PERFORMANCE CHARACTERISTICS OF A NEW SINTER-HARDENING LOW-ALLOY STEEL

Robert J. Causton and W. Brian James Hoeganaes Corporation
Riverton, NJ 08077

John J. Fulmer
Burgess-Norton Manufacturing Company Geneva, IL 60134

Presented at the Annual Powder Metallurgy Conference Chicago, Illinois, June 9 - 12, 1991

ABSTRACT

A martensitic microstructure can be developed in some powder metallurgy materials without the need for a secondary heat treatment operation provided the material is cooled sufficiently rapidly from the sintering temperature. These P/M materials are termed "sinter-hardening" steels. The partially alloyed powder, Distaloy 4800A, and nickel-molybdenum prealloyed steels such as Ancorsteel ® 4600V with copper additions are capable of being sinter-hardened.

Ancorsteel 85 HP, a new highly compressible low-alloy powder employing molybdenum as the primary alloying element, is also capable of being sintered-hardened when copper and graphite additions are made to it. Ancorsteel 85 HP has a higher compressibility than nickel-molybdenum prealloyed powders.

The effect of cooling rate has been studied on the microstructure and mechanical properties of Ancorsteel 85 HP + 2% copper + 0.9% graphite. Tensile and impact properties have been evaluated for a range of material densities and compared with those obtained with samples based on Ancorsteel 4600V.

INTRODUCTION

As powder metallurgy develops, parts manufacturers and powder producers are faced with the need to produce parts with improved strength levels, higher densities and surface hardness. In many cases, parts are heat treated by quenching and tempering after sintering to develop the optimum performance levels. The recent development of highly compressible prealloyed powders, such as Ancorsteel 85 HP, offers the parts fabricator the opportunity to produce parts at higher density levels than was previously possible with prealloyed materials. In addition, premixes of the new prealloyed powder with elemental alloying additions such as copper, nickel and graphite offer the possibility of attaining high strength and hardness without the need for a separate quenching and tempering operation. The current paper examines the effect of cooling rate on the properties of premixes that contain 2% copper and 0.9% graphite using Ancorsteel 4600V and Ancorsteel 85 HP as low-alloy base powders. This information represents the first portion of a continuing investigation into the response to thermal processing of low-alloy premixes.

EXPERIMENTAL PROCEDURE

Materials

Two 500-pound test premixes were made using the ANCORBOND® process [1,2,3]. The premix compositions are shown in Table I.

Table I: Premix Compositions

	Weight (%)		
Ingredient	Material A	Material B	
Copper	2	2	Alcan 8081
Graphite	0.9	0.9	Southwestern 1651
Zinc Stearate	0.5	0.5	Witco Lubrizinc W
Low-Alloy Steel	Ancorsteel 4600V Balance	Ancorsteel 85 HP Balance	

The chemistry and sintered properties of the mixes are shown in Tables II and III.

Table II: Properties of the Materials

Material	Compaction Pressure (tsi)	Green Density (g/cm^3)	D.C (%)	TRS (psi)	Hardness (HRC)
A	30	6.50	+0.10	82,870	29
A	45	6.90	+0.21	112,440	38
B	30	6.76	+0.17	139,150	22
B	45	7.01	+0.25	174,420	28

Sintering: 2050'F, Dissociated Ammonia, 30 minutes

Table III: Chemistry of the Materials

	Weight (%)				
Material	Cu	Ni	Mo	Mn	Sintered Carbon
A	2.11	1.75	0.59	0.20	0.86
B	2.08	0.05	0.87	0.14	0.85

Test Specimen Preparation

All tensile properties were measured using as-pressed ASTM E8 "dog-bone" tensile specimens. Charpy impact testing was performed using unnotched specimens as shown in ASTM E23. Test pieces were produced with a range of densities to determine the effect of density upon mechanical properties. Specimens of low and intermediate density were compacted at 30 and 45 tsi, respectively. The higher density test pieces were produced by double pressing and sintering where the test pieces were initially compacted at 45 tsi, presintered at 1400°F under nitrogen atmosphere, then re-pressed at 45 tsi and sintered.

Sintering

All test pieces were sintered under production conditions at Burgess-Norton Mfg. Co. The basic sintering cycle is indicated below:

Sintering Temperature:	2050° F
Atmosphere:	Endothermic with carbon control
Dew Point:	32-35'F
Equilibrate:	1650 ' F
Time:	20 minutes

The sintering furnace was equipped with a controlled cooling zone, such that the cooling rate could be varied considerably. Two processes, referred to as accelerated and conventional, were used in the current work.

In the accelerated cycle, the cooling time from 1650'F to 390°F was 10.75 minutes. the conventional mode, the time to cool between these temperatures was 14.75 minutes. The sintered parts were stress relieved at 380°F for one hour prior to testing.

Testing

Tensile testing was performed with an Instron tester at a crosshead speed of 0.02 inches/minute. The Charpy impact test pieces were broken on a Baldwin impact test machine. Apparent hardness measurements were made using a Rockwell Hardness Tester and Rockwell B or Rockwell C scales depending on the apparent hardness of the material. In order to graph the data on a common scale, these hardness were converted to Vickers hardness using the conversion tables in ASTM E140.

Metallography

Sections for metailographic examination were cut from the impact test pieces, and prepared according to the procedures in Reference 4.

RESULTS

The ultimate tensile strength, impact energy and apparent hardness of the test pieces are presented in Tables IV and V. The microstructures of the different materials are illustrated in Figures 1-4. The data show that by accelerated cooling from the sintering temperature it is possible to obtain microstructures and mechanical properties that are very similar to those obtained by conventional quenching and tempering treatments.

DISCUSSION

Metallography

The microstructures of sections cut from the impact test pieces are shown in Figures 1 - 4, which clearly show that accelerated cooling had a strong effect and led to the formation of martensite in both materials. For ease of comparison, the microstructures presented are those for materials pressed at 45 tsi to densities of approximately 6.9 to 7.1 g/cm^3.

Under the slower cooling conditions of conventional cooling, the microstructures of the two materials differed somewhat. The microstructure of material A (Figure 1) contained a mixture of a light etching martensitic phase mixed with a dark etching lameliar pearlite. Intermixed with the lameliar pearlite there was a darker etching, very fine microstructural constituent - possibly bainite.

Under slow cooling conditions, material B had a microstructure of ferrite plus pearlite (Figure 3). There was a light etching, ferrite plus carbide phase, forming almost a network or "necklace" around the prior particles. Within this light etching phase were islands of a darker etching, very fine, pearlitic phase. There were also occasional areas of a lighter

gray, unresolvable, microstructural constituent, which may have been martensite or possibly, a bainitic phase.

Under conditions of accelerated cooling, the microstructure of material A consisted of a mixture of martensite and retained austenite (Figure 2). There appeared to be relatively coarse, lightly tempered martensitic needles throughout the microstructure. Between these needles were regions of almost uniformly dispersed fine martensite, possibly not tempered, intermixed with a light etching retained austenite. It is believed that on accelerated cooling, the martensite transformation is suppressed such that a mixed martensitic and retained austenitic phase forms. On cooling from the stress relief temperature, a proportion of the retained austenite transforms to untempered martensite.

Accelerated cooling of material B resulted in a light etching martensitic microstructure (Figure 4). It was relatively finer than that developed in material A but still contained some retained austenite. Within the microstructure were occasional islands of a darker etching, very fine constituent, possibly bainite.

Thus, the effect of cooling rate was clearly to move from a pearlitic microstructure at low cooling rates to a much harder martensitic microstructure at the accelerated cooling conditions. This change had a significant effect upon mechanical properties.

Ultimate Tensile Strength

The effect of density and cooling rate upon the ultimate tensile strength of the test premixes is shown in Figure 5. The graph shows that the ultimate tensile strength of both materials is improved by accelerated cooling and increasing density.

The data for material A show that, using conventional cooling, the strength increased with density from 45,000 psi to a high of approximately 90,000 psi. Under accelerated cooling conditions, the strength increased from approximately 78,000 psi to a high approaching 120,000 psi at the highest density of 7.14 g/cm^{3}. Material B followed a similar pattern. Under conventional cooling conditions, the ultimate tensile strength increased from approximately 78,000 psi at 6.81 g/cm^{3} to 120,000 psi at the highest density of 7.38 g/cm^{3}. Using accelerated cooling, the strength increased from 89,000 psi at 6.81 g/ cm^{3} to approximately 148,000 psi at 7.36 g/cm^{3}. The curves are relatively smooth with increasing density and show clearly the benefits of increased density and increased cooling rate upon ultimate tensile strength.

Impact Energy

The curves of impact energy (Figure 6) show a similar improvement of properties with increasing cooling rate and density for both compositions.

For material A, using conventional cooling, impact energy increased with density from 3 ft.lbf at 6.4 g/ cm^{3} to 8 ft.lbf at 7.09 g/cm^{3}. Under accelerated cooling, the impact energy increased from 5 ft. lbf at low density to a maximum of 11 ft.lbf at 7.08 g/cm^{3}. Accelerated cooling also improved the impact energy of material B. An impact energy of 4 ft.lbf obtained using the conventional cooling rate at low compaction pressure increased to a level of 6 ft.lbf using the accelerated cooling rate. However, at the highest density level of 7.3 g/cm~, the impact energy of 12 ft.lbf was unchanged by accelerated cooling.

The premix compositions used in this study resulted in high apparent hardness under conditions of accelerated cooling. The effect of density and cooling rate on hardness is shown in Figure 7. The effect of cooling rate upon hardness is dominant. Density is less significant with these premix compositions.

For material A, following conventional cooling, hardness increased with density from approximately 230 HV to 270 HV. Under accelerated cooling conditions, the hardness increased at all density levels, from 275 HV to nearly 400 HV.

A different pattern was observed for material B where the effect of increased cooling rate was more significant. With the conventional cooling cycle, hardness increased with density from 171 HV to 240 HV. Under accelerated cooling conditions, the hardness increased from 344 HV to 452 HV.

Comparison with Quenched and Tempered Properties

The experimental results presented have concentrated upon the properties achieved by cooling without a discrete quenching and tempering operation. However, the ability to develop martensitic microstructures in an as-sintered low-alloy matrix following accelerated cooling from the sintering temperature has produced mechanical properties that compare well with those previously published for quenched and tempered P/M low-alloy steels and "sinter-hardened" materials compacted under similar conditions [5-7].

Ultimate Tensile Strength

The ultimate tensile strength of the rapidly cooled materials compares well with the properties of heat-treated P/M low-alloy steels. In prior work, a fully heat-treated Ancorsteel 4600V, 0.6% graphite composition attained an ultimate tensile strength of about 116,000 psi at 6.9 g/cm^3 [6]. The current work shows that material B, following accelerated cooling, attains a similar ultimate tensile strength to that of the quenched and tempered low-alloy material. Similarly, the ultimate tensile strength of the Ancorsteel 85 HP, 0.6% graphite composition, compacted at 40 tsi is approximately 117,000 psi in the quenched and tempered condition [5]. Material B shows equivalent tensile strength when rapidly cooled from the sintering temperature (Figure 8).

Impact Energy

Materials A and B when compacted at 45 tsi and rapidly cooled attain impact energies of approximately 8 or 9 ft.lbf (Figure 6). These values compare favorably with that of 7 ft. lbf for a heat-treated Ancorsteel 4600V, 0.6% graphite composition compacted at 45 tsi as indicated in References 6 and 7.

The impact energies produced by accelerated cooling of material B are similar to those of the quenched and tempered Ancorsteel 85 HP, 0.6% graphite composition at a similar density [5] (Figure 9).

SUMMARY

The results indicate that it is possible to significantly change the microstructure, and hence the mechanical properties, of both test materials by changing the rate of cooling from the sintering temperature. As anticipated, the greater compressibility of the prealloyed matrix of material B produced a higher density at a given compaction pressure than was obtained with material A. Consequently, material B showed generally superior mechanical properties, except for hardness, under conventional cooling conditions. However, following accelerated cooling, the very fine martensitic microstructure of material B gave equivalent properties to the more highly alloyed material A at the same density (Figures 5 - 7). Thus, the higher compressibility of material B offers the ability to develop superior mechanical properties at the same compaction pressure or to develop equivalent properties at lower compaction pressures.

The data show that by accelerated cooling from the sintering temperature, it is possible to obtain microstructures and mechanical properties that are very similar to those obtained by conventional quenching and tempering treatments. These values may enable greater efficiencies in processing where part geometry and machining operations enable a separate heat treatment operation to be omitted.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of the Burgess-Norton Manufacturing Company and Hoeganaes Corporation. They would like to thank the staff of Burgess-Norton Mfg. Co. and, in particular, Mr. T. J. Krave for his assistance in producing and processing the test specimens. They are particularly grateful for the cooperation of the following Hoeganaes personnel: Messrs. R. Fitzpatrick and C. Gamble for measurement of mechanical properties along with G. Golin and S. Kolwicz for metallography.

REFERENCES

1. U.S. Patent No. 4,834,800, Iron Based Powder Mixtures.

2. M. J. McDermott, "P//M Parts Fabrication Experience with ANCORBOND (Binder Treated) Premixes", Advances in Powder Metallurgy, 1990, Vol. 1, pp 209, published by Metal Powder Industries Federation, Princeton, NJ.

3. F. J. Semel, "Properties of Parts Made from an ANCORBOND Processed F-0008/Carbon Steel Mix", Modern Developments in Powder Metallurgy, 1988. Vol. 21, pp 101, published by Metal Powder Industries Federation, Princeton, NJ.

4. C-A. Blände, T.F. Murphy, et al, "Non-Metallic Inclusion Measurement of Powder Forged Steels Using an Automated Image Analysis System", Horizons of Powder Metallurgy, 1986, Part II, pp 727, published by Verlag Schmid GmbH, Freiburg, Germany.

5. R. J. Causton, J. J. Fulmer, “Tensile, Impact and Fatigue Performance of a New Water Atomized Low-Alloy Powder - Ancorsteel 85 HP”, Advances in Powder Metallurgy, 1990, Vol. 2, published by Metal Powder Industries Federation, Princeton, NJ.

6. R. C. O'Brien, "Fatigue Properties of P/M Materials", SAE Technical Paper 880165, 1988, Society of Automotive Engineers, Cobo Hall, Detroit, MI.

7. R. C. O'Brien, "Impact and Fatigue Characterization of Selected Ferrous P/M Materials," Progress in Powder Metallurgy, 1987, Vol. 43, pp 749, published by Metal Powder Industries Federation, Princeton, NJ.

Table IV: Properties of Material A: Ancorsteel 4600V, 2% Cu, 0.9% Graphite, 0.5% Zinc Stearate

		Tensile						Impact			
Pressure (tsi)	Condition	Density (g/cm³)	0.2% Proof Stress (psi)	UTS (psi)	Elong. (%) in One Inch	Hardness HV	Sintered Carbon (%)	Density (g/cm³)	D.C. (%)	I.E. (ft.lbf)	Hardness HV
30	Conventional	6.57	NY	44,800	0.3	230	0.87	6.43	+0.13	3	193
45	Conventional	6.94	NY	67,090	0.5	234	0.86	6.85	+0.19	5	220
45+45	Conventional	7.16	NY	91,670	0.6	275	0.81	7.09	+0.28	8	257
30	Accelerated	6.57	NY	77,512	0.5	275	0.81	6.46	-0.03	5	282
45	Accelerated	6.94	NY	78,790	0.3	335	0.79	6.87	+0.09	8	353
45+45	Accelerated	7.14	NY	119,350	0.6	393	0.78	7.08	+0.28	11	393

Table V: Properties of Material B: Ancorsteel 85HP, 2% Cu, 0.9% Graphite, 0.5% Zinc Stearate

		Tensile						Impact			
Pressure (tsi)	Condition	Density (g/cm³)	0.2% Proof Stress (psi)	UTS (psi)	Elong.(%) in One Inch	Hardness HV	Sintered Carbon (%)	Density (g/cm³)	D.C. (%)	I.E. (ft.lbf)	Hardness HV
30	Conventional	6.81	73,820	78,620	0.7	171	0.87	6.67	+0.23	4	164
45	Conventional	7.11	91,022	93,460	0.6	193	0.86	7.00	+0.26	6	198
45+45	Conventional	7.38	94,440	120,030	2.5	240	0.81	7.32	+0.26	12	227
30	Accelerated	6.81	NY	89,400	0.4	344	0.85	6.71	+0.03	6	335
45	Accelerated	7.12	NY	118,760	0.5	393	0.82	7.02	+0.12	9	404
45+45	Accelerated	7.36	NY	149,720	0.6	452	0.78	7.31	+0.20	12	440

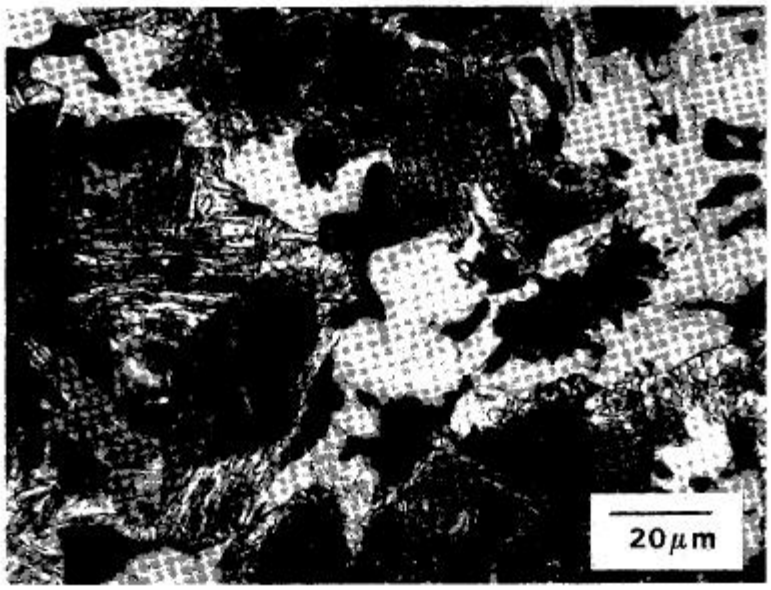

Figure 1: Photomicrograph of material A following conventional cooling from the sintering temperature. Etched with a combination of 2% nital/4% picra Original magnification 750X.

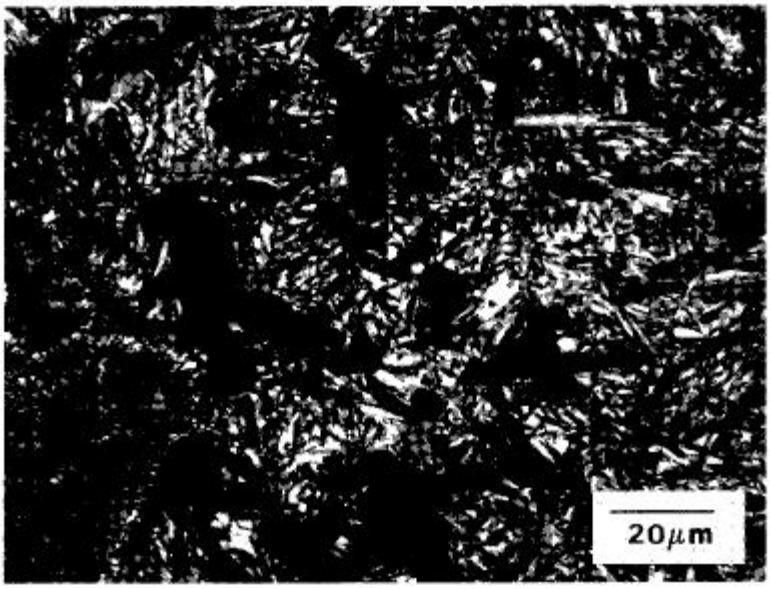

Figure 2: Photomicrograph of material A following accelerated cooling from the sintering temperature. Etched with a combination of 2% nital/4% picra Original magnification 750X.

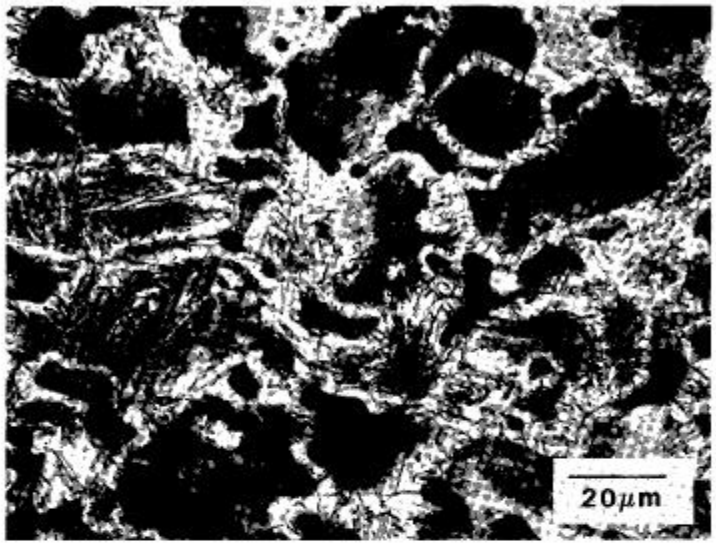

Figure 3: Photomicrograph of material B following conventional cooling from the sintering temperature. Etched with a combination of 2% nital/4% picral. Original magnification 750X.

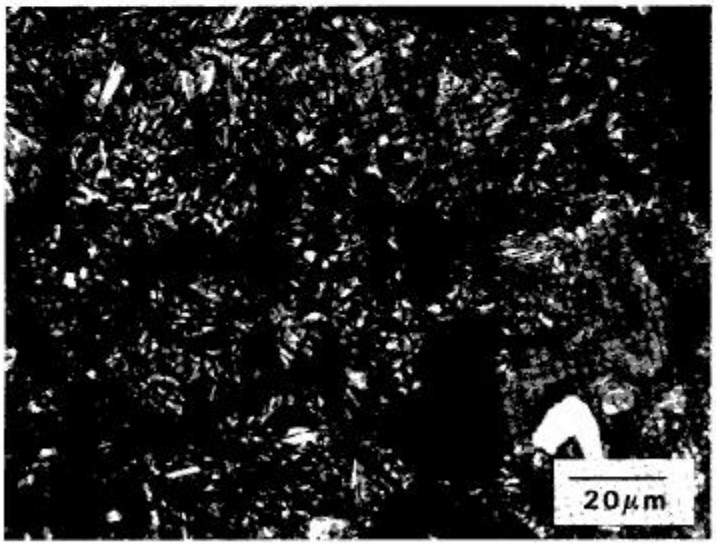

Figure 4: Photomicrograph of material B following accelerated cooling from the sintering temperature. Etched with a combination of 2% nital/4% picral. Original magnification 750X.

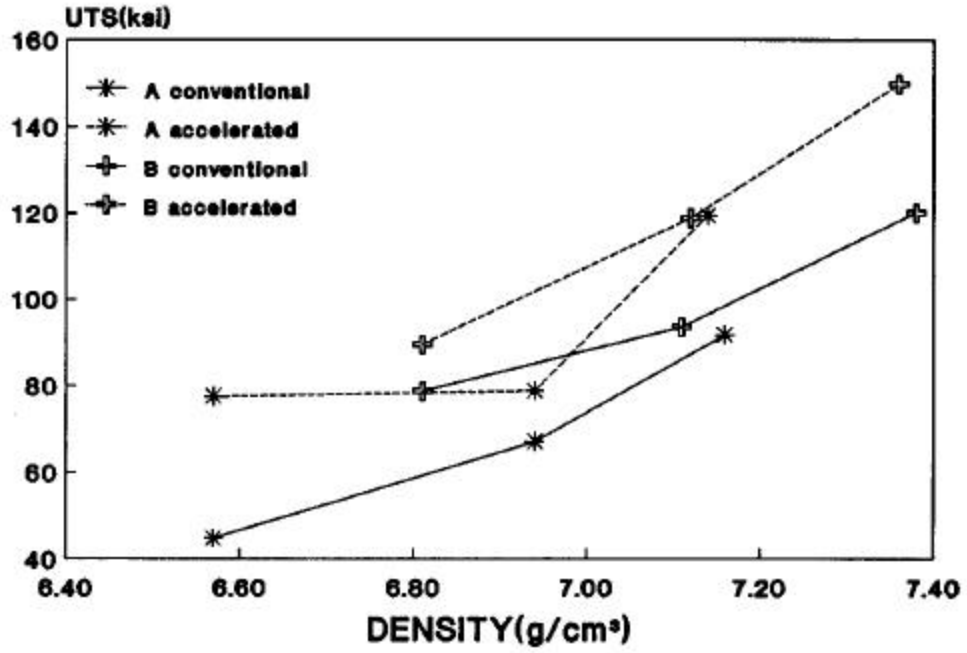

Figure 5: The effect of sintered density and cooling rate on the ultimate tensile strength of materials A and B.

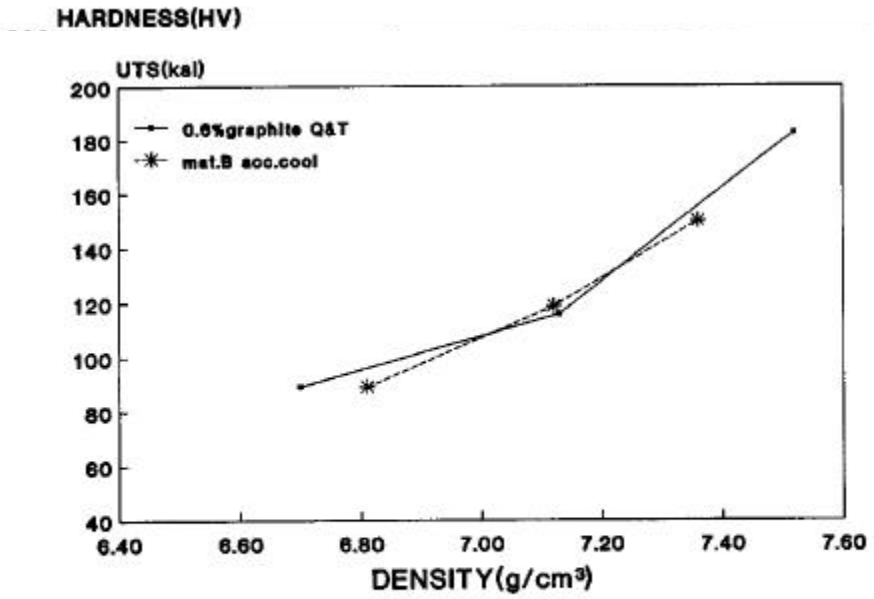

Figure 8: Comparison between the ultimate tensile strength of quenched and tempered Ancorsteel 85 HP, 0.6% grpahite, and material B following

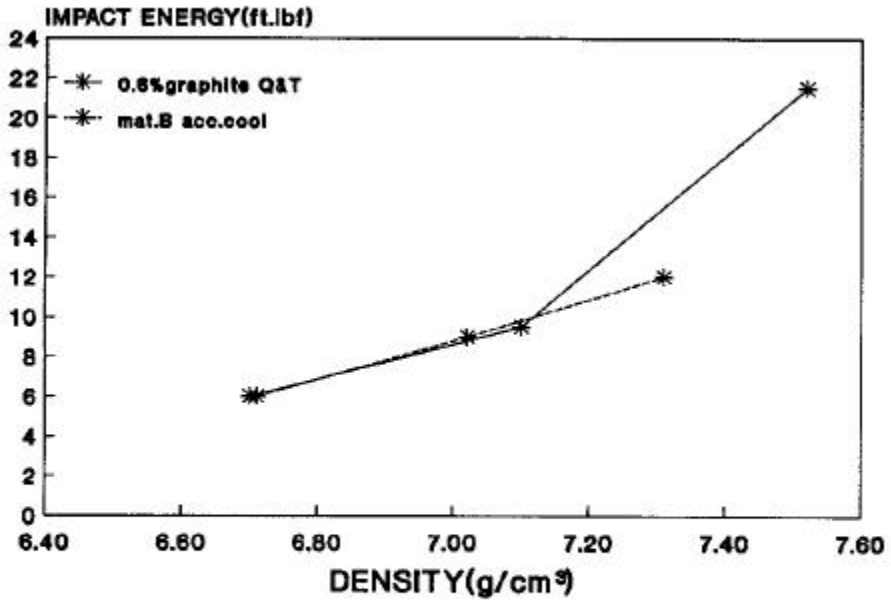

Figure 9: Comparison of unnotched Charpy impact energy of quenched and tempered Ancorsteel 85 HP, 0.6% graphite, and material B following accelerated cooling from the sintering temperature.