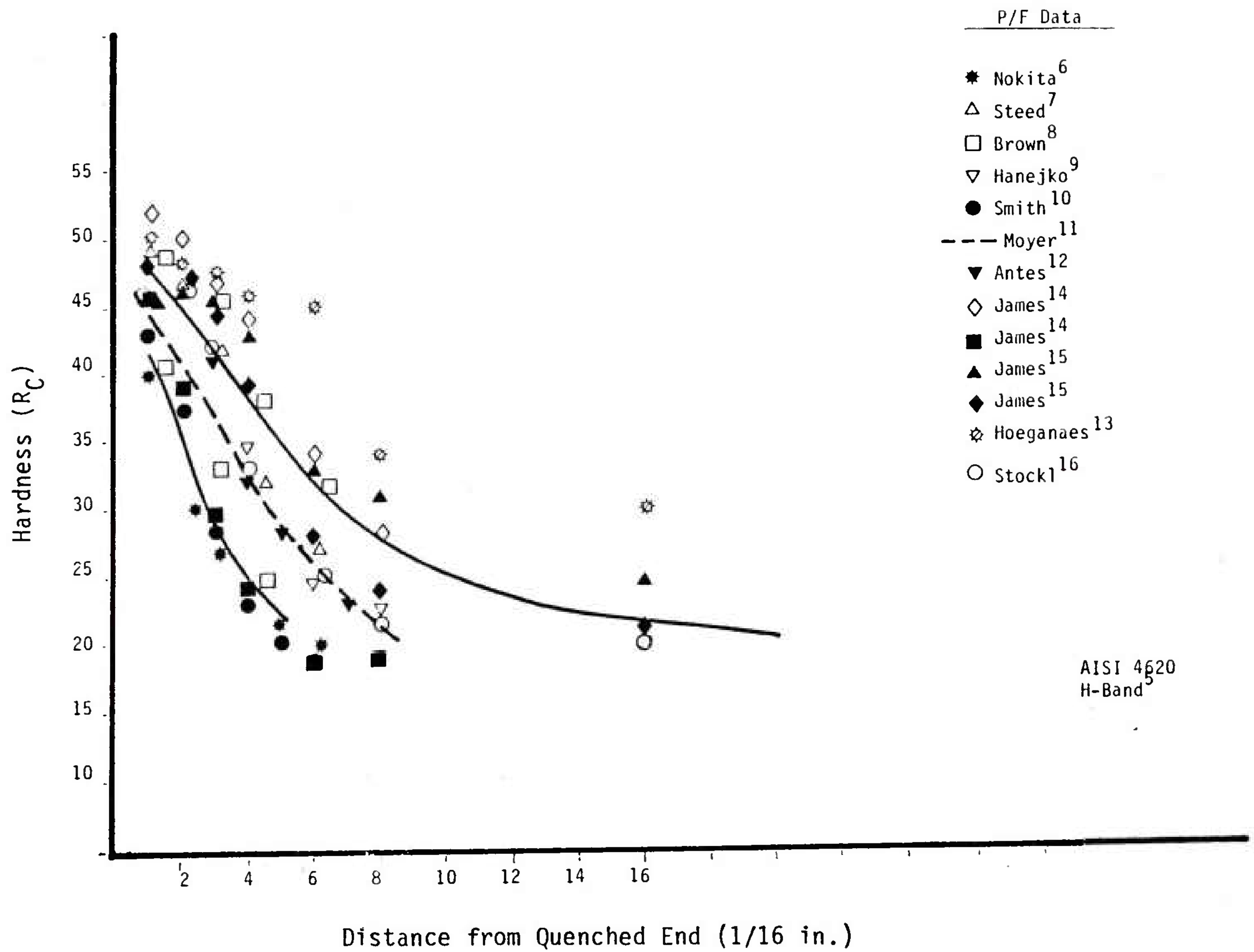

Figure 1. Hardenability of P/F 4620 vs. AISI 4620.

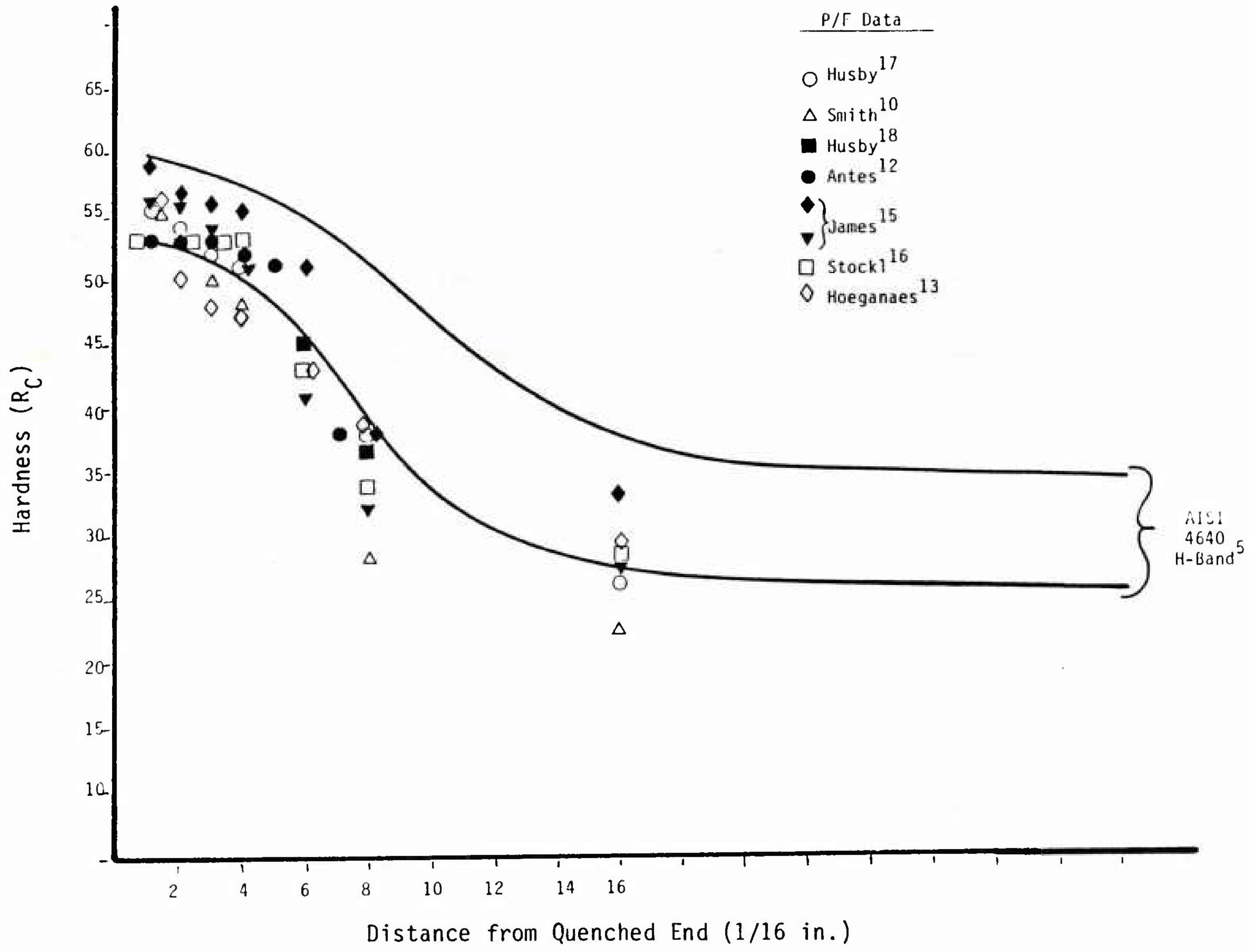

Figure 2. Hardenability of P/F 4640 vs. AISI 4640.

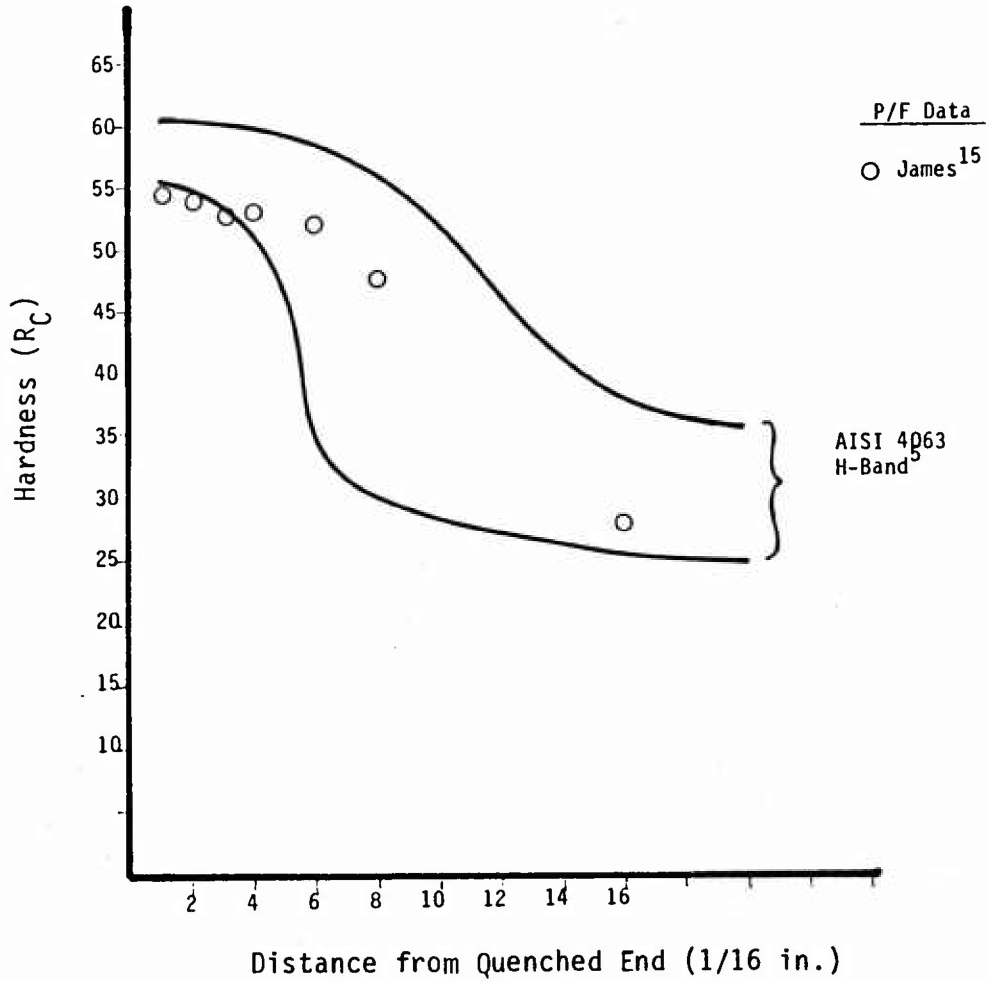

Figure 3. Hardenability of P/F 4660 vs. 4063.

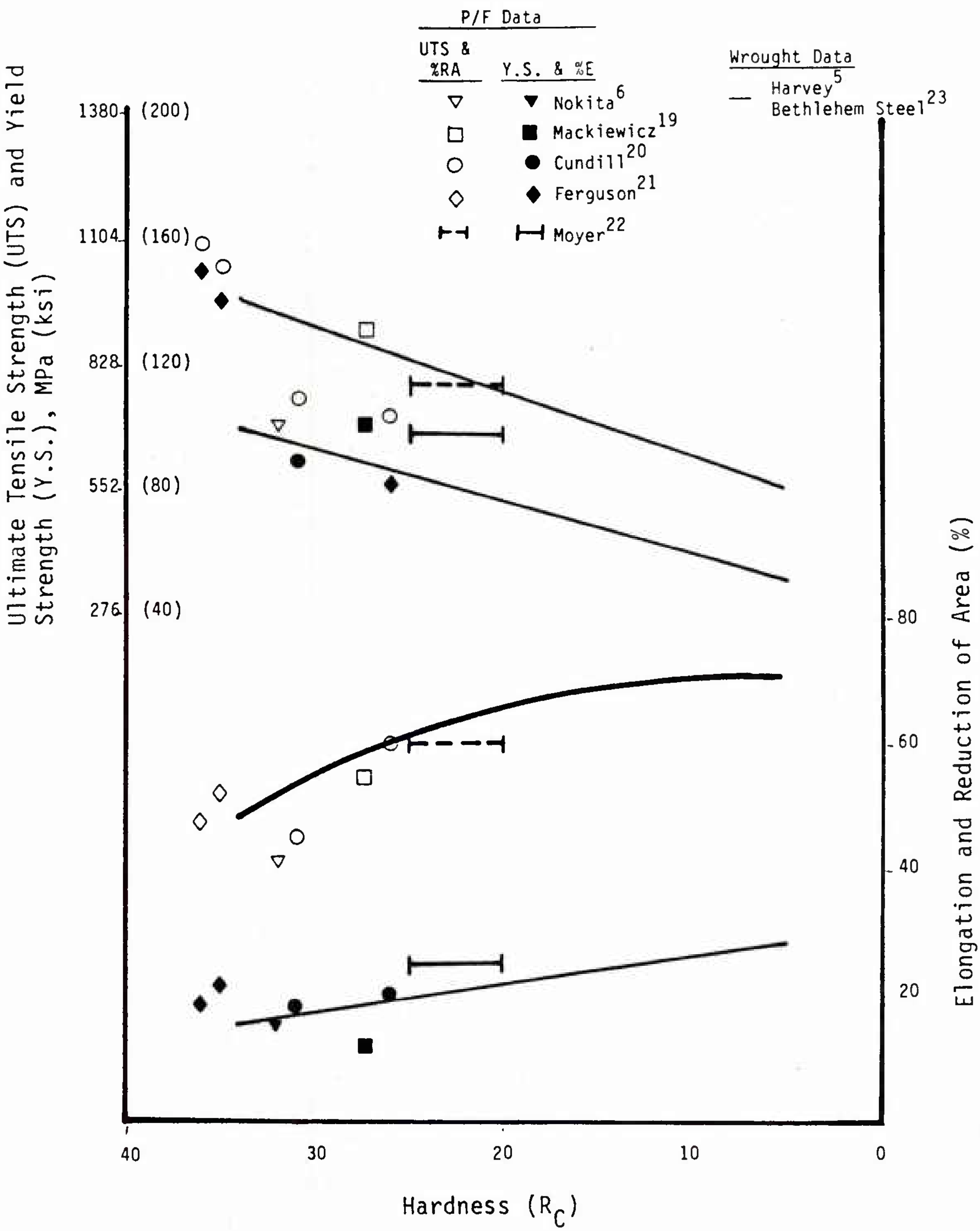

Figure 4. Tensile properties of P/F 4620 vs. AISI 4620.

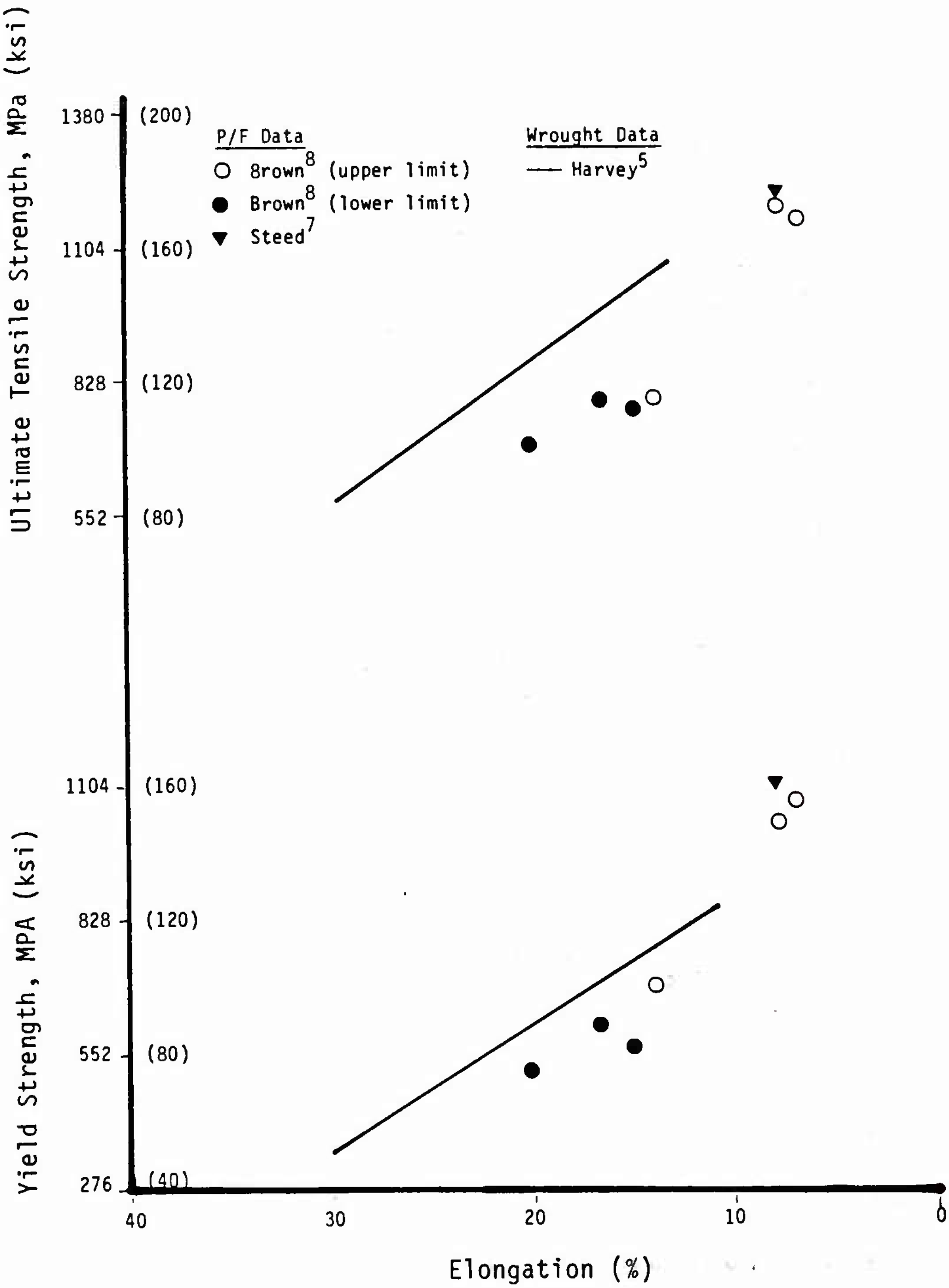

Figure 5. Strength vs. elongation for P/F 4620 vs. AISI 4620.

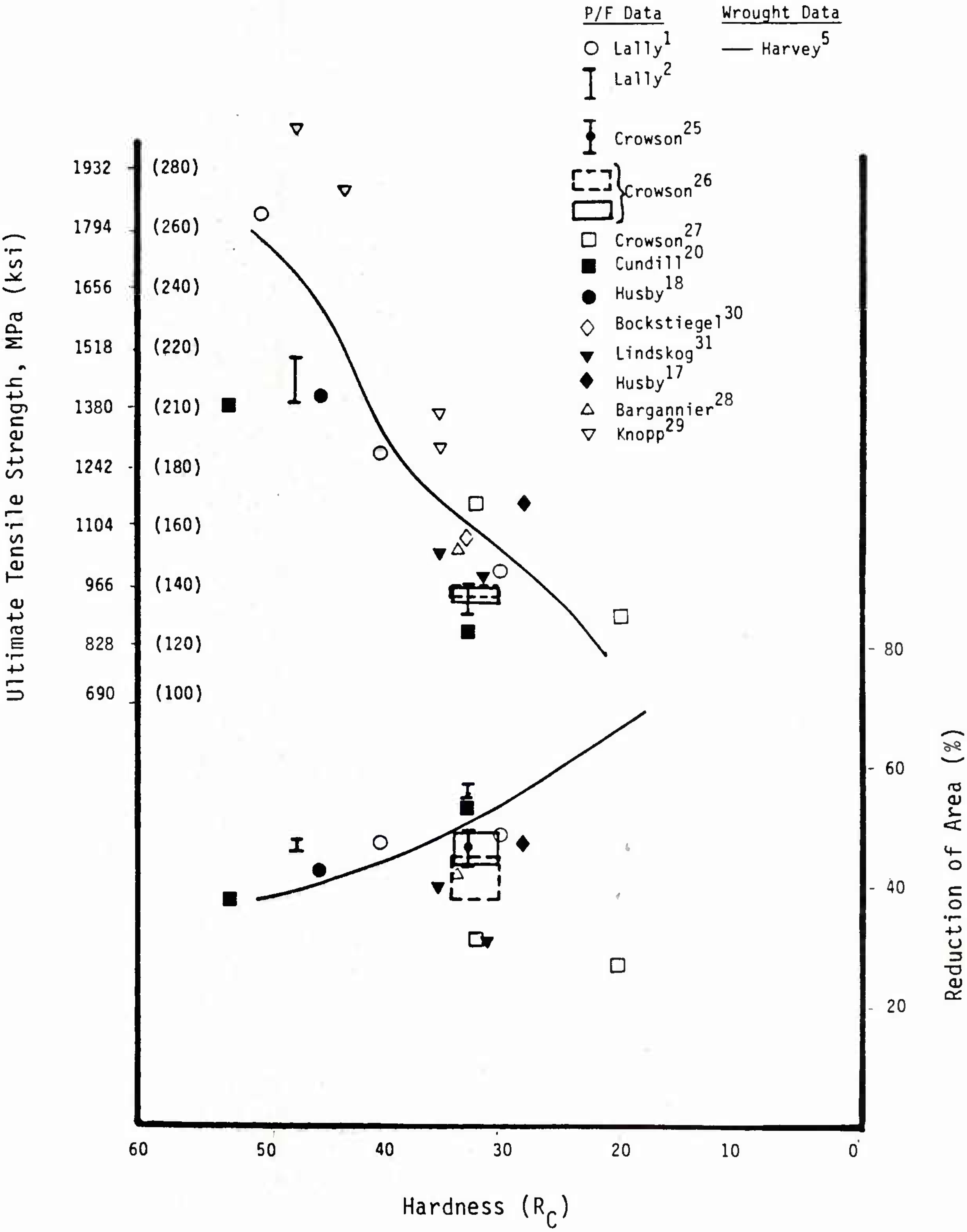

Figure 6a. Ultimate tensile strength and reduction of area for P/F 4640 vs. AISI 4640.

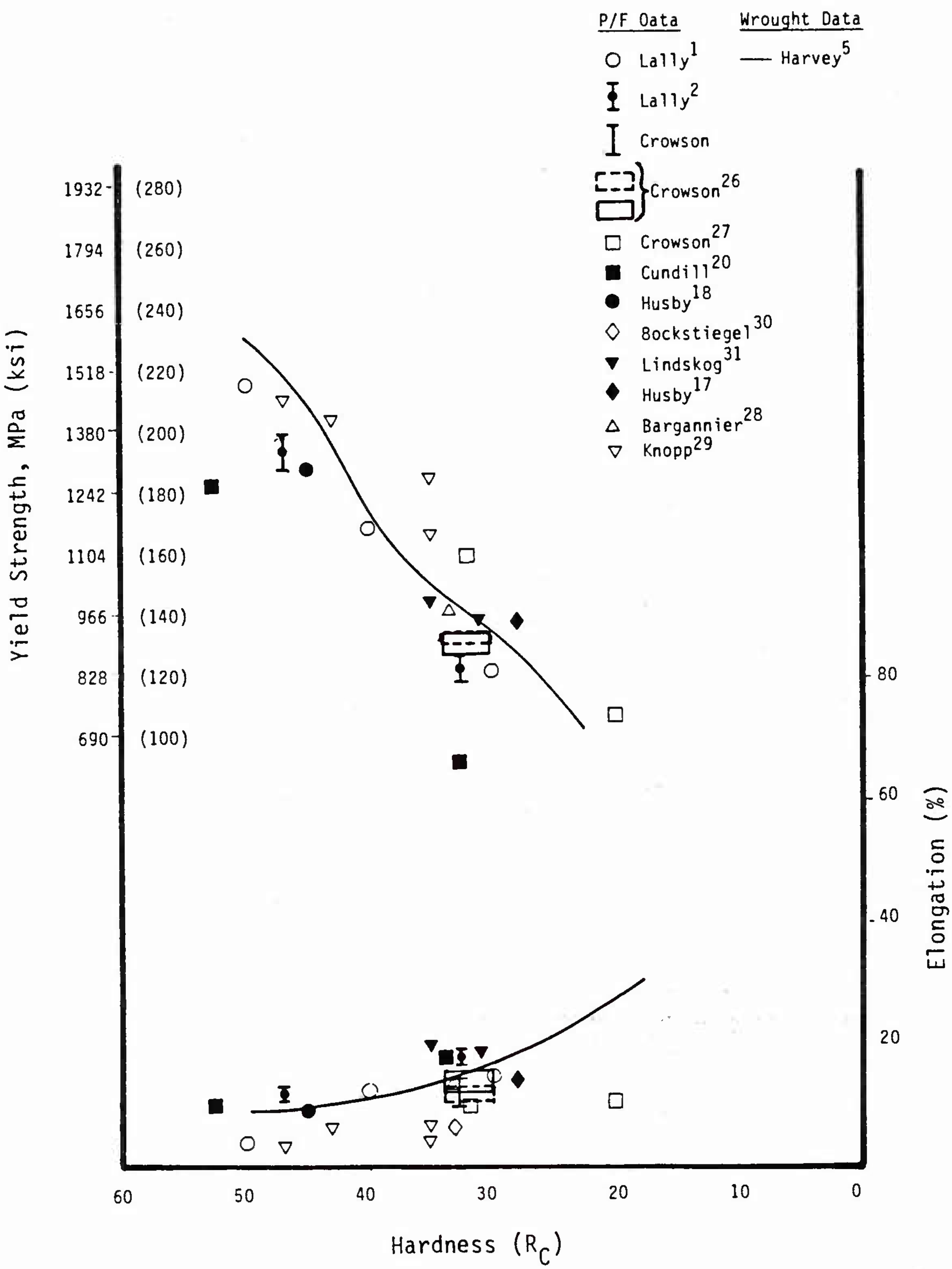

Figure 6b. Yield strength and elongation for P/F 4640 vs. AISI 4640.

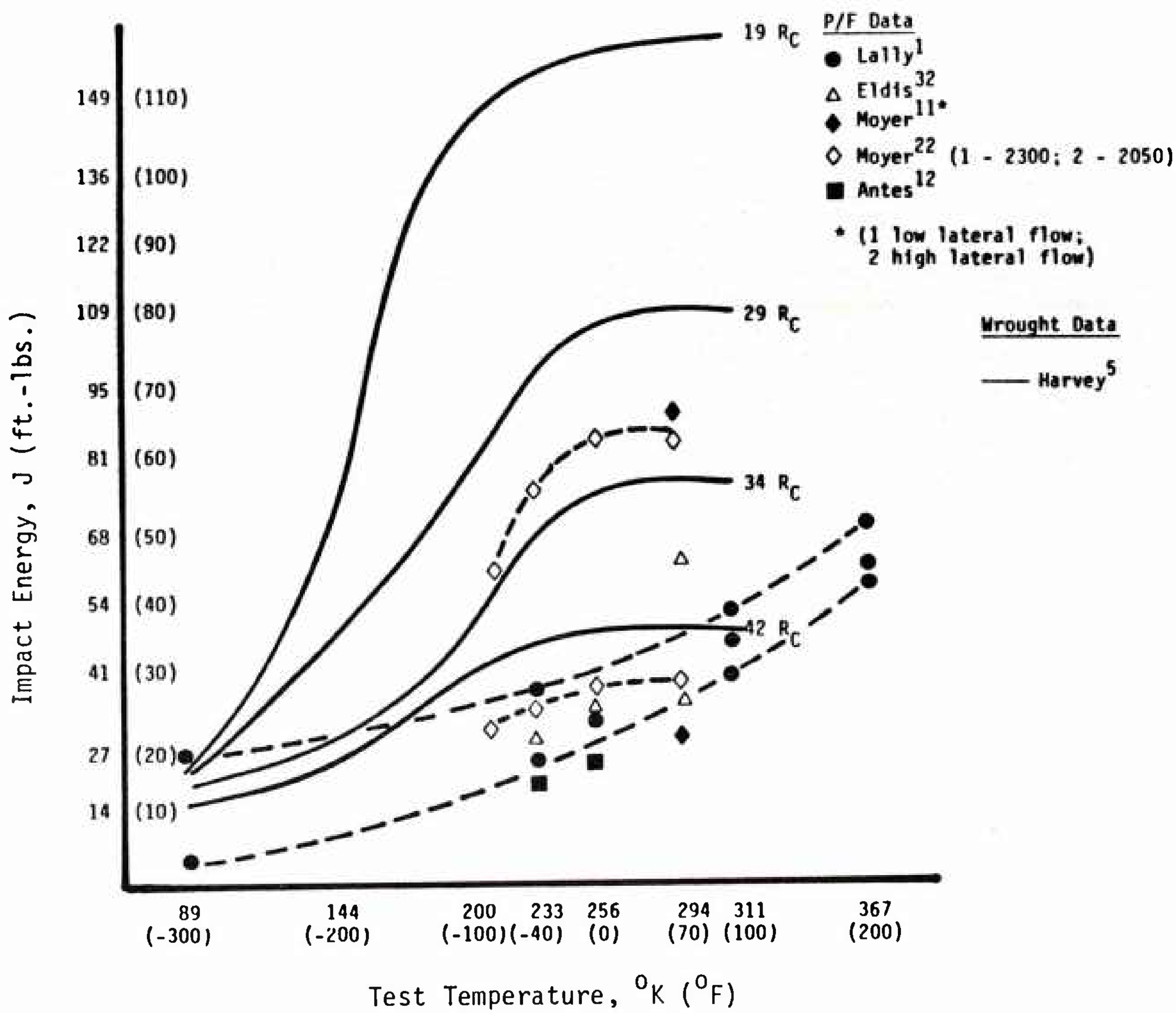

Figure 7. Impact properties of P/F 4620 vs. AISI 4620 (shown from different hardness levels).

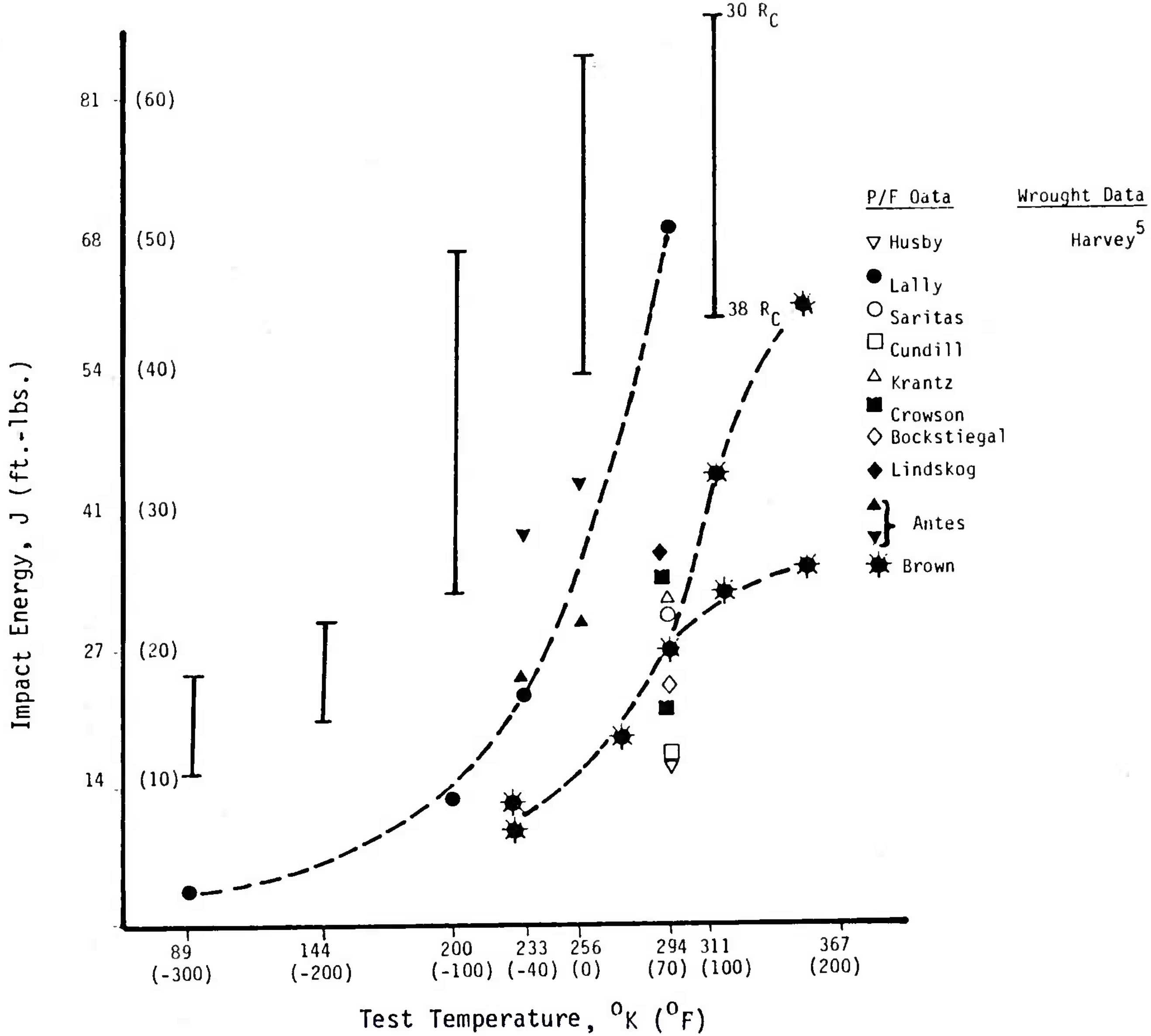

Figure 8. Impact properties of P/F 4640 vs. AISI 8640.

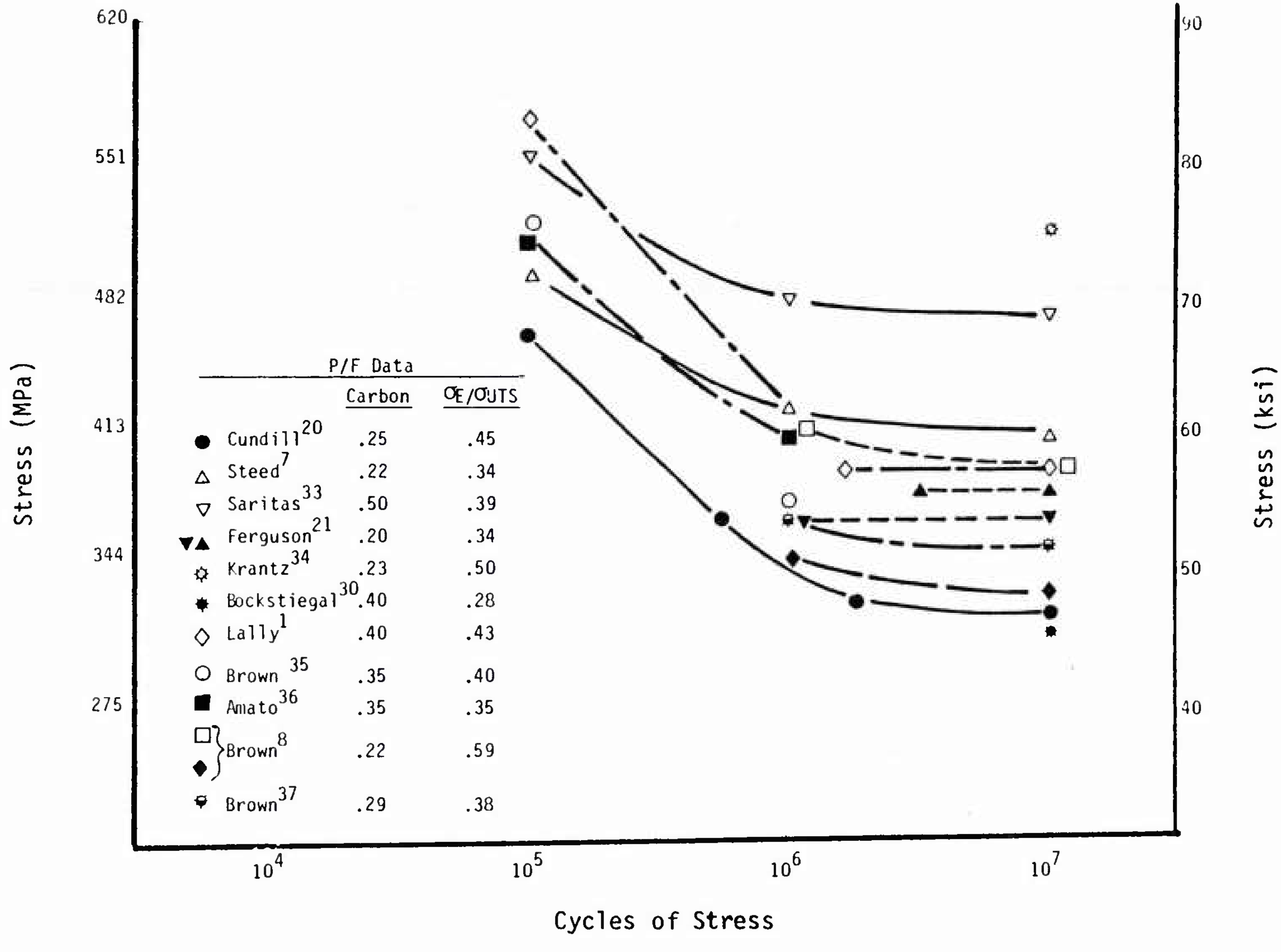

Figure 9. Fatigue properties of P/F 46XX.

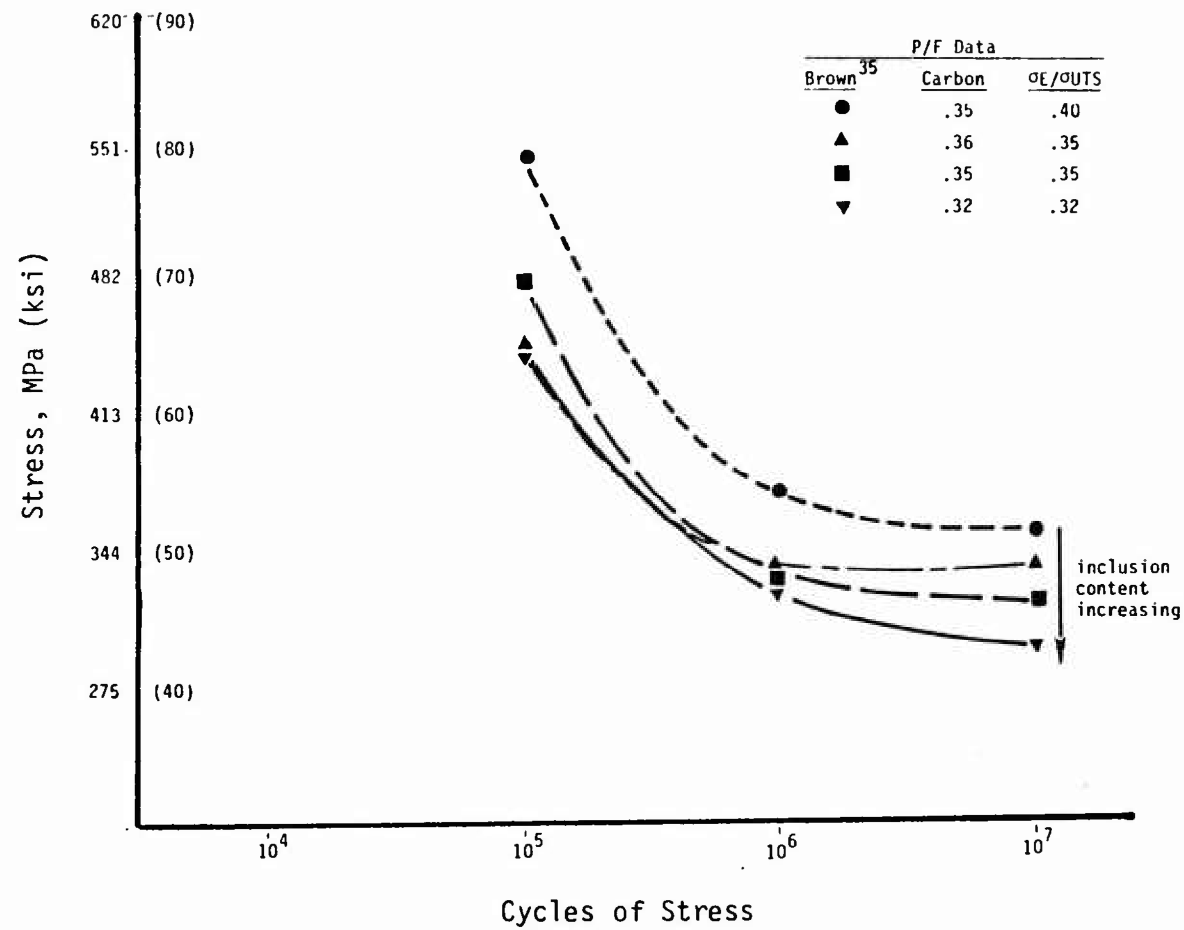

Figure 10. Effect of inclusion content on the fatigue properties of P/F 46XX.

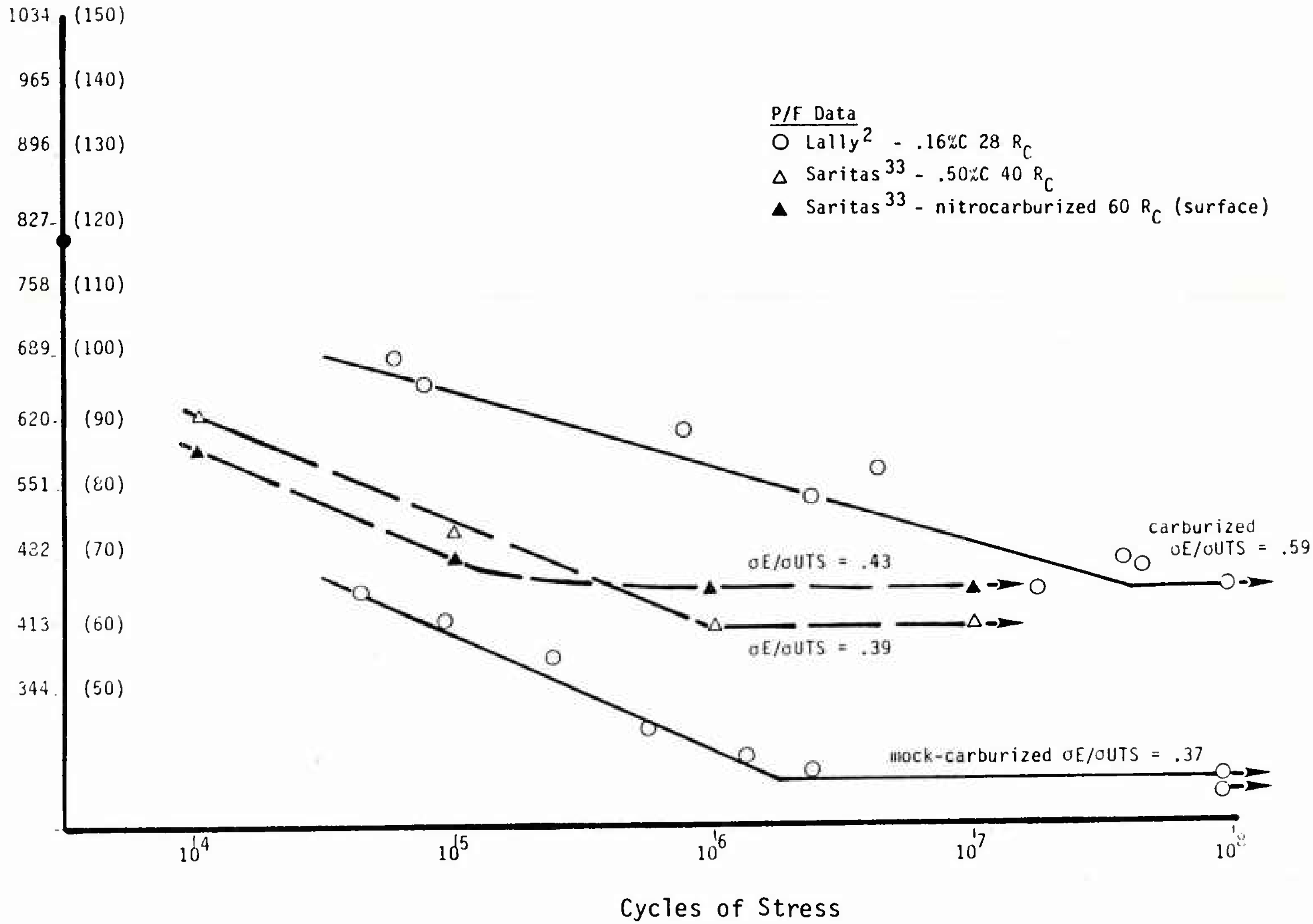

Figure 11. Effect of surface treatment on the fatigue properties of P/F 46XX.

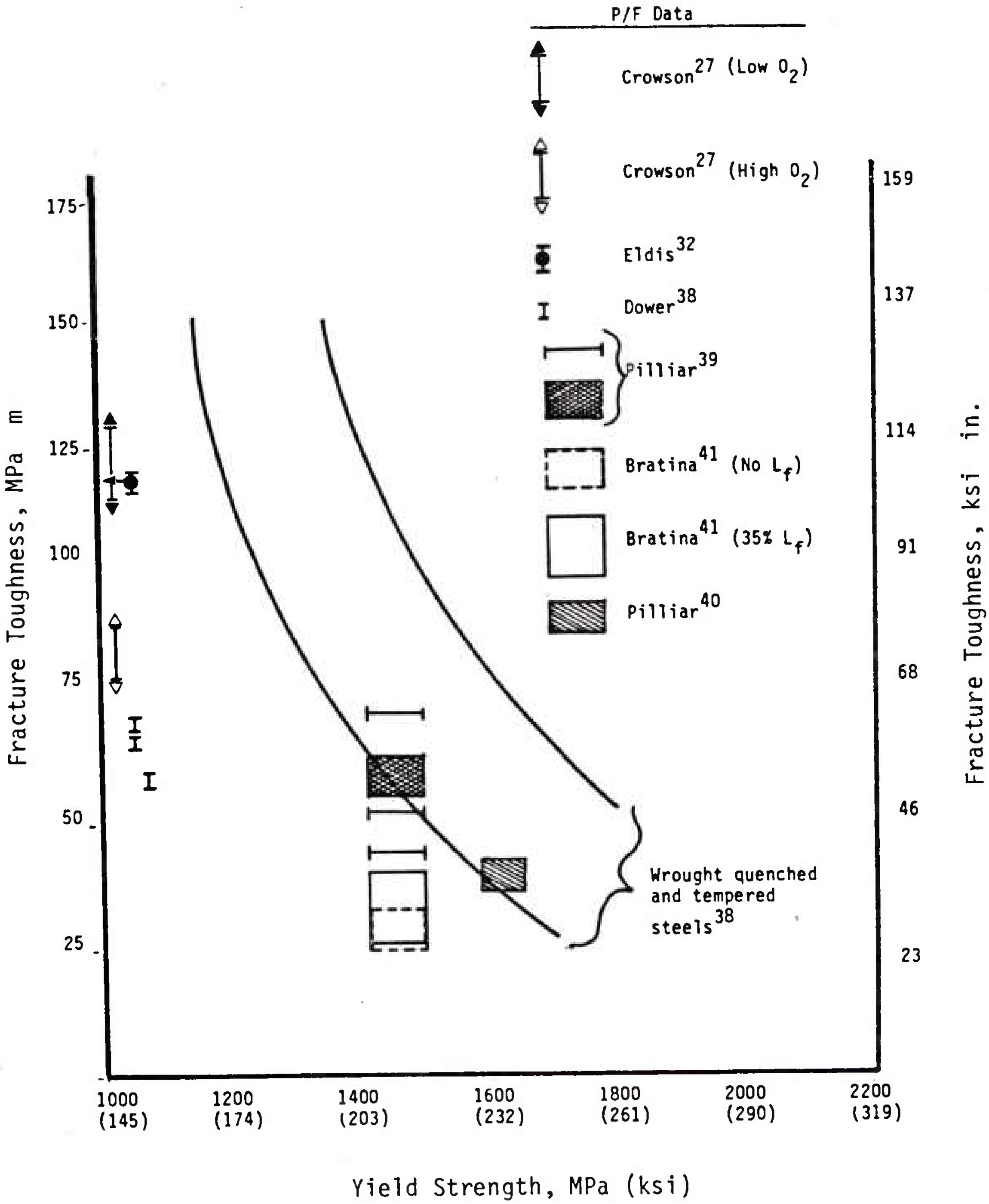

Figure 12. Fracture toughness of P/F 46XX vs. wrought low alloy steels.

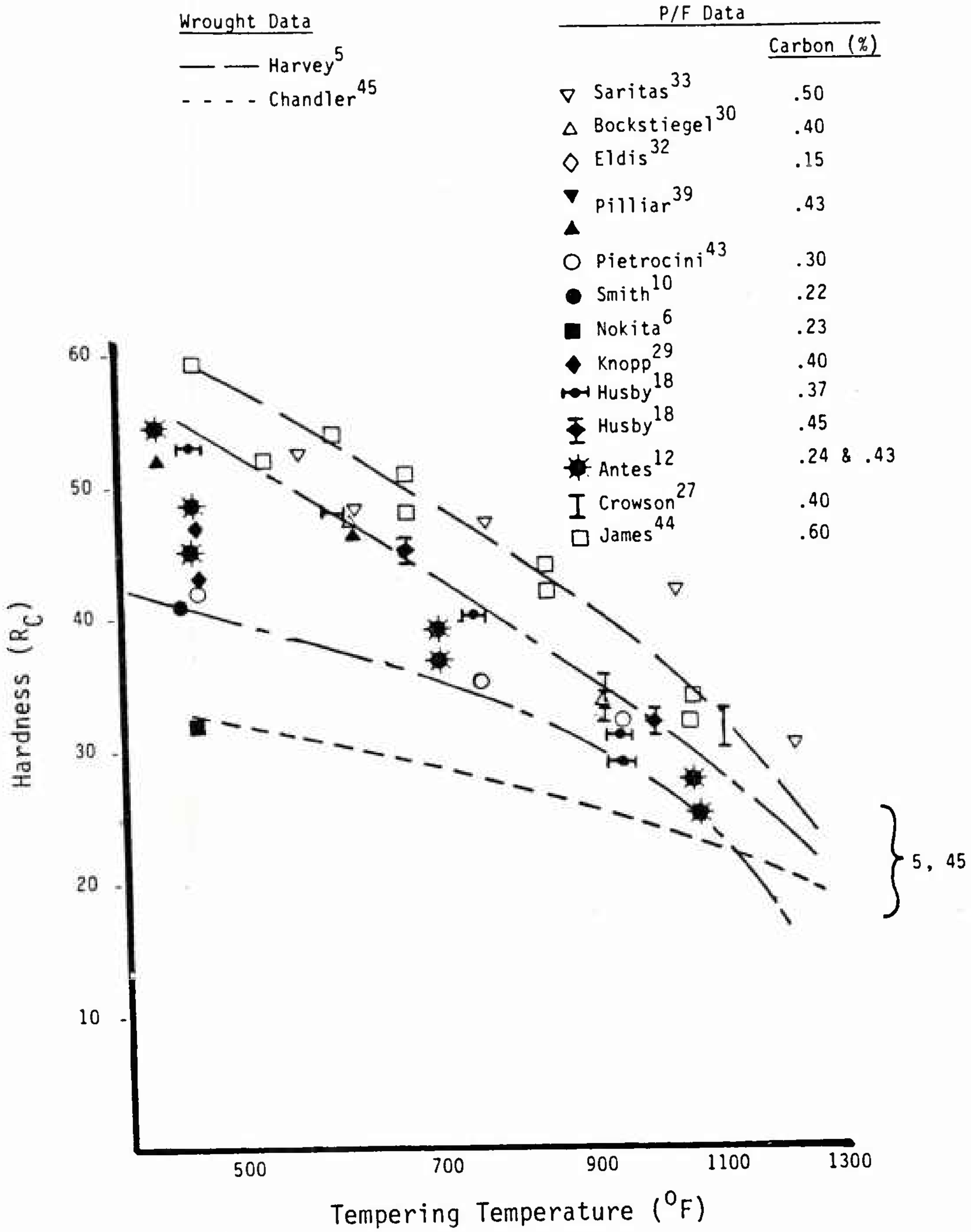

Figure 13. Tempering response of P/F 46XX vs. AISI 46XX.

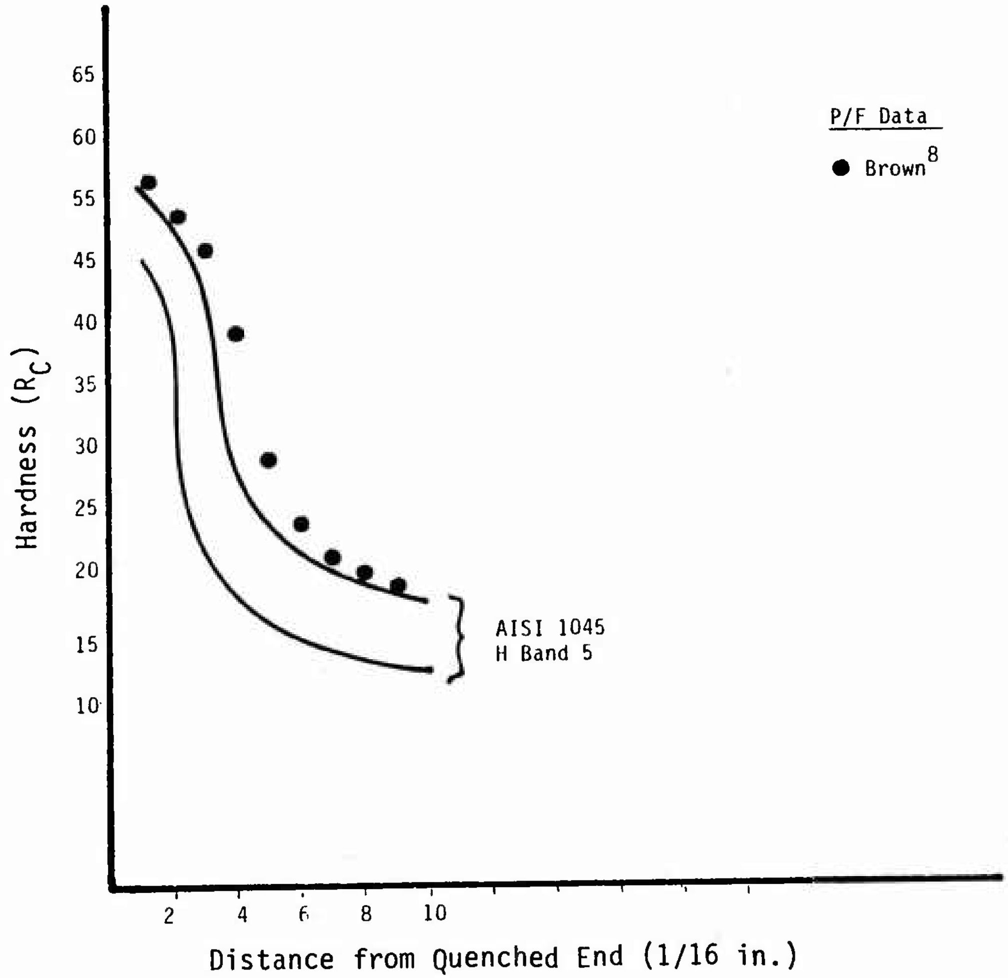

Figure 14. Hardenability of P/F 1047 vs. AISI 1045.

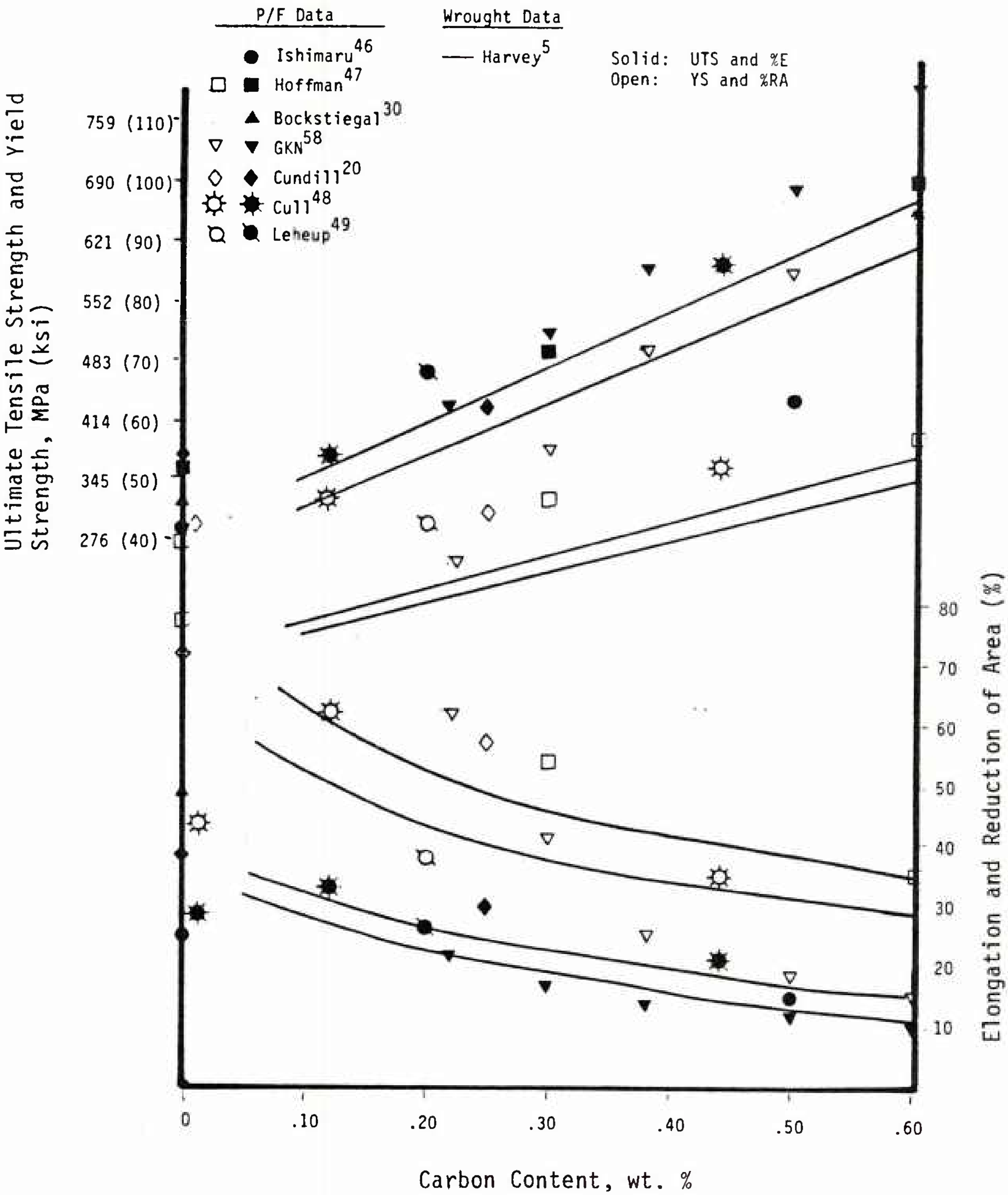

Figure 15. Tensile properties of P/F 10XX vs. AISI 10XX, as forged or normalized.

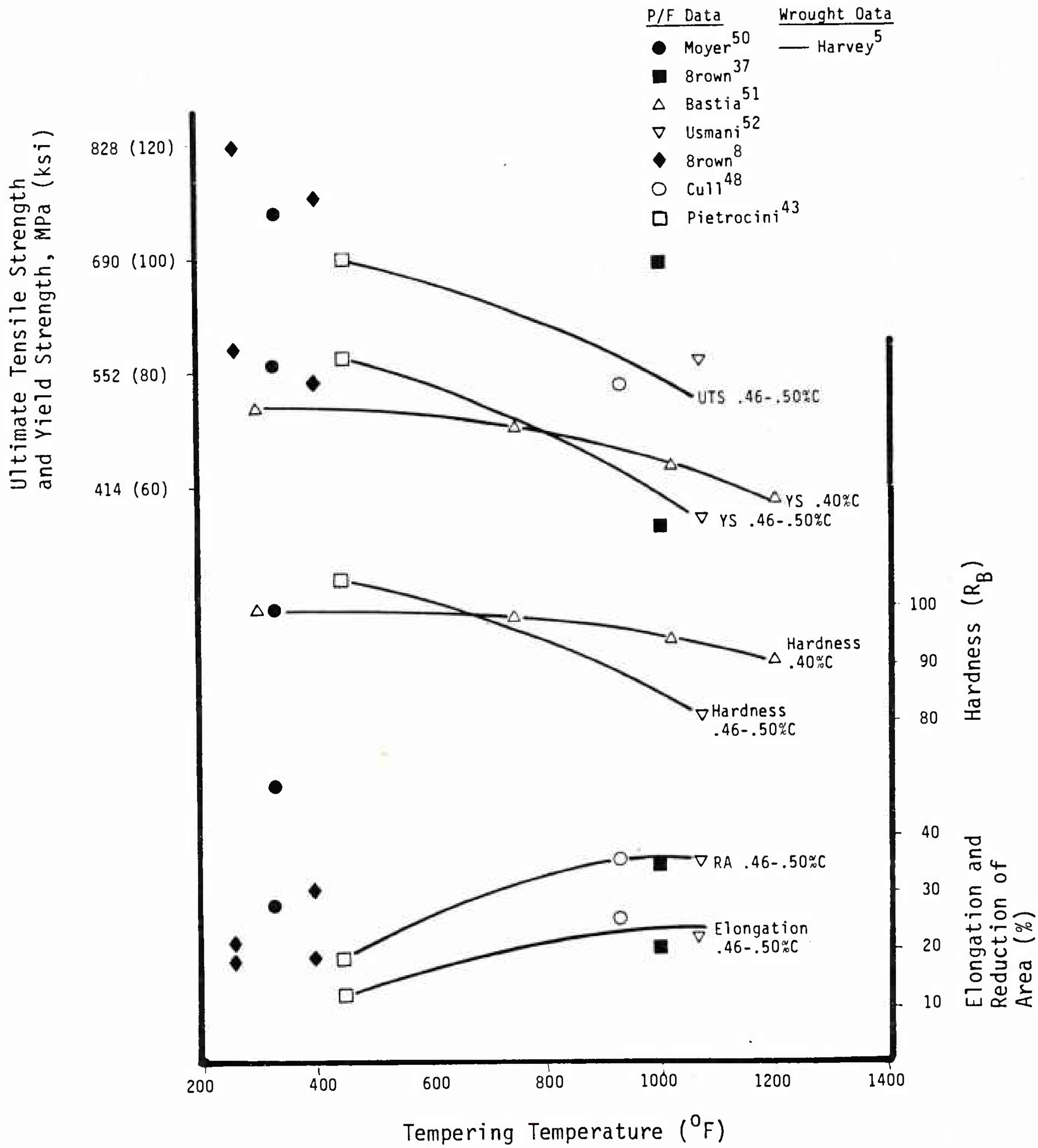

Figure 16. Tensile properties of P/F 10XX vs. AISI 10XX, quenched and tempered (Solid symbols: No tempering temperature given).

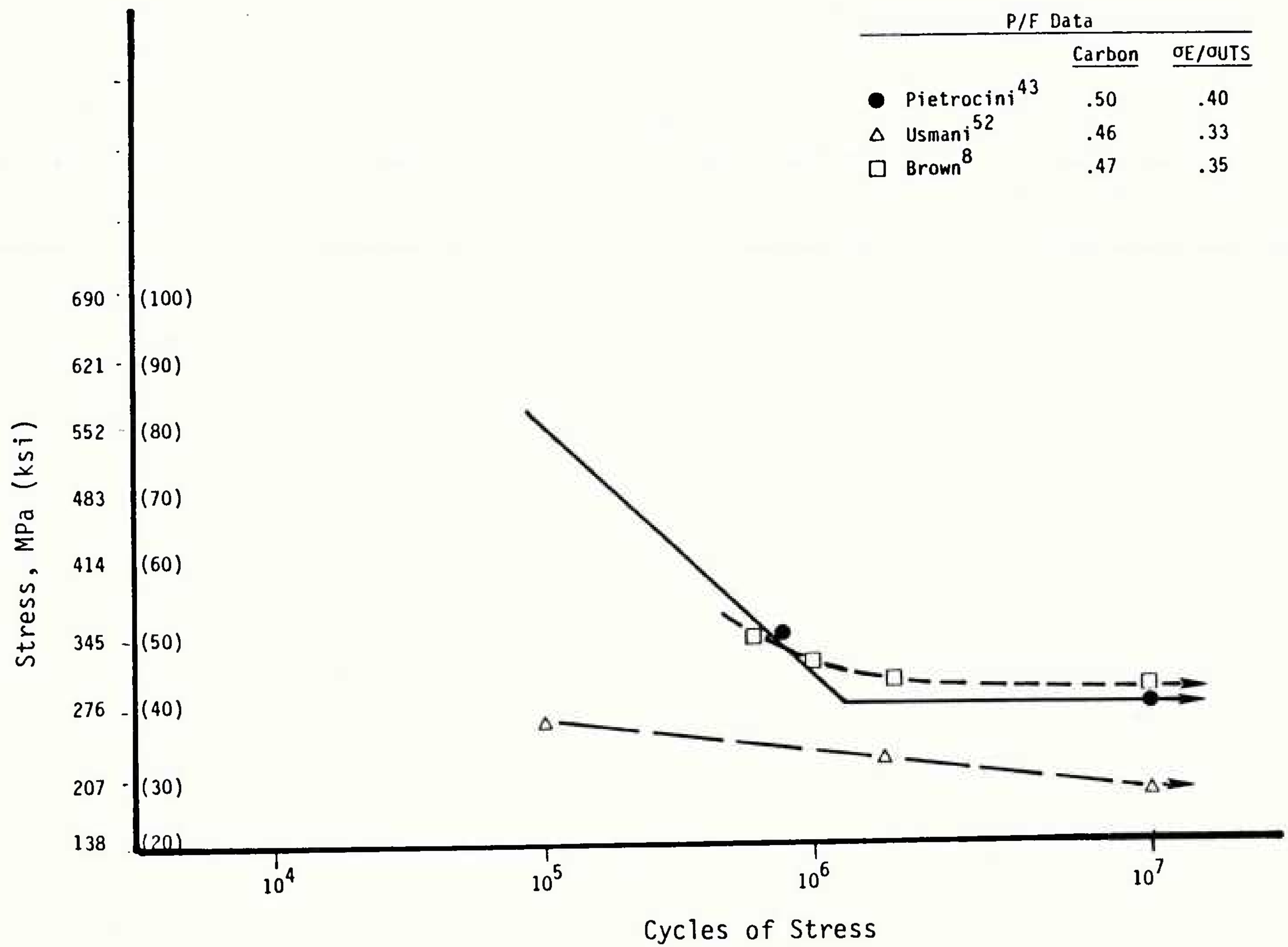

Figure 17. Fatigue properties of P/F 10XX.

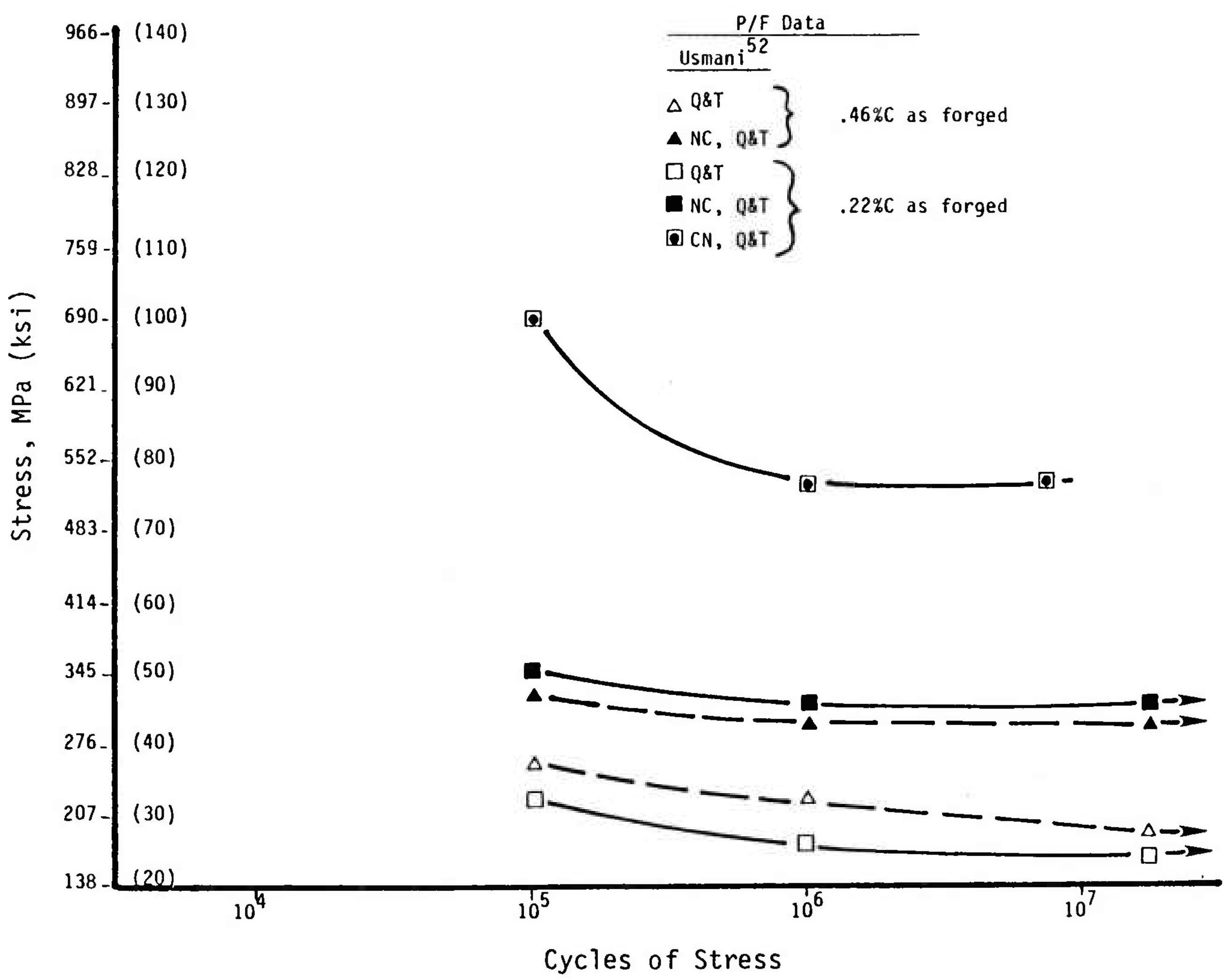

Figure 18. Effect of surface treatment on the fatigue properties of P/F 10XX.

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APPENDIX B

Feasibility of Producing Small Weapon
Components by Powder Forging -- Report
Submitted to SPS Technologies by
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May 11, 1984

Feasibility of Producing Small Weapon Components by Powder Forging

by

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Report Submitted to:
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A total of thirty armament parts drawings have been reviewed and evaluated to determine the feasibility of producing these parts by powder forging. This evaluation included a determination of the powder forged shape from the standpoints of achieving net surfaces where possible, adding any necessary material in the form of a forging envelope, calculating metal removal volumes per type of finish machining operation, and ranking the parts according to these criteria. Because the Army was not able to furnish cost information for parts produced by current production routes, it is believed that this type of approach to ranking these parts is most useful for determining actual economic feasibility.

A fundamental idea underlying this evaluation is that costs for parts procured by the Department of Defense cannot be evaluated on the same basis as parts procured by the private sector. A premium is placed on performance, especially for armament parts. Tooling is normally government property and is not amortized against production; this practice is significantly different from private sector practice. Because these parts are procured in small lots (per private-sector standards) and because of the mentioned differences between government and private-sector procurement, normal conventions for evaluating powder forging do not apply. Prime importance is placed on minimization of machining operations by forging net surfaces where possible or by incorporating a machining envelope to reduce machining requirements.

A. <u>Rating Strategy</u>:

The rating method was designed to emphasize the minimization of machining operations through formation of net surfaces. Three basic areas of part cost were rated, with these areas being given an importance factor in terms of overall cost. This approach removes actual dollar values from the rating, except for material costs.

The factors were considered according to their benefit on manufacturing. The three factors considered were:

1. <u>Net Surface</u>, which represents a positive factor in the manufacturing process;

2. <u>Material Cost</u>, which represents a negative factor; and

3. <u>Finish Machining</u>, which also represents a negative factor in the manufacturing process.

The method of determining these individual factors is described below.

These factors have been assigned values of 0.5, 0.15 and 0.35 respectively. These values reflect SPS's manufacturing capabilities for production of the armament components. (Cost analyses will be based on how SPS would manufacture the components.) These values can be altered according to user preference. With emphasis on net surface formation, where possible, to eliminate a machining operation(s) and set-up, it was decided to rate this area highest of the three. The importance of material cost was reduced from 0.3 to 0.15 to reflect the low cost of these materials in relation to the final value of these parts. Utilization was factored into the material cost rating. The importance of finish machining was increased from 0.2 to 0.35, again to reflect the importance of final part cost on machining. The overall rating was then calculated from these factors by:

Overall Rating = Net Surface Factor
- Material Factor
- Machining Factor

1. <u>Net Surface Rating Factor</u>:

The net surface rating factor is based on the formation of a surface that does not need finish machining and the type of machining operation that was eliminated. Each net surface is given an index, and these indices are added together and then multiplied by the importance factorof 0.5 to determine the final net surface rating factor. The net surface factor is given by:

$$\text{Net Surface Factor} = [\,\Sigma \text{indices}\,] * 0.5$$

where the indices for net surfaces are:

4-6 for gear teeth that replace hobbing operations,
2 for net splice teeth,
1.5 for surfaces which eliminate milling,
1 for surfaces which eliminate turning or facing,
1 for net through holes, and
0.5 for through holes requiring finishing.

Net surface is a positive factor in the overall rating since it represents cost reduction. For net surfaces which eliminate multiple machining operations, the net surface factor should be adjusted accordingly. Large net surface factors point to cost effective application of powder forging.

2. <u>Material Rating</u>:

The material rating factor is given by:

$$\text{Material Factor} = \frac{\$/\text{lb. P/M}}{\$/\text{lb. bar}} * \frac{\text{wt. P/M}}{\text{wt. bar}} * 0.15$$

The volumes of material used per part were estimated for powder-forged and conventionally-produced parts. The bar stock weights used are conservative since actual starting slug dimensions are unknown. For example, the amount of bar used as a forging "handle" for gripping is unknown and is not entered in the equation weight term. Similarly, kerf losses are not taken into account. Since density of the final part is independent of production route, volume can be used in place of weight. Raw material costs used in equation 3 are given in Table I.

TABLE I

Raw Material Costs

9310H bar stock	- $0.45/lb.
4340 bar stock	- $0.43/lb.
4130 bar stock	- $0.33/lb.
8620 bar stock	- $0.36/lb.
4615 bar stock	- $0.43/lb.
1035 bar stock	- $0.26/lb.
12L14 bar stock	- $0.31/lb.
A1000 preblended powder	- $0.34/lb.*
A4600 preblended powder	- $0.49/lb.*

Cost information estimated by: Mr. F. Hanejko,
Hoeganaes Corporation,
March 16, 1984

The material rating factor is viewed as a negative contributor to manufacturing and the overall rating. The raw powder cost is higher than conventional bar stock cost on a $/lb. basis. Therefore, for powder forging to be beneficial, the volume of powder required should be significantly less than the volume of bar stock required to produce the part. High utilization of powder vs. low utilization of bar stock translates into a low material rating factor -- the factor is less negative. Thus, high material utilization in this model means that the final rating is penalized less than a case where material utilization is poor.

For this contract, the material cost importance is low. This is generally true for parts that are produced in low volumes in a job-shop type of environment, and a premium is paid for performance. Other markets, such as automotive, place greater importance on material cost and utilization.

3. Finish Machining Factor:

The finish machining factor is probably the most difficult to describe quantitatively due to differences in machining operations, material differences and set-up differences. To determine this rating factor, machining is broken into milling, drilling/reaming, and turning/facing operations. Each of these operations is evaluated separately, and results are combined into a single machining factor that is multiplied by the importance value of 0.35. This factor is negative, with high rating values indicating high finish machining requirements. Low machining factors point to effective application of powder forging.

For each machining operation, size and material are important. Since powder forging necessitates material substitution, machinability can be affected. Using machinability indices of speed and feed for bar stock found in Cold Finished Bar Machining Data published by Republic Steel Corporation, indices were calculated for machining operations.

These indices are contained in Table II and represent metal removal rates. From Table II, it is obvious that free machining steels such as 12L14 have high indices, while alloy grades such as 4140 have lower indices. Powder-forged materials were assigned indices equal to conventional bar stock indices for that grade; for example, powder-forged 4620 was assigned indices identical to 4620 bar stock. The ratio of machinability indices between powder-forged and conventional material could then be used to determine a machining factor.

TABLE II

Machinability Indices for Weapon Materials

Material	Machining Operation	Size, in. Diameter	Speed	Feed	Index
12L14	Milling	0.5	280	.0035	0.980
		1.0	260	.0030	0.780
		1.5	260	.0029	0.754
	Drilling	0.25	165	.0063	0.040
		0.50	165	.0069	1.139
		0.75	180	.0081	1.458
	Reaming	<0.5	227	.0098	2.225
		>0.5	227	.0136	3.087
1020	Milling	0.5	120	.0018	0.216
		1.0	115	.0014	0.161
		1.5	115	.0013	0.150
	Drilling	0.25	76	.0035	0.266
		0.50	76	.0040	0.304
		0.75	83	.0047	0.390
	Reaming	<0.5	104	.0050	0.520
		>0.5	104	.0072	0.749
1035	Milling	0.5	115	.0017	0.196
		1.0	112	.0014	0.157
		1.5	112	.0013	0.146
	Drilling	0.25	73	.0034	0.248
		0.50	73	.0038	0.277
		0.75	80	.0045	0.360
	Reaming	<0.5	102	.0049	0.500
		>0.5	102	.0070	0.714

TABLE II - Continued

10L35	Milling	0.5	138	.0016	0.221
		1.0	132	.0013	0.172
		1.5	132	.0012	0.158
	Drilling	0.25	84	.0034	0.286
		0.50	84	.0037	0.311
		0.75	91	.0045	0.410
	Reaming	<0.5	120	.0046	0.552
		>0.5	120	.0066	0.792
1060	Milling	0.5	85	.0013	0.111
		1.0	83	.0010	0.083
		1.5	83	.0009	0.075
	Drilling	0.25	54	.0027	0.146
		0.50	54	.0030	0.162
		0.75	59	.0035	0.207
	Reaming	<0.5	75	.0036	0.270
		>0.5	75	.0057	0.428
4620	Milling	0.5	110	.0016	0.176
		1.0	106	.0013	0.138
		1.5	106	.0012	0.127
	Drilling	0.25	69	.0033	0.227
		0.50	69	.0036	0.248
		0.75	76	.0044	0.334
	Reaming	<0.5	96	.0046	0.442
		>0.5	96	.0066	0.634
4340	Milling	0.5	95	.0014	0.133
		1.0	91	.0012	0.109
		1.5	91	.0010	0.091
	Drilling	0.25	60	.0028	0.168
		0.50	60	.0031	0.186
		0.75	65	.0037	0.241
	Reaming	<0.5	83	.0040	0.332
		>0.5	83	.0057	0.473

Machining factors were calculated by:

$$\text{Machining factor} = [\ \varepsilon(\text{OF} * \text{MI} * \text{GF})] * 0.35$$

where: the operation factors (OF) were:

OF = 2 for milling operations
1.5 for drilling operations
1 for turning operations

the machinability index (MI) is:

$$\text{MI} = \frac{\text{Machinability index of bar stock}}{\text{Machinability index of powder forging}}$$

the geometric factor (GF) takes into account the difficulty of the operation.

GF = 1.0 for most operations
0.5 for drilling or reaming through holes that were powder forged under final size
1.5 for exceptionally difficult geometries

For the most part, the geometric factor was assigned 1.0 except for cases where a through hole was forged undersize and only required reaming, counterboring, etc., without first drilling the through hole; this case was assigned a geometric factor of 0.5. The value 1.5 was available to use for difficult machining cases, such as milling of recesses and undercuts, or where set-up was difficult.

B. Evaluation of Armament Parts:

1. Sleeve Guide for M240 Machine Gun:

At first appearance, the sleeve guide seems suited to powder forging. However, the thin walls and the lack of axisymmetric shape require that the part be forged as a solid shape. There is still a material utilization benefit by powder forging, as machining needs a 10L35 bar stock weight of 0.077 lbs., while powder forging requires only 0.031 lbs. of 1035 powder. The outer surfaces are forged as net surfaces, with the exception of chamfering corners. Slots must be milled on the sides of the top projection.

The rating for this part is:

Net shape factor = [1.5 + 1.5 + 0.5] * 0.5 = 1.75

Material factor = [(0.34/0.34) * (1.774/4.467)] * 0.15
= 0.065

Machining factor = [2 * (2 * (0.221/0.196) * 1) + (1.5 * (0.311/0.277) * 0.5) + (1.5 * (0.311/0.277) * 1)] * 0.35 = 2.463

Overall rating = 1.75 - 0.065 - 2.463 = -0.778

2. Back Buffer Plate for M240 Machine Gun:

The back buffer plate was judged impractical for powder forging due to the thin wall of the bore, the through hole configurations and the inability to reduce significantly machining and set-ups.

3. Threaded Machine Plug for M240 Machine Gun:

The threaded machine plug is currently machined from ~0.318 lbs. of 1035 or 1045 bar stock. It can be powder forged to a near-net shape using 0.173 lbs. of 1040 powder. The hex head can be completely formed; the bottom blind hole can be formed; the bottom side of the shoulder can be formed; and the threaded section can be formed to the outer diameter dimension of the thread. The only finish machining required is threading and cutting the top chamfer on the outer diameter of the part. The benefits of net shape and material utilization make this an economical application of powder forging in comparison to machining.

The rating for the threaded machine plug in comparison to machining is:

Net shape factor = [(3 * 1.5 + 1 + 1] * 0.5 = 3.25

Material factor = [(0.34/0.26) * (9.996/18.363)] * 0.15
= 0.107

Machining factor = [(1 * 1 * 1) * 2] * 0.35 = 0.700

Overall rating = 3.25 - 0.107 - 0.700 = 2.443

SPS plans to forge the threaded machine plug from bar stock, forming the hex head to net dimensions. The cost differential between powder forging and conventional forging is different from the above rating. The net surface benefit of powder forging is equaled by conventional bar stock forging in this case. Due to lower bar-stock cost, conventional forging is more economical than powder forging for this part.

The rating of this part in comparison to conventional forging is:

Net shape factor = [1] * 0.5 = 0.5

Material factor = [(0.34/0.26) * (9.996/11.000)] * 0.15
= 0.178

Machining factor = same as forging

Overall rating = 0.5 - 0.178 - 0 = 0.322

4. Extractor Block for M240 Machine Gun:

Powder forging of the extractor block would produce a solid shape with a net profile. This is an easy shape to powder forge. Milling the side flats and facing for height sizing would be eliminated. Raw-material usage would be cut from 0.107 lbs. of 12L14 bar stock to 0.070 lbs. of 1020 powder. However, drilling of the through holes, counter boring and threading of the off-axis through hole, drilling of the small blind hole, and milling of the groove must be performed. Powder metal is at a disadvantage in this case owing to the excellent machinability of 12L14 in comparison to conventional 1020 bar stock or a similar, low carbon-steel. Table II shows that 12L14 has a milling index 4.8 times greater than conventional 1020 bar and a drilling index about four times that of conventional 1020. This machinability penalty and the finish machining requirements hurt the economic performance of powder forging.

The rating for the extractor block is:

Net shape factor = [1.5 + 1.5 + 1] * 0.5 = 2.00

Material factor = [(0.34/0.31) * (4.007/6.172)] * 0.15 = 0.107

Machining factor = [2 * (0.78/0.161) * 1 +
2 * (1.5 * (1.04/0.266) * 1) +
1.5 * (1.04/0.266) * 1.5)] * 0.35
= 10.576

Overall rating = 2.0 - 0.107 - 10.576 = -8.683

5. <u>Front Block for M240 Machine Gun</u>:

The block front was judged impractical for powder forging. The complex shape and through-hole configurations make machining necessary on all surfaces. The result -- powder forging offers no advantages over conventional forging.

6. <u>Feed Pawl for M240 Machine Gun</u>:

The feed pawl (part no. 11826180) can be powder forged with net outer surfaces; thus, powder forging has higher material utilization than conventional machining, with 0.020 lbs. of 1060 powder being needed to forge the pawl, as opposed to at least 0.026 lbs. to machine plate stock. Bar stock would require considerably more material. In spite of net outer surfaces, considerable machining effort must be expended to mill the part slot (40 cu. mm metal removed), drill and counterbore the through holes in the tangs (50 cu. mm metal removed), and drill the flat-bottomed blind hole (73 cu. mm metal removed). These operations make powder forging economically open to question. The rating in comparison to forging would be lower, and powder forging definitely would not be economical.

The rating for this feed pawl is:

Net shape factor = [1.5 + 1.5 + 1 + 1] * 0.5 = 2.5

Material factor = [(0.34/0.26) * (1.175/1.469)] * 0.15 = 0.157

Machining factor = [(2 * 1 * 1) + 2 * (1.5 * 1 * 1)] * 0.35
= 1.75

Overall rating = 2.5 - 0.157 - 1.75 = 0.593

7. Feed Pawl for M240 Machine Gun:

The feed pawl (part no. 11826188) can be forged from powder, but the process does not appear to be economical. The outer surfaces can be forged net to save milling operations; however, the slot must be forged undersize (~ 6 mm wide) so milling or grinding is needed to size the slot. Also, the flat-bottomed blind hole must be machined, as well as the through hole in the tangs; the end corners must be rounded and/or angled as well. Machining from plate stock requires just 0.061 lbs. of material, and while powder can reduce the necessary starting stock weight to 0.044 lbs., this is not a high cost reduction for a limited volume part. Any benefit of powder forging is lost when compared to conventional forging because of the finish machining requirements.

The rating for this feed pawl is:

Net shape factor = [3 * 1.5] * 0.5 = 2.25

Material factor = [(0.34/0.26) * (2.540/3.519)] * 0.15
= 0.142

Machining factor = [2 * (2 * 1 * 1) + (2 * 1 * 0.5) +
(1.5 * 1 * 1)] * 0.35 = 2.275

Overall rating = 2.25 - 0.142 - 2.275 = -0.167

8. Tripping Lever for M240 Machine Gun:

The tripping lever was also judged impractical for powder forging owing to the thin walls of the part. A powder-forged part would have to be solid, with a tremendous amount of machining needed to finish the part. This would erase any benefit of forging net outer surfaces, and mate- utilization would be terrible.

9. Catch for M240 Machine Gun:

The catch is a candidate for powder forging, but, as described below, development and/or modification of the final dimensions would be needed. Material utilization can be improved by adopting powder forging, as only 0.037 lbs. of powder is needed to form the part as opposed to at least 0.066 lbs. of 1060 bar stock. More significant is the potential achievement of net surfaces and the limitation of expensive milling operations. Two powder forging possibilities exist. In one, the forging direction is selected to be parallel to the axis of the end through hole. The profile is forged to net shape, as are the top and bottom surfaces with the exception of the latch notches. The ability to forge the round projects on the one end of the catch to net outer dimensions is the real benefit of powder forging as the eliminated machining operation is viewed as a costly set-up and machining operation. Finish machining is relegated to drilling and reaming the cross hole (87 cu. mm metal removed), drilling and counterboring the end hole (148.3 cu. mm metal removed), and milling or grinding the notches in the other end projection. Two problem areas with this approach are the sharp corners needed on the tooling at the junction of the raised circular projection and the part surface, and the fact that all dimensions locate off the center through hole which must be drilled after all other surfaces are fixed. Modification of the final dimensions can eliminate the first problem by providing radii to strengthen the tooling; a fixture for finishing can reduce the location problems but not eliminate them.

Selection of the forging direction to be parallel to the center through hole reduces the problem of location and allows the part profile to be forged to net dimensions. The through hole cannot be forged to actual size owing to tolerance and size considerations; it can be forged undersized using a nonstandard and unrefined practice of replaceable core rods. End machining, sizing of the center through hole, and milling one side to adjust thickness would be required.

Although a low rating is projected for the catch, the rating could be higher with the above mentioned changes. With these, the catch would remain a difficult forging operation and require tight process controls to achieve the advantages of net surfaces. Development would most likely be required, and for this reason, the catch should not be a prime candidate at this time.

The rating for the catch is:

Net shape factor = [(3 * 1.5] + (1 * 1 * 0.5)] * 0.5 = 2.50

Material factor = [(0.34/0.26) * (2.124/3.795)] * 0.15
= 0.110

Machining factor = [(2 * 1 * 1) + 2 * (1.5 *1*1)] * 0.35
= 2.75

Overall rating = 2.5 - 0.110 - 1.75 = 0.640

10. Extractor Spacer for M240 Machine Gun:

Powder forging of the extractor spacer relies on the use of an oval preform to form the non-axisymmetric part shape. Placement of the preform in the cavity is critical. The bore must be forged undersize due to wall thickness considerations. The diameter of the core pin is marginal, and distortion is probable, especially in light of the non-symmetric shape. The flat on the outer wall cannot be forged and must be milled or ground. The finishing needed results in a slight material utilization benefit by powder forging of 0.101 lbs. of 1020 powder as opposed to 0.126 lbs. of 12L14 bar stock. However, the machinability differences between 12L14 bar stock and 1020 powder forged stock are great enough to remove this material benefit.

The rating for the spacer is:

Net shape factor = [1.5 + 1] * 0.5 = 1.25

Material factor = [(0.34/0.31) * (5.822/7.278)] * 0.15 = 0.132

Machining factor = [(2 * (0.78/0.161) * 1) + (1.5 * (1.044/
0.266) * 1)] * 0.35 = 5.444

Overall rating = 1.25 - 0.132 - 5.444 = -4.326

11. <u>Safety Catch for M240 Machine Gun</u>:

The safety catch was judged impractical for powder forging. The round shape and dimensions do not lend themselves to powder forging of net or near-net surfaces.

12. <u>Breech Bolt for M240 Machine Gun</u>:

The breech bolt is a complex shape. Powder forging has the ability to produce many of the top and bottom details to net shape and to produce the side profiles. Capability can minimize material requirements and most importantly eliminate milling set-ups and operations. Exact material requirements are difficult to determine for bar forging and for powder forging. For one, the extra bar required to hold the forging during hammer forging cannot be determined from the drawing. The exact amount of powder needed cannot be determined. With these limitations, it appears that powder forging will require at most 1.271 lbs. of 4650 powder; bar forging will require at least 1.593 lbs. of 8650 bar stock. Finish machining of the powder forging will include drilling of cross holes, milling of thin grooves on sides and undercuts, milling of fine details on the leading end of the bolt, and drilling of all lengthwise through- and blind holes. Since milling is not eliminated on many surfaces, this part is a marginal candidate for powder forging.

The rating for the breech bolt is:

Net shape factor = [5 * 1.5] * 0.5 = 3.75

Material factor = [(0.49/0.36) * (73.295/91.892)] * 0.15 = 0.163

Machining factor = [2 * (2 * 1 * 1) + 2 * (1.5 * 1 * 1)] * 0.35
= 2.45

Overall rating = 3.75 - 0.163 - 2.45 = 1.137

13. <u>Piston Extension Link for M240 Machine Gun</u>:

The piston link can be forged from a powder preform with net outer surfaces on all sides. Finish machining is required for the slot and the two through holes. The edges must also be chamfered. The part can be forged from preforms of 0.069 lbs. of 4650 steel powder. Machining from bar flats or plate would require at least 0.086 lbs. of raw stock, and bar stock would require even more weight. The benefits of powder forging to net profiles are offset by the drilling and milling needed to finish the part. Economics may be marginal and should be considered further.

The rating for this part is:

Net shape factor = [3 * 1 + 2 * 1.5] * 0.5 = 3.0

Material factor = [(0.49/0.36) * (3.978/4.974)] * 0.15 = 0.163

Machining factor = [(2 * 1 * 1) + 2 * (1.5 * 1 * 1)] * 0.35
= 1.75

Overall rating = 3.0 - 0.163 - 1.75 = 1.087

14. <u>Locking Lever for M240 Machine Gun</u>:

The locking lever falls into the category of parts that are amenable to powder forging by virtue of net surface capabilities, even for complex shapes. A conventional forging must be machined on all surfaces and requires a starting weight of at least 1.279 lbs. of 9310H bar stock. A powder forging requires at most 0.422 lbs. of 4620 powder and would have most of the top and bottom surface details forged to final dimensions, thus eliminating much milling. In addition, the open slot would be partially formed, and the tapered through slot would be near-net and possibly net. This shape capability reduces finish machining requirements to the drilling of cross holes and milling of fine details. However, locating will be more difficult due to the presence of some net surfaces and some surfaces that require machining. These difficulties are not factored into the rating.

The rating for this part is when compared to a hammer forging:

Net shape factor = [2 + 4 * 1.5 + 0.5] * 0.5 = 4.25

Material factor = [(0.49/0.45) * (24.323/73.800)] * 0.15 = 0.054

Machining factor = [(5 * (2 * 1 * 0.5) + 2 * (1.5*1*1.5)] * 0.35
(1.5 * 1 * 1.5)] * 0.35 = 3.325

Overall rating = 4.25 - 0.054 - 3.325 = 0.871

15. <u>Sear for M240 Machine Gun</u>:

The sear can be powder forged with a net bottom surface and a partially net top surface, with milling being eliminated. Other surfaces, however, cannot be forged to final dimensions and must be milled to size. For this reason, the part is not practical for powder forging. Even though the material utilization for powder forging is 100% better than for conventional machining, with 0.365 lbs. of 9310H stock being required as opposed to 0.188 lbs. of 4620 powder, economic success is not predicted for powder forging.

The rating for this part is:

Net shape factor = [1.5 + 1.5] * 0.5 = 1.5

Material factor = [(0.49/0.45) * (10.840/21.063)] * 0.15 = 0.084

Machining factor = [2 * (2 * 1 * 1) + 2 * (2 * 1 * 0.5)] +
(1.5 * 1 * 1)] * 0.35 = 2.625

Overall rating = 1.5 - 0.084 - 2.625 = -1.209

16. Housing Cap Damper for M242 Chain Gun:

The housing cap damper also was judged impractical for powder forging. No net surfaces could be forged, which eliminates any benefit of P/M forging for this part.

17. Aft Feed Sprocket for M242 Chain Gun:

The aft feed sprocket is judged to be a good candidate for powder forging. All surfaces, except the bore, can be forged to final dimensions. The dimensional precision of the bore demands machining. This amounts to 1902 cu. mm metal to be removed by drilling, reaming and countersinking. The benefit of net surfaces is the elimination of drilling and magnatrace machining to form the four sprocket fingers and the set-up involved. This shape promotes high material utilization for a precision process such as powder forging. Bar stock required to machine the part weights 1.366 lbs., while only 0.368 lbs. of powder is needed to forge the part.

Alternative processes are feasible and should be considered as production candidates. This shape could be milled in bar stock; individual pieces could then be sectioned. This approach offers set-up cost savings. Another approach to consider is blanking followed by gang milling. This approach saves material and still derives the benefit of milling more than one part at a time. A third possible approach involves sectioning bar stock into blanks, clamping these in stacks, and cutting the sprocket fingers by wire EDM on a multi-head wire machine. Although wire EDM is expensive, the ability to cut many parts simultaneously may make this method economical.

The rating for powder forging this part is:

Net shape factor = [4 * 1.0 + 4 * 1.5 + 1.5 + 1.0 + 0.5] * 0.5
= 6.25

Material factor = [(0.49/0.33) * (21.200/78.800)] * 0.15 = 0.060

Machining factor = [(1.5 * 1 * 1.5)] * 0.35 = 0.788

Overall rating = 2.25 - 0.060 - 0.788 = 5.402

18. Worm Gear Shaft for M242 Chain Gun:

The worm gear shaft can be forged from a powder preform, with the teeth being formed net. All other surfaces of the forging would require machining. The bore must be forged undersize and then reamed (1,330 cu. mm metal removed) and slotted. The outer surface must be turned (20,358 cu. mm metal removed). The top surface and the bottom surface must be faced. Chamfers must be cut. The benefit of net teeth is offset partially by the necessary machining. Material utilization for powder forging is slightly better than for machining of bar stock, with 0.909 lbs. of powder being required as opposed to 1.225 lbs. of bar stock.

The rating for this part is:

$$\text{Net shape factor} = \lfloor 4 + 0.5 \rfloor * 0.5 = 2.25$$

$$\text{Material factor} = [(0.49/0.33) * (52.449/70.686)] * 0.15 = 0.165$$

$$\begin{aligned}\text{Machining factor} &= [(1.5 * 1 * 0.5)] + 3 * (1 * 1 * 1)] * 0.35 \\ &= 1.313\end{aligned}$$

$$\text{Overall rating} = 1.25 - 0.324 - 0.75 = 0.776$$

19. <u>Drive Sprocket for M242 Chain Gun</u>:

The drive sprocket is an excellent candidate for powder forging. A powder-forged drive sprocket would have net sprocket teeth and net spline teeth, with the top section of the bore also being net. Finish machining would include turning the outer diameter undercut and turning the inner diameter undercut on one side only. Top and bottom surfaces would be net. The material requirements to make this part would be 1.706 lbs. of 4230 bar stock as opposed to 1.008 lbs. of 4630 powder.

The rating for this part is:

$$\text{Net shape factor} = [6 + 2 + 1 + 1] * 0.5 = 5.0$$

$$\text{Material factor} = [(0.49/0.33) * (58.172/98.417)] * 0.15 = 0.132$$

$$\text{Machining factor} = [(1 * 1 * 1) + (1 * 1 * 0.5)] * 0.35 = 0.525$$

$$\text{Overall rating} = 5.0 - 0.132 - 0.525 = 4.343$$

20. <u>Feeder Handle Latch for M242 Chain Gun</u>:

The feeder handle latch can be powder forged with many net surfaces. All profile surfaces can be forged net, with only drilling of the through hole (437 cu. mm metal removed to form the 4.37 mm diameter hole) and milling of the recess (336 cu. mm metal removed) being needed to finish the part. Because of net surface formation, material utilization of powder is significantly higher than for bar stock, with 0.066 lbs. of 4630 powder being needed as opposed to 0.367 lbs. of 4130 bar stock. This part is rated to be a good candidate for powder forging as opposed to total machining because of the achievement of net surfaces and minimization of machining. In comparison to conventional forging, powder forging does not have significant advantages for this part.

Precision casting of 17-4 PH stainless steel is listed as an acceptable alternative and should be considered.

The rating for this part in comparison to machining is:

Net shape factor = [4 * 1.5] * 0.5 = 3.0

Material factor = [(0.49/0.33) * (3.814/21.147)] * 0.15 = 0.040

Machining factor = [(2 * 1 * 1) + (1.5 * 1 * 1)] * 0.35 = 1.225

Overall rating = 3.0 - 0.040 - 1.225 = 1.735

21. Clutch Spur Gear for M242 Chain Gun:

The outer gear teeth and external spline teeth of the clutch spur gear can be powder forged as net surfaces. This represents the only advantage of powder forging for this part. The bore must be forged undersize (~10.1 mm diameter) because of the thin wall section behind the spline teeth. Thus, the bore must be drilled and reamed (~12,500 cu. mm metal to be removed). The top face of the gear section must be faced (56,670 cu. mm metal to be removed). The cup must be faced, turned and milled in two places to form the inner diameter wall indents (27,500 cu. mm metal to be removed). Even with this level of finish machining, powder forging has an appreciable material utilization advantage over conventional machining. Machining requires a raw weight of 6.431 lbs. of 4140 bar stock as opposed to 3.047 lbs. of 4640 powder for forging.

The rating for this part is:

Net shape factor = [4 + 2 + 0.5] * 0.5 = 3.25

Material factor = [(0.49/0.33) * (175.757/371.009)] * 0.15
= 0.106

Machining factor = [[(2 * 1 * 1) + (1.5 * 1 * 1.5)] + (1*1*1)] *
(1 * 1 * 1)] * 0.35 = 1.838

Overall rating = 3.25 - 0.106 - 1.838 = 1.306

22. Clutch Dog for M242 Chain Gun:

The clutch dog can be powder forged with high material efficiency by virtue of net surface formation. Machining from bar stock can produce two parts per bar section, requiring 0.222 lbs. per part. The powder weight requirement is 0.070 lbs. per part. Machining needed to finish the forging is turning of the stem, chamfering, and drilling and counterboring of the through holes. The ability to machine two parts per section of bar stock reduces the benefit of powder forging, especially in light of the inability to forge the shaft to a net surface. Powder forging benefit may be further reduced if 4340 tube stock is used.

The rating for this part is:

Net shape factor = [2 * 1.5 + 2 * 1.0] * 0.5 = 2.50

Material factor = [(0.49/0.43) * (4.049/12.831)] * 0.15
= 0.054

Machining factor = [(1 * 1 * 1) + 2 * (1.5 *1*1)] * 0.35
= 0.054

Overall rating = 2.5 - 0.054 - 1.046 = 1.046

23. Feed Shaft Clutch for M242 Chain Gun:

The feed shaft clutch for the M242 chain gun cannot be powder forged to a net shape. Nonetheless, it is a viable powder forging. The internal spline would be forged to a net surface, with all other surfaces requiring some type of machining. The cup section would require finishing on the outer diameter, either a finishing pass on the lathe or outer diameter grinding. The inner diameter of the cup would be partially formed during forging and would require turning of the inner diameter and facing on the bottom, with 12,090 cu. mm of metal to be removed. The four windows in the cup wall would have to be milled or ground to remove 431 cu. mm of metal per window. The outer diameter groove must be turned, with 15,700 cu. mm of metal to be removed. The outer diameter across the end lugs must be turned, and the end lugs must be faced. The cross holes in the end lugs must be drilled as well as the two through holes in the cup bottom. While this amounts to considerable machining, it is significantly less than the machining required currently, especially in light of net spline teeth. Benefits of powder forging are the net spline, near-net lugs which require no milling, and a near-net cup outer diameter, which requires just one finishing pass. Material utilization for powder forging is higher than for conventional machining, with 1.091 lbs. of powder needed to forge the part as opposed to 2.186 lbs. of 4340 bar stock to machine the part.

The rating for this part is:

Net shape factor = [2 + 2 * 1.5 + 2 * 0.5] * 0.5 = 3.0

Material factor = [(0.49/0.33) * (62.929/126.096)] * 0.15
= 0.111

Machining factor = [(2 * 1 * 1) + 3 * (1 * 1 * 1)] * 0.35 = 1.75

Overall rating = 3.0 - 0.111 - 1.75 = 1.139

24. Motor Gearbox Bevel Gear for M242 Chain Gun:

The aim of powder forging the motor gearbox bevel gear is the formation of net gear and internal spline teeth. Through tight control of the process variables, this can be achieved. However, significant turning of the gear's back face will be necessary to form the undercut and to size the hub outer diameter. The hub outer diameter must be forged oversize due to the thinness of the finished wall. A weight of 1.418 lbs. of 4340 bar stock is estimated to be required to produce this part by conventional methods. A powder forging would weigh 0.879 lbs., which represents more efficient material utilization by powder forging. Finish machining would include outer diameter turning to size the hub and form the back face details (step and undercut) and cutting the angle on back side of the gear teeth, facing the small diameter end, and chamfering. This part represents a good candidate for powder forging.

The rating for this part is:

Net shape factor = [6 + 2 + 1] * 0.5 = 4.5

Material factor = [(0.49/0.43) * (50.718/81.781)] * 0.15
= 0.106

Machining factor = [(1 * 1 * 2) + (1 * 1 * 1.5)] * 0.35 = 1.225

Overall rating = 4.5 - 0.106 - 1.225 = 3.169

25. Cluster Gear for M242 Chain Gun:

The cluster gear is not a candidate for conventional powder forging. The outer gear tooth sections would require complex metal flow and a complex preform in order to consider the possibility of forging net gear teeth. Extensive machining would be required, including forming the bore undercut, drilling the lightening holes, milling the relief between the small and large gear, and sizing the bearing surface. Because of the high machining requirements and the complexity of the preform and forging operation, a monolithic powder forging is not practical.

Design changes should be examined to permit other configurations to be applicable. For example, a small gear and a large gear could be powder forged separately and then joined by pins, bolts or some other mechanical-joining technique.

26. Bevel Pinion for M242 Chain Gun:

The bevel pinion can be powder forged with net gear teeth and net internal spline teeth with the proper process controls. A potential problem area is the top face of the gear owing to the thinness of material between the bore spline and the outer gear teeth, which limits the size of the bottom punch. (The gear would be forged teeth down.) Material volume requirements are 0.423 lbs. of 4340 bar stock as opposed to 0.253 lbs. of 4640 powder. The powder forging would require turning on the back face of the gear to size the hub and to form the angled face; this amounts to 3,320 cu. mm of metal to be removed. The stem must be faced to achieve the correct part thickness. The ability to eliminate gear cutting makes this a candidate for powder forging.

The rating for this part is:

Net shape factor = [6 + 2 + 2] * 0.5 = 5.0

Material factor = [(0.49/0.43) * (14.585/24.423)] * 0.15
= 0.102

Machining factor = [2 * (1 * 1 * 0.5)] * 0.35 = 0.35

Overall rating = 5.0 - 0.102 - 0.35 = 4.548

27. <u>Firing Pin for M242 Chain Gun</u>:

The firing pin for the M242 chain gun is not feasible for powder forging owing to its shape. Thin, round parts with long lengths are generally not suited to powder forging.

28. <u>Bolt Carrier for M242 Chain Gun</u>:

The carrier bolt is currently machined from forged 4340 steel. It is a complex shape; machining is required on all surfaces to finish the part. The benefit of powder forging for this part is the achievement of some net surfaces. Due to the complexity of shape, that is, large noncircular through holes, thin webs, etc., this part is not considered to be currently viable and would require development work prior to commercial production by powder forging. Justification for this development can be derived from these projections. Raw material weight requirements can be decreased by at least 2.7 lbs. by switching to powder forging. Milling requirements can be reduced, which combine with material utilization to support implementation of powder forging for this part.

The overall rating for this part is projected below, but bear in mind that development work would be required prior to commercial production.

Net shape factor = [7 * 1.5] * 0.5 = 5.25

Material factor = [(0.49/0.43)*(438.004/595.594)] * 0.15
= 0.126

Machining factor = [3*(2*1*1.5)] * (1.5*1*1)] * 0.35 = 0.3675

Overall rating = 5.25 - 0.126 - 3.675 = 1.449

29. <u>Chain Sear Arm for M242 Chain Gun</u>:

Currently, the chain sear arm is machined from 4340 bar stock. It can be forged from a 4640 steel powder preform with many net surfaces. The top-surface details can be forged to final dimensions, eliminating milling operations. Bottom and back face details also can be forged net. Owing to tooling limitations, the top half of each side must be milled after forging, and the round shaft must be turned. Milling or grinding of the shaft bottom depression is recommended. Because of the finish machining requirements, the material utilization projected for powder is only slightly higher than that of bar stock. For bar stock, ~ 0.296 lbs. of material is required as opposed to ~ 0.246 lbs. of powder.

Milling the side steps removes 1,300 cu. mm of stock, turning the shaft round removes 4960 cu. mm, and grinding the shaft depression removes 2,640 cu. mm.

The rating for this part is:

Net shape factor = [5 * 1.5] * 0.5 = 3.75

Material factor = [(0.49/0.43) * (14.210/17.064)] * 0.15
= 0.142

Machining factor = [4 * (2 * 1 * 1) * (1 * 1 * 1)] * 0.35 = 3.15

Overall rating = 3.75 - 0.142 - 3.15 = 0.458

30. Clutch Gear for M242 Chain Gun:

The clutch gear represents a two-level forging that requires complex metal flow. Nonetheless, this part can be powder forged, with the benefits being net gear teeth, a net outer diameter shaft surface, and an undersized through hole. Material utilization for powder forging is high, with conventional machining requiring 0.815 lbs. of 4340 bar stock as opposed to 0.354 lbs. of 4640 powder. Finishing the powder forging includes the removal of ~162 cu. mm of metal from the bore, ~950 cu. mm by milling to form the shaft slot, turning of 1,950 cu. mm of metal to form the bearing surface, and chamfering. Machining requirements for this part outweight the benefits of net and near-net surfaces.

The rating for this part is:

Net shape factor = [6 + 1.0 + 0.5 * 0.5 = 3.75

Material factor = [(0.49/0.43) * (20.436/47.012)] * 0.15
= 0.074

Machining factor = [(2 * 1 * 1.5) + (1*1*2)] + (1*1*0.5)] * 0.35
= 1.925

Overall rating = 3.75 - 0.074 - 1.925 = 1.751

C. Summary of Results:

The results of the ratings are contained in Table III for 10XX steel parts and Table IV for 46XX steel parts. High ratings indicate high chances of successfully implementing powder forging from both an economic and manufacturing standpoint. It is evident that parts which offer high material utilization and, most importantly, net surfaces are the best candidates.

The 10XX series parts do not represent a collection of parts which should be forged from powder. The ratings in Table III show that there are only three parts -- the threaded machine plug, the catch, and the feed pawl (no. 18826180) -- that have any promise at all, and that these are not strong candidates in terms of economic success.

The 46XX series of parts contains four prime candidates and several secondary but still promising candidates. The major feature of the primary candidates is the achievement of a net complex surface, such as a gear tooth or sprocket surface, with no machining required on that surface. The secondary candidates also achieve net surfaces, but in many cases, machining is needed on adjacent surfaces that cause location problems or reduce the benefit of a partial net surface. Some machining can cost as much or more than total machining of a surface.

The recommended parts to consider for powder forging are:

1. Aft Feed Sprocket (part no. 1252-4153) - 4630 powder

2. Bevel Pinion (part no. 1252-4456) - 4640 powder

3. Drive Sprocket (part no. 1252-4393) - 4630 powder

4. Bevel Gear (part no. 1252-4457) - 4640 powder

These parts stand out from the others as prime candidates for powder forging because of their ratings; other parts stand out as poor candidates because of low ratings. There are several parts that fall into the middle ground. These are parts that can be forged with some net surfaces, but considerable finish machining is required. Depending on the actual manufacturing operation against which they are being compared, they may or may not prove to be economical. This category includes parts with ratings between 1 and 2, such as the feeder latch handle, the feed shaft clutch, the clutch dog, the clutch gear, the clutch spur gear, and the piston extension link. As economic considerations change, these parts may project higher ratings and, at that time, would become candidates for implementation of powder forging.

TABLE III

Ratings for 10XX Armament Parts

Part	Current Material	Powder Material	Rating
Guide Sleeve	10L35	1035	-0.778
Back Buffer Plate	10L35	1035	impractical
Threaded Machine Plug	1035/ 1045	1040	2.443 (vs. machining) 0.322 (vs. forging)
Extractor Block	12L35	1035	-8.683
Block Front	1060	1060	impractical
Feed Pawl (#11826180)	1060	1060	0.593
Feed Pawl (#11826188)	1060	1060	-0.167
Tripping Lever	1060	1060	impractical
Catch	1060	1060	0.640
Extractor Spacer	12L14	1020	-4.326

TABLE IV

Ratings for 46XX Armament Parts

Part	Current Material	Powder Material	Rating
Housing Cap Damper	4130	4630	impractical
Aft Feed Sprocket	4130	4630	5.402
Worm Gear Shaft	4130	4630	0.776
Drive Sprocket	4130	4630	4.343
Feed Latch Handle	4130	4630	1.735
Clutch Spur Gear	4140	4640	1.306
Clutch Dog	4340	4640	1.046
Feed Shaft Clutch	4340	4640	1.139
Bevel Gear (motor gearbox)	4340	4640	3.169
Cluster Gear	4340	4640	impractical
Bevel Pinion	4340	4640	4.548
Firing Pin	4340	4640	impractical
Bolt Carrier	4340	4640	1.499 (R&D)
Chain Sear Arm	4340	4640	0.458
Clutch Gear	4340	4640	0.901
Safety Catch	4140	4640	impractical
Breech Bolt	8650	4650	1.137
Piston Extension Link	8650	4650	1.087
Locking Lever	9310H	4620	0.871
Sear	9310H	4620	-1.209

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