

# **IMPACT AND FATIGUE CHARACTERIZATION OF SELECTED FERROUS P/M MATERIALS**

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## **Abstract**

Dynamic property data on pressed and sintered ferrous powder metallurgy materials have come under increasing demand as the P/M industry has grown into areas of application involving more highly stressed components. Data collected from relatively simple dynamic property tests will provide new avenues for P/M alloy development.

Un-notched Charpy impact energy and rotating bending fatigue tests have been used to characterize commonly used P/M steels. The endurance ratios of porous steels have been found to be relatively insensitive to processing, with higher strength materials giving proportionally higher endurance limits. Since impact energy was not strongly affected by varying the carbon content up to the eutectoid composition, increasing the carbon content of low alloy steels is a viable way of increasing endurance limit.

Impact energy transition temperature has been found to be a factor in carbon-free phosphorus steels, but not in conventional low alloy steels. As has been indicated in the literature, sintered density is crucial to both impact energy and fatigue endurance limit.

Metallographic examination of the fatigue cracks has provided some insight into the nature of the R.B.F. test.

## **Introduction**

In response to demand from design engineers, several parts producers have begun to compile independent databases on dynamic properties of porous steels. The purpose of the present study is to take a first step in providing a public domain database on dynamic properties of commonly used commercial P/M alloys.

Un-notched Charpy impact energy and rotating bending fatigue strength measurements have been used in this study to characterize dynamic properties.

### **Impact Energy**

*Comparison of Fully Dense and Porous Steels* - The impact energy of porous steels is so much lower than that of fully dense materials that the two cannot be compared directly. The standard impact energy test specimen for wrought steels has a machined notch, as shown in Figure 1. The purpose of the notch is to

create a triaxial tensile stress state at the notch tip on loading. Without the notch, many low alloy steels could not be broken in typical impact test machines. In contrast, porous steels must be tested in the un-notched condition to yield any measurable impact energy at all. For example, when a Distalloy 4800A steel having an un-notched impact energy of 30 ft-lbs was tested with a standard V-notch, the impact energy fell to less than two ft-lbs.

Thus, the impact energies reported here could not be used in part design in the same way that impact energy data on wrought materials are. Instead, they are best used as a means of comparison between different porous steels, and in conjunction with experience with other materials known to be successful in similar parts.

Impact Energy Transition Temperature - One aspect of the impact energy has been found to hold true regardless of the porosity of the material: the impact energies of wrought and P/M steels alike vary with the test temperature. The impact energy of Ancorsteel 1000B with 0.55%P added was 10 ft-lbs when measured at room temperature. At 32°F, the impact energy was 3 ft-lbs. Increasing the density by double pressing shifted the whole impact energy curve upward, but did not change the sharpness of the impact energy transition on cooling. Fortunately, the impact energy/temperature curves for low alloy steels at medium carbon levels were found to have much more gradual slopes than those of the carbon free phosphorus steels.

#### Fatigue Strength

Comparison of Fully Dense and Porous Steels - Unlike impact energy, the fatigue strength of porous steels is comparable to that of wrought steels in the same way that their tensile strengths are comparable. For example, Ancorsteel 4600V which has been hot pressed to full density and heat treated to a tensile strength of 220,000 psi has an endurance limit of 78,000 psi (at 0.3% carbon). At 92% of theoretical density (and 0.5% carbon), the tensile strength in the heat treated condition decreased to 173,000 psi, and the endurance limit was 57,000 psi. The endurance ratio did not vary significantly with density.

Thus, unlike impact energy measurements, which can only be used for comparison between different P/M steels, endurance limit measurements on porous steels have direct applicability to part design considerations.

Comparison of Fatigue Testing Methods - Rotating bending fatigue (RBF) tests yield generally higher endurance limit results than uniaxial fatigue tests on the same materials. Some possible causes for this are presented in the Discussion section. Which test method is more applicable to part design is not clear. While the uniaxial tests are more flexible in stress ratio and yield more conservative endurance limits, R.B.F. tests often closely simulate the real life operating conditions of rotating parts.

The results reported here are based on materials tested under laboratory conditions, as outlined in the Experimental section. Accordingly, their applicability to real world must be judged while taking into account the potential effects of flaws that occur in real P/M parts, such as low density areas and ejection cracks.

## Experimental

### Materials

All admixed materials were based on Ancorsteel A1000B high compressibility atomized iron. Elemental alloy additions to the admixed steels consisted of Inco 123 nickel powder and Alcan 8081 copper. The phosphorus additions were in the form of Hogaas Fe<sub>3</sub>P; all carbon additions were made as Asbury 3203 natural graphite. Unless noted otherwise, all mixes were lubricated with 0.5% Glyco

Acrawax C.

### Test Specimen Preparation

Tensile tests were done on specimens conforming to ASTM E8-85. Impact energy specimens were prepared according to MPIF 40. All sintering was carried out in a dissociated ammonia atmosphere, at 2050°P or 2300°F as indicated, for 30 minutes at temperature in a laboratory pusher furnace. The samples were placed on a bed of alumina powder in a ceramic tray, and covered with more alumina powder to prevent decarburizing. After sintering, the trays were pushed to a water-cooled zone.

Austenitizing was done in a muffle furnace in D.A., with propane added to maintain carbon potential. The specimens were quenched in circulating synthetic oil coolant, which was preheated to 150°F. Tempering was done in air.

### Testing

Impact energy specimens were tested in the un-notched condition. When low temperature testing was done, specimens were stabilized in a methanol bath cooled with liquid nitrogen.

Rotating bending fatigue specimens as shown in Figure 2 were tested at 3300 RPM, with survival to 10 million cycles considered a "run-out". Bending moments were chosen by the "staircase" method until appropriate stress levels for the "two-point" method were found. (1) The 95% survival stresses were then estimated according to the two-point method, assuming an exponential distribution.

## Results

### Impact Energy

Single-Pressed, As-Sintered Impact Energy: Low Alloy Steels - Single-pressed Distalloys with 0.4% graphite, tested in the as-sintered condition, had an un-notched impact energy of 18 it-lbs (Table 2). Under the same conditions, Ancorsteel 4600V prealloyed steel had an impact energy of 8 it-lbs; FN-0208 admixed nickel steel 11 it-lbs; FC-0208 admixed copper steel 12 ft-lbs.

Single-Pressed, As-Sintered Impact Energy: "Air Hardening" Steels - Ancorsteel 4600V with 2% copper and 1% graphite added, sintered and stress relieved at 500°F, had a tensile strength of 135,000 psi with nil ductility. The impact energy was 6 ft-lbs (Table 2). When the same mix was based on Ancorsteel 2000, the tensile strength was 107,000 psi, with an impact energy of 6 ft-lbs.

Single-Pressed, As-Sintered Impact Energy: Phosphorus Steels - Ancorsteel 1000B iron powder with 0.8% P added as Fe<sub>3</sub>P and 0.4% graphite had a yield strength of 60,000 psi, 5% elongation, and an impact energy of 18 ft-lbs (Table 2). Carbon-free 0.55% phosphorus steel had a yield strength of 49,000 psi, 15% elongation, and an impact energy of 18 ft-lbs.

Effect of Sintering Temperature - Single pressed Ancorsteel 4600V in the as-sintered condition had an un-notched impact energy of 8 ft-lbs after sintering at 2050°F. When sintered at 2300°F, the impact energy did not change significantly (Table 3).

The un-notched impact energies of Distaloy 4600A and 4800A at single pressed densities were in the neighborhood of 20 ft-lbs.

When the sintering temperature of Distaloy 4600A with 0.4% graphite was increased to 2300°F,

impact energy increased from 18 to 20 ft-lbs. Under similar conditions, held true for Distaloy 4800A + 0.4% graphite had an impact energy of 19 ft-lbs regardless of sintering temperature.

Effect of Sintered Density: Distalloys - Table 4 shows the result of increasing the density of Distalloys with 0.4% graphite from 7.1 to 7.3 g/cm<sup>3</sup> by double pressing. The impact energy increased from 18 to 42 ft-lbs for Distaloy 4600A; 19 to 28 ft-lbs for Distaloy 4800A.

For Distalloys with 0.6% graphite, increasing the density by double pressing increased the impact energy from 15 to 30 ft-lbs for Distaloy 4600A; from 19 to 47 for Distaloy 4800A (Table 4).

When sintered at 2300°F, the corresponding increases in impact energy with density for the Distalloys are 20 to 36; 18 to 28 ft lbs. (Table 5).

Table 6 shows that the double-pressing/double-sintering process alone, when not used to increase the density of the Distalloys with 0.6% graphite, increased the impact energy of Distaloy 4800A from 19 to 24 ft-lbs; had no effect on the impact energy of Distaloy 4600A.

Double pressing Distaloy 4600A + 0.6% Gr. at 50-50 TSI resulted in a final sintered density of 7.42 g/cm<sup>3</sup> using 45-45 TSI (0.4% graphite) gave a density of 7.21 g/cm<sup>3</sup>. The effect of sintered density on the impact energy of the Distalloys with 0.6% graphite is also shown in Figure 3.

Effect of Sintered Density: Prealloyed Steel - The impact energy of heat treated Ancorsteel 4600V prealloyed steel with 0.6% graphite was also increased by double pressing, from 7 ft-lbs at 6.95 g/cm<sup>3</sup> to 13 ft-lbs at 7.25 g/cm<sup>3</sup> (Table 7).

Effect of Sintered Density: Phosphorus Steel - The impact energy of carbon free Ancorsteel 60P at 7.18 g/cm<sup>3</sup> was 18 ft-lbs. As shown in Table 7, double pressing to 7.43 g/cm<sup>3</sup> (and reducing the phosphorus content to .55%P) increased the impact energy to 90 ft-lbs. Adding 1-4X copper to the 0.55% alloy increased the yield strength to 64,000 psi, but decreased the impact energy to 60 ft-lbs.

The impact energy of Ancorsteel 90PC was 8 ft-lbs regardless of density.

Effect of Graphite Addition and Heat Treatment - Varying the graphite addition to Distaloy 4600A from 0.4% to 0.8% resulted in impact energies ranging from 10 to 16 ft-lbs, the lower carbon contents having the higher impact energies (Table 8). A similar trend was found in Distaloy 4800A.

When the Distalloys were austenitized, quenched and stress relieved at 450°F, the impact energies decreased to 7-10 ft-lbs, over a range of 0.4% to 0.8% graphite (Table 9).

Quenched and stress relieved Ancorsteel 4600V with graphite additions ranging from 0.2% to 0.6% had impact energies of 5-7 ft-lbs (Table 10). Increasing the density of the heat treated Ancorsteel 4600V by double pressing resulted in an increase in tensile strength to 170,000 psi, and an impact energy of 13 ft-lbs.

Impact Energy Transition Temperature - Distaloy 4800A with 0.4% graphite in the single pressed, as-sintered condition, had an impact energy of 16 to 19 ft-lbs when tested at temperatures ranging from -50 to +100°C. Testing at -175°C decreased the impact energy to 9 ft-lbs. (Figure 4).

Double pressed Distaloy 4800A with 0.6% graphite had a room temperature impact energy of 19 ft-lbs. The impact energies at -30 and -50°C were 27 and 26 ft-lbs.

The impact energy curves for FN-0208 and FC-0208 admixed steels are compared with that of Distaloy 4800A with 0.4% graphite in Figure 5. The admixed steels have impact energy curves about 6 ft-lbs lower than Distaloy, but for all three materials this energy level is maintained to -30°C.

The room temperature impact energy of 10 ft-lbs for 0.55% P carbon free single pressed steel was decreased to 3 ft-lbs when the temperature was decreased to 0°C (Figure 6). Increasing the density by double pressing raised the room temperature impact energy to over 30 ft-lbs. The impact energy at -30°C was 6 ft-lbs.

### Fatigue Endurance Limits

Fatigue endurance limit results have been summarized by plotting them against their respective ultimate tensile strengths in Figure 7. The results are also presented in tabular form so that the yield strength, ductility, impact energy, and dimensional change results can also be compared.

Low Alloy Steels - Single pressed Distaloy 4800A with 0.6% graphite had an endurance limit of 33,000 psi (Table 11). When the density was increased to 7.42 g/cm<sup>3</sup> by double pressing, the endurance limit increased to 43,000 psi, with the endurance ratio roughly constant at 0.32.

Raising the sintering temperature of Distaloy 4800A + 0.4% graphite from 2050°F to 2300°F increased the tensile strength from 103,000 to 119,000 psi, but did not improve the endurance limit.

Table 11 also shows that the endurance limit of heat treated Ancorsteel 4600V with 0.6% graphite added was 38,000 psi, when single pressed to 6.95 g/cm<sup>3</sup>. When the density was increased to 7.25 g/cm<sup>3</sup> by double pressing, the endurance

Table 1: Typical Compositions of the Materials Used

Material	Ni	Mo	Cu	Mn	P	C	O
Ancorsteel 1000B	--	--	--	--	--	<.01	.08
Ancorsteel 4600V	1.80	.50	--	--	--	.02	.13
Ancorsteel 2000	.45	.60	--	.30	--	.02	.17
Distaloy 4600A	1.80	.55	1.60	--	--	<.01	.16
Distaloy 4800A	4.05	.55	1.60	--	--	<.01	.16
"90PC"	--	--	--	--	0.9	.20	.08



Table 2: Single Pressed, As-Sintered Impact Energies of Various P/H Steels

Material, Process	Briq. Press. (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Rckwl. Hrdns.	Yield Str. (psi)	Tensile Str. (psi)	% El.	I.E. (ft- lbs)	Std. Dev.
<b>DIFFUSION BONDED</b>									
Distaloy 4600A with 0.4% Gr.	45	+ .25	7.13	B 92	54,870	84,250	4	16	2.2
Distaloy 4800A with 0.4% Gr.	45	+ .02	7.11	B 96	67,190	90,690	4	19	2.2
<b>PREALLOYED</b>									
A4600V - 0.4% Total Carbon	--	--	6.80	--	37,600	43,900	2	8	--
<b>ADMIXED</b>									
Cu - Ni Admixed Steel: A1000B + 2% Ni + 1% Cu + 0.75% Gr.	45	+ .27	7.09	B 84	53,430	78,550	2	11	0.9
FC-0208: A1000B + 2% Cu + 0.75% Gr.	45	+ .35	7.05	B 86	63,910	90,820	3	12	1.1
FN-0208: A1000B + 2% Ni + 0.75% Gr.	45	+ .05	7.12	B 77	36,160	64,450	3	11	1.1
<b>AIR HARDENING - Tempered 500°F, 1 Hr.</b>									
A4600V + 2% Cu + 1% Gr.	45	+ .15	6.87	C 27	131,630	135,930	< 1	6.6	0.6
A2000 + 2% Cu + 1% Gr.	45	+ .11	6.95	B 95	94,020	106,850	< 1	6.4	0.6
<b>PHOSPHORUS STEELS</b>									
A1000B + .8% P + .04% Gr.	50	--	6.94	C 27	59,650	79,370	5	12	1.5
"A55P": A1000B + 0.55% P	45	--	7.18	B 69	48,520	67,230	15	18	5

Table 3: Effect of Sintering Temperature on the Impact Energy of Various P/M Steels

Material, Process	Briq. Press. (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Rckwl. Hrdns.	Yield Str. (psi)	Tensile Str. (psi)	% El.	I.E. (ft- lbs)	Std. Dev.
Ancorsteel 4600V +.4% T.C.	--	--	6.80	--	37,600	43,900	2	8	--
Same, 2300°F	--	--	6.80	--	42,600	53,400	3	5	--
Distaloy 4600A + 0.4% Gr.	45	+ .25	7.13	B 82	54,870	84,250	4	18	2.2
Same, 2300°F	45	+ .08	7.17	B 84	63,870	90,690	5	20	1.8
Distaloy 4800A + 0.4% Gr.	45	+ .02	7.07	B 96	67,190	106,350	4	19	1.5
Same, 2300°F + 0.4% Gr.	45	- .19	7.11	C 24	67,240	118,920	3	18	2.1
Distaloy 4800A + 0.4% Gr.	50	--	7.20	B 92	63,500	103,240	4	24	2.6
Same, 2300°F	50	--	7.24	B 98	77,940	119,080	4	23	3.0

Table 4: Effect of Sintered Density on the Dynamic Properties of Distaloy

Material, Process	Briq. Press. (TSI)	Prsnt Temp. (F)	Wa- Press (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Reql. Hrdna.	Yield Str. (psi)	Tensile Str. (psi)	% EL.	I.E. (ft- lbs)	Std. Dev.
Distaloy 4600A + 0.4% Gr.	65	--	--	+25	7.13	B 82	54,870	84,250	4	18	2.2
Same, DP-DS	45	1600	45	+22	7.31	B 86	58,860	89,660	6	42	7.2
Distaloy 4800A + 0.4% Gr.	45	--	--	+02	7.07	B 96	67,190	106,350	4	19	1.5
Same, DP-DS	45	1600	45	+03	7.21	B 98	65,310	109,180	5	28	5.7
Distaloy 4600A + 0.6% Gr.	45	--	--	--	--	--	--	--	--	15	2.2
Same, DP-DS	45	1600	45	--	--	--	--	--	--	30	3.8
Distaloy 4800A + 0.6% Gr.	45	--	--	--	7.01	B 90	--	--	--	15	1.7
Same, DP-DS	50	1600	50	+0.13	7.32	C 23	71,020	134,140	4	47	4.0

Table 5: Effect of Sintered Density on Impact Energy of Distalloys Sintered at 2300°F

Material, Process	Briq. Press. (TSI)	Prnt. Temp. (F)	Re-Press (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Rckwl. Hrdns.	Yield Str. (psi)	Tensile Str. (psi)	% El	I.E. (ft-lbs)	Std. Dev.
Distaloy 4600A + 0.4% Gr. 2300°F	45	--	--	+0.08	7.17	B 84	63,870	90,690	5	20	1.8
Distaloy 4600A + 0.4% Gr. DP-DS - 2300°F	45	1600	45	+0.06	7.33	B 88	67,430	93,040	6	36	1.3
Distaloy 4800A + 0.4% Gr. 2300°F	45	--	--	-0.19	7.11	C 24	76,240	118,920	3	18	2.1
Distaloy 4800A + 0.4% Gr. DP-DS - 2300°F	45	1600	45	-0.18	7.22	C 26	74,110	114,740	4	28	6.6

Table 6: Impact Energy of Distalloys: Effect of Single Pressing and Double Pressing to the Same Densities

Material, Process	Briq. Press. (TSI)	Prnt. Temp. (F)	Re-Press (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Rckwl. Hrdns.	Yield Str. (psi)	Tensile Str. (psi)	% El	I.E. (ft-lbs)	Std. Dev.
Distaloy 4600A + 0.6% Gr.	50	--	--	NM	7.11	B 95	71,650	100,480	2	16	2.6
Same, DPDS	35	1550	35	NM	7.10	B 96	69,725	106,910	3	16	--
Distaloy 4800A + 0.6% Gr.	50	--	--	NM	7.18	B 101	73,650	116,750	2	19	1.5
Same - DPDS	35	1550	39	NM	7.15	B 99	73,770	121,850	3	24	1.5

Table 7: Effect of Sintered Density on the Impact Energy of Prealloyed Steel and Phosphorus Steel

Material, Process	Briq. Press. (TSI)	Prnt Temp. (F)	Re-Press (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Recl. Hrdns.	Yield Str. (psi)	Tensile Str. (psi)	% El.	I.E. (ft-lbs)	Std. Dev.
Ancorsteel 4600V + 0.6% Cr.- Q&T	45	--	--	- .11	6.95	C 26	--	115,700	< 1	7	0.8
Ancorsteel 4600V + 0.6% Cr. DP-DS - Q&T	45	--	45	- .13	7.25	C 35	165,310	173,250	--	13	1.1
"A55P": A1000B + 0.55% P	45	--	--	--	7.18	B 69	48,520	67,230	15	18	4.7
Same, DPDS	45	1600	45	- .32	7.43	B 77	50,720	71,470	21	90	14.8
55P + 2% Cu	50	1400	50	+ .13	7.35	B 85	64,260	81,600	11	60	--
"90PC"	50	--	--	+ .23	7.06	B 80	59,850	78,770	7	8	--
90PC + DP-DS	50	1400	50	+ .11	7.25	B 88	68,700	84,770	4	8	2.7

Table 8: Effect of Graphite Addition on the Impact Energy of Distalloys Tested in the As-Sintered Condition at 7.0 g/cm<sup>3</sup>

Material, Process	Graphite Addition (%)	B.P. (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Reql. Hrdns.	I.E. (ft-lbs)	Std. Dev.
Distaloy 4600A	0.4	50.5	+17	6.99	74	16	2.2
	0.6	50.5	+17	6.96	86	11	1.3
	0.8	50.5	+17	6.96	92	10	0.6
	0.8*	50.5	+13	6.96	92	10	-
Distaloy 4800A	0.4	48.5	+03	7.01	86	16	1.1
	0.6	49.5	-01	7.01	90	15	1.7
	0.8	49.5	-11	7.00	95	13	0.4
	0.8*	49.5	-14	7.00	93	14	0.4

\* Stress relieved 350°F for 60 minutes in air.

Table 9: Effect of Graphite Addition on the Impact Energy of Distalloys Tested in the Heat Treated Condition at 7.0 g/cm<sup>3</sup>

Material Process	Graphite Addition	Austenitizing Temp.	Tempering Temp.	Briq. Press. (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Reql. Hrdns.	I.E. (ft-lb)	Std. Dev.
Distaloy 4600A	0.4	1550	350	45	+13	6.90	B 92	8	0.8
	0.6	1500	375	45	+10	6.88	C 20	9	0.9
	0.8	1475	450	45	+06	6.88	C 22	8	1.3
Distaloy 4800A	0.4	1550	350	42	-01	6.99	C 13	7	0.6
	0.6	1500	375	42	-07	6.98	C 26	9	1.5
	0.8	1476	450	43	-11	6.98	C 26	9	1.0

Table 10: The Impact Energy of Single Pressed, Prealloyed Heat Treated Steels

Material, Process	Graphite Addition (%)	Briq. Press. (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Recl. Hrdns	Yield Str. (psi)	Tens. Str. (psi)	% El.	I.E. (ft-lbs)	Std. Dev.
Acorsteel 4600V Quenched and Tempered	0.2	45	-24	6.97	B 95	99,890	104,780	< 1	5	0.6
	0.4	45	-31	6.95	C 22	--	114,230	< 1	7	0.6
	0.6	45	-25	6.96	C 26	--	115,780	< 1	7	0.8
Acorsteel 2000 Quenched and Tempered	0.5	45	-15	6.99	C 26	--	113,670	M1	7	0.6

Table 11: Fatigue and Impact Properties of Distalloys and Acorsteel 4600V

Material, Process	Briq. Press. (TSI)	Prnt Temp. (F)	Re-Press. (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Recl. Hrdns	Yield Str. (psi)	Tensile Str. (psi)	% El.	Endur. Lim. (psi)	Endur. Ratio	I.E. (ft-lbs)	Std. Dev.
<b>DISTALLOYS</b>													
Distalloy 4600A + .6% Gr.	45	--	--	--	--	--	--	98,910	--	51,000	0.33	--	--
Same, 2300 F	45	--	--	--	--	--	--	106,310	--	29,000	0.27	--	--
Distalloy 4600A 6.9 g/cm <sup>3</sup>	--	--	--	--	--	--	--	85,460	--	23,000	0.26	--	--
Distalloy 4800A + .6% Gr.	45	--	--	--	--	--	--	102,658	--	42,500	0.41	--	--
Distalloy 4800A + 0.6% Gr. DP-DS	50	1600	50	+13	7.32	C 23	71,020	134,140	4.3	45,000	0.34	47	4.0
Distalloy 4800A + 0.4% Gr.	50	--	--	--	7.20	B 92	63,500	103,240	4.2	37,000	0.36	24	2.6
Same, 2300°F	50	--	--	--	7.23	B 98	77,940	119,080	3.5	37,000	0.31	23	3.0
<b>HEAT TREATED PREALLOYED STEEL</b>													
Acorsteel 4600V + .6% Gr.	45	--	--	-11	6.95	B 72	--	119,560	0.1	43,000	0.36	7	--
Same, DP-DS	45	--	45	-13	7.25	C 35	165,310	173,250	--	59,000	0.34	13	1.1

Table 12: Fatigue and Impact Energies of Admixed Steels

Material, Process	B.P. (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Rehwl. Hrdns.	Yield Str. (psi)	Tensile Str. (psi)	% El.	Endur. Lim. (psi)	End Ratio	I.E. (ft- lbs)	Std. Dev.
<b>NICKEL STEELS</b>											
FN-0208:											
A1000B + 2% Ni + 0.75% Cr.	45	+09	7.12	B 77	36,160	64,450	3	23,000	0.36	8	0.6
"Lean" FN-0208:											
A1000B + 1% Ni + 0.6% Cr, Q&T	45	+01	7.14	C 31	--	135,180	<1	41,000	0.30	8	0.6
<b>COPPER STEELS</b>											
FC-0208:											
A1000B + 2% Cu + 0.9% Cr.	45	--	7.01	--	73,090	94,100	2	35,000	0.37	--	--
Same, Shot Peened	45	--	7.01	--	73,090	94,100	2	41,000	0.44	--	--
FC-0208 Low Density	--	--	6.65	B 83	--	46,400	--	14,000	0.30	--	--
<b>AIR HARDENING ALLOYS Tempered 500 F, 1 hr.</b>											
AA600V + 2% Cu + 1% Cr.	45	+15	6.87	C 27	131,630	135,930	< 1	25,000	0.18	7	0.6
A2000 + 2% Cu + 1% Cr.	45	+11	6.95	B 95	94,020	106,850	< 1	32,000	0.30	6	0.6

Table 13: Fatigue Strength and Impact Energies of Some Phosphorus Steels

Material, Process	Briq. Press. (TSI)	Prsnt Temp. (F)	Re- Press (TSI)	D.C. (%)	Sint. Dens. (g/cm <sup>3</sup> )	Yield Rckwl. Hrdns.	Str. (psi)	Tensile Str. (psi)	% El.	Endur. Lim. (psi)	Endur. Ratio	I.E. (ft- lbs)	Std. Dev.
A1000B + .8% P + 0.4% Cr.	50	--	--	--	6.94	B 81	59,650	79,370	5	35,000	0.44	12	1.51
90PC	50	--	--	+23	7.06	B 80	59,850	78,770	--	30,000	0.38	8	--
90PC - DP-DS	50	1400	50	+11	7.25	B 88	68,700	84,700	4	43,000	0.51	8	2.68

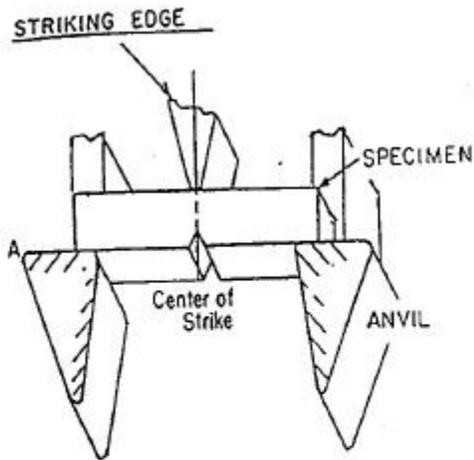


Figure 1: Charpy impact energy test configuration. Porous steels are tested in the un-notched condition.

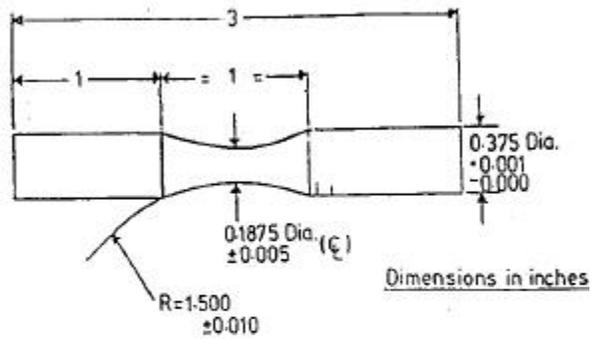


Figure 2: Rotating bending fatigue test specimen.

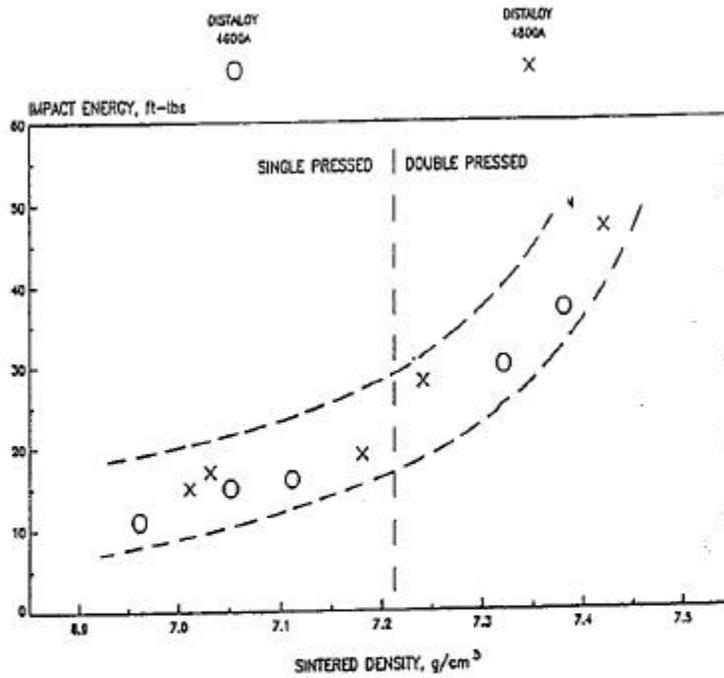


Figure 3: Effect of Sintered Density on the Room Temperature Impact Energy of the Distalloys with 0.6% Graphite

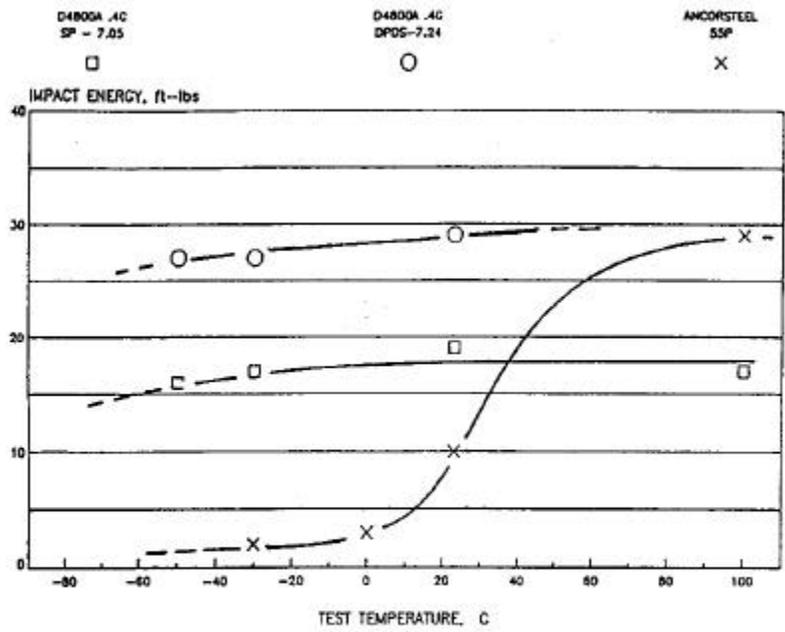


Figure 4: Effect of test temperature on the impact energy of Distaloy, compared with Ancorsteel 55P.

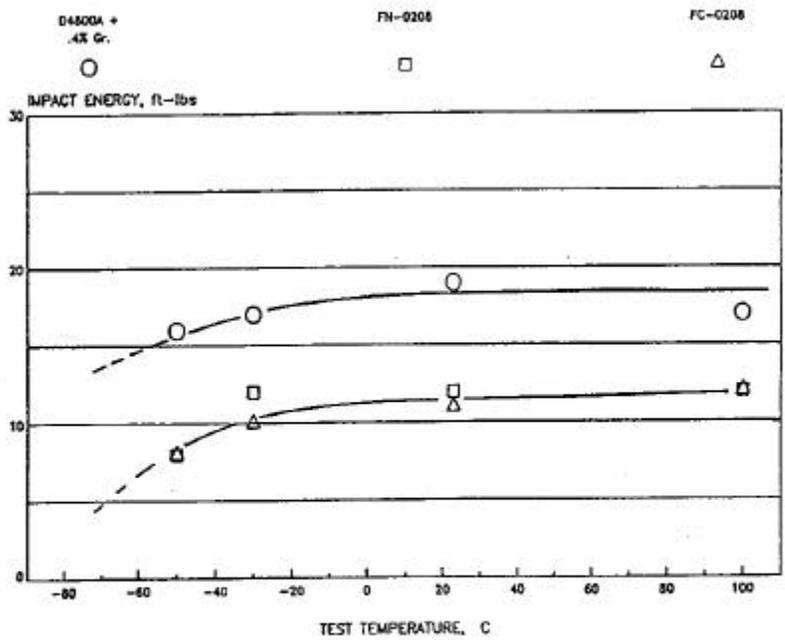


Figure 5: Effect of test temperature on the impact energy of admixed steels, compared with Distaloy 4800A.

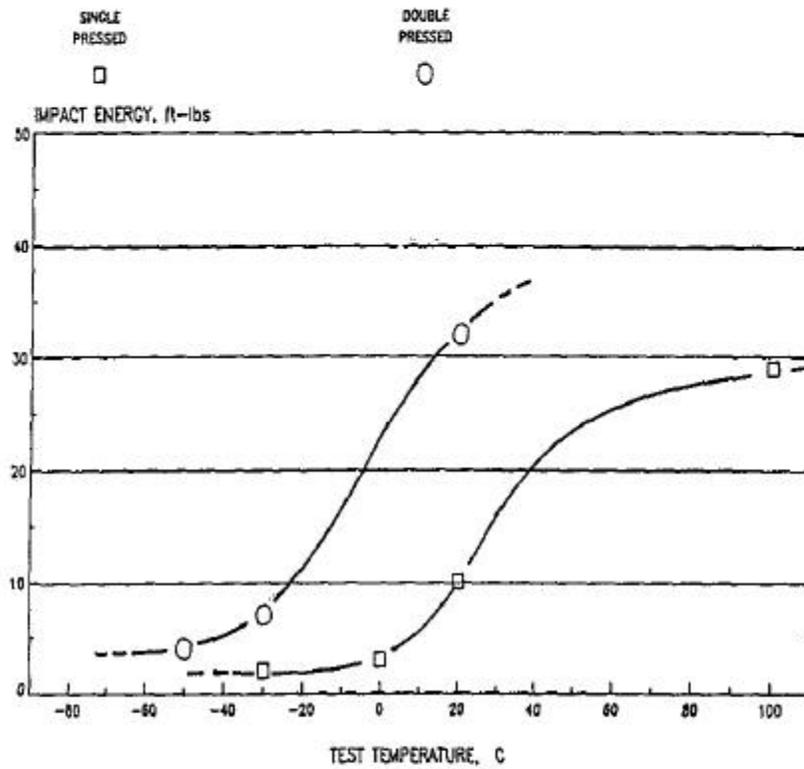


Figure 6: Effect of sintered density on the impact energy transition temperature of Ancorsteel 55P