

# **IMPROVED DIMENSIONAL CONTROL AND ELIMINATION OF HEAT TREATMENT FOR AUTOMOTIVE PARTS**

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

## **ABSTRACT**

The automotive industry has expressed concern about the general quality of heat treatment (austenization and quenching) and the desire to reduce or eliminate dependence upon this process whenever possible. Therefore, in a continuing effort for improvement during the past year, a process has been developed that eliminates the conventional heat treating operation for some applications.

Some of these finished parts require both a high impact strength and a hardened wear resistant surface.

The Charpy impact, tensile and TRS properties of a binder treated premix based on a partially alloyed powder have been evaluated utilizing a variety of processing conditions. These include various carbon contents, sintering temperatures and sintering times.

Quantitative metallography was used to evaluate the pore size, pore shape and microstructural constituents present as a result of the various materials and processes. These factors were then correlated with the measured properties.

## **INTRODUCTION**

This paper summarizes portions of the effort to develop a material with high impact energy, superior and consistent dimensional control and a hardened surface, all without a conventional heat treatment operation.

Presently, there are six tilt levers, requiring a quench and temper heat treatment to surface carburize the parts, utilized in automotive steering columns. Evaluation of this material was covered in a previous paper [1].

Currently, there is one part, a "pawl steering column lock", being manufactured for the automotive industry by a press, pre-sinter, coin, "sinter-harden" and temper operation.

Powder metallurgy processing permits the microstructure of the part to be tailored to the demands of the application. The microstructural constituents have a significant effect on the mechanical properties of the material. In order to optimize the performance, the correct balance must be achieved between the microstructure of the inner and inter-particle regions [2,3].

This paper will indicate that proper control of chemistry and processing will permit manufacture of a material with high impact energy and a hardened wear resistant surface without the need for a separate quench and temper operation.

## EXPERIMENTAL PROCEDURE

### Materials

All premixes were binder treated using the ANCORBOND process to reduce dusting and segregation. The base material for the premixes was a partially alloyed powder (Distaloy 4800A).

The premix compositions are indicated in Table I. The significant variables were graphite and nickel content. Premixes A, B and C had a graphite addition of 0.75%, 0.80% and 0.85%, respectively. Premix D had no extra nickel added, while the remainder had 2% additional nickel resulting in a total nickel content of 6.0%. Premix E, however, had only 0.30% graphite.

**Table I: Premix Compositions**

Premix	Base Material (%)	Nickel (%)	Graphite (%)	Acrawax (%)
A	96.50	2.00	0.75	0.75
B	96.45	2.00	0.80	0.75
C	96.40	2.00	0.85	0.75
D	98.45		0.80	0.75
E	96.95	2.00	0.30	0.75

Premixes A, B, C and D will "sinter-harden" during the sintering operation. There will be some transformation to martensite and bainite while cooling in the sintering furnace with the remainder of the microstructure consisting of pearlite and nickel-rich areas. The "sinter-hardened" parts, therefore, require tempering.

Premix E required a special quench and temper heat treatment to develop the required surface hardness and impact properties.

### Processing Procedure

The unnotched Charpy impact specimens were nominally 0.394" x 0.394" x 3.00"; reference MPIF Standard No. 40. The tensile specimens were the molded "standard fiat un-machined tensile test" specimens nominally 0.25" thick; reference MPIF Standard No. 10. The transverse rupture strength (TRS) specimens were nominally 1.25" x 0.50" x 0.25"; reference MPIF Standard No. 41.

The specimens were pressed to a density of 6.9 g/cm<sup>3</sup>; presintered at 1400°F and repressed to 7.3 g/cm<sup>3</sup>. However, Premix B, Process No. 4, was presintered at 1500°F. The final density of the specimens averaged 7.38 g/cm<sup>3</sup> for all three configurations.

All the specimens were sintered in production furnaces for varying periods of time: 30, 37 and 45 minutes at a temperature of 2050°F; except Process No. 6 where specimens were sintered at 2150°F.

The process variables are shown In Table II. Most specimens were "sinter-hardened" during the sintering operation and tempered at 375°F. The exceptions were Premix B, Process No. 5, tempered at 450°F; and

Premix E, Process No. 7, low graphite, 20 minutes sinter plus quench and temper heat treatment.

**Table II: Process Variables**

Process No.	Presintering Temperature (°F)	Sintering Temperature (°F)	Sintering Time (mins.)	Tempering Temperature (°F)
1	1400	2050	30	375
2	1400	2050	37	375
3	1400	2050	45	375
4	1500	2050	37	375
5	1400	2050	37	450
6	1400	2150	37	375
7	1400	2050	20	*

\* Heat-treated, quenched and tempered at 375°F

The combinations of premix and processes evaluated in this paper are summarized in Table III.

**Table III: Premix & Process Combinations Evaluated**

Process No.	1	2	3	4	5	6	7
Premix A	X	X	X				
Premix B	X	X	X	X	X	X	
Premix C	X	X	X				
Premix D		X					
Premix E							X

For each premix and process combination evaluated, five unnotched Charpy specimens were tested at room temperature. There were also three tensile specimens and three TRS specimens tested.

## METALLOGRAPHIC EXAMINATION

Sample cross-sections were cut from the impact test specimens and prepared for metallographic examination. All metallographic preparation was done on a Struers Abrapoi automated grinder/polisher. Automated polishing was essential to provide the high quality scratch-free and stain-free surface required for quantitative metallography.

Pore size and shape measurements were carried out using a Leitz TAS-Plus automated image analyzer according to the procedure described in reference 1.

The specimens were then etched with a combination of 2% nital/4% picral prior to carrying out a quantitative estimate of their microstructural constituents (Figures 1-4). For the quenched and tempered samples, this was relatively straightforward. However, before this could be done for the sinter-hardened samples, a decision had to be made concerning which microstructural features should be included in the analysis. The decision was aided by the use of semi-quantitative X-ray analysis on a scanning electron microscope. Energy dispersive analysis was used to compare the relative concentrations of nickel, copper and molybdenum in selected microstructural features including: pearlite, the ferrite rim surrounding many pearlite colonies, and the non-etching nickel-rich areas in the inter-particle regions. Further details of the

procedure are presented in reference 1. The percentages of the following microstructural constituents were assessed:

- pearlite
- ferrite
- nickel-rich ferrite (containing divorced carbides)
- nickel-rich non-etching regions
- martensite (dark etching - found in quench-hardened samples)
- dark etching martensite plus retained austenite
- light etching martensite plus retained austenite
- porosity

These features are illustrated in Figures 1-4. The light etching martensite in the sinter-hardened samples contains a higher nickel concentration than the dark etching martensite. A quantitative point count estimate of the percentage of the respective microstructural constituents present in selected samples was carried out using a 20-point grid (with a point spacing of 20 mm) at a magnification of 750 diameters. Twenty random fields were examined per sample and the average results reported.

## RESULTS

The mechanical properties of the three major premixes and processes are compared in Table IV.

Table V lists the results for selected premix/process combinations and compares the mechanical properties of various combinations of three premixes and five processes.

There was found to be no significant difference between the samples with respect to pore size or pore shape. Photomicrographs illustrating the microstructures of selected samples are presented in Figures 1-4. The estimates of percentages of different microstructural constituents present in these samples are summarized in Table VI and shown graphically in Figures 5-7.

## DISCUSSION

The primary purpose of the present study was to determine the effect of a small range of graphite content, and a range of sintering times at 2050°F, as shown in Table IV. Table V lists other factors; i.e., different pre-sintering temperature 1500°F; different tempering temperature 450°F; different sintering temperature 2150°F; premix without added nickel; plus the current premix and production process for most applications.

The ultimate tensile strength was greater for premix B (0.8% graphite) than either premix A (0.75% graphite) or premix C (0.85% graphite). The strength for all three premixes increased with greater sintering time as would be expected.

The yield strength was also greater for premix B (0.8% graphite) than either premix A or C, except for premix C sintered for 45 minutes which had the largest value.

The percentage elongation averaged slightly better for premix B (0.8% graphite) but was essentially the same for premixes A, B and C with Processes 1, 2 and 3.

The unnotched Charpy impact energy was again higher for premix B compared with **either A or C**.

The above conditions and trends are displayed in graphs shown in Figures 8, 9 and 10.

The Rockwell C hardness values for the tensile specimens, Table IV, does not indicate any particular trend.

The Rockwell C hardness values for the Charpy impact specimens do, however, indicate a trend with premix B having slightly higher values.

Table V indicates that there is no significant difference in the values for premix B sintered at 2050°F under various conditions. Hence, raising the temperature of the presinter or temper slightly does not appear to change the properties significantly.

Premix D (without nickel) however, had significant changes. The ultimate tensile strength was approximately 10,000 psi lower, the yield strength approximately 10,000 psi higher, and the Charpy impact values were 10 ft. lbf lower than for premix B, Process No. 2. However, the Rockwell C hardness, density and TRS values were similar.

### **Microstructure**

The microstructures of most of the samples were quite similar, Figures 1-6. However, in the material that did not contain the extra 2% nickel, there were two forms of pearlite present; a coarse pearlite in addition to the finer form present in most of the other samples. This material (D2) also contained a lower percentage of dark and light etching martensite than the other "sinter-hardened" samples. The microstructure of the quench-hardened material (E7) was predominantly martensitic with a small percentage of bainite (Figures 4 and 7) shown that high temperature sintering led to pore rounding and pore coalescence [2]. However, a sintering temperature of 2425°F was used in the prior work while in the present study the maximum sintering temperature was 2150° F.

### **CONCLUSIONS**

The combination of premixes B and Process 2 provides a new material for the automotive and other industries. This material, while achieving a hardness of over 20 HRC will have superior dimensional control, greater impact energy, and better elongation compared with material heat treated by quenching and tempering. The elimination of conventional heat treatment will result in improved dimensional control and greater consistency of mechanical properties.

The addition of 2% nickel to the base material increases all mechanical properties: impact energy by 8 ft.lbf, ultimate tensile strength by 8,000 psi, and elongation by 1% (B2 compared with D2).

The binder treatment of the premixes was beneficial with the small increments in graphite content used in this study as there was no indication of segregation.

The lower properties for premix A (0.75% graphite) would tend to indicate that a graphite content of less than 0.8% is insufficient for optimum strengthening of the test specimens. However, a graphite content of 0.85% was not particularly beneficial for this material.

A sintering time of 30 minutes exhibited decreased property values compared with 37 minutes. The properties for 45 minutes sintering time were generally only slightly less than for 37 minutes.

From a manufacturing viewpoint, this slight difference in mechanical properties obtained between 0.8% and 0.85% graphite content, 1400°F to 1500°F pre-sintering temperature and 375-450°F tempering temperature indicates a process with considerable tolerance to process variations.

## **REFERENCES**

1. W. B. James, V. C. Potter and T. F. Murphy, "Sintering Column Tilt Lever - P/M Material Development", presented at 1990 SAE International Congress and Exposition, CoHo Hall, Detroit, MI, February 1990, SAE Technical Paper 900381.
2. W. B. James, "Fatigue Properties of Ferrous P/M Materials", presented at P/M Seminar, Sac Paulo, Brazil, October 1989.
3. T. Saito and M. Obayashi, "High Strength Sintered Steel Without Heat Treatment", Modern Developments in Powder Metallurgy, Vol. 21, pp 197, 1988, published by Metal Powder Industries Federation, Princeton, NJ.

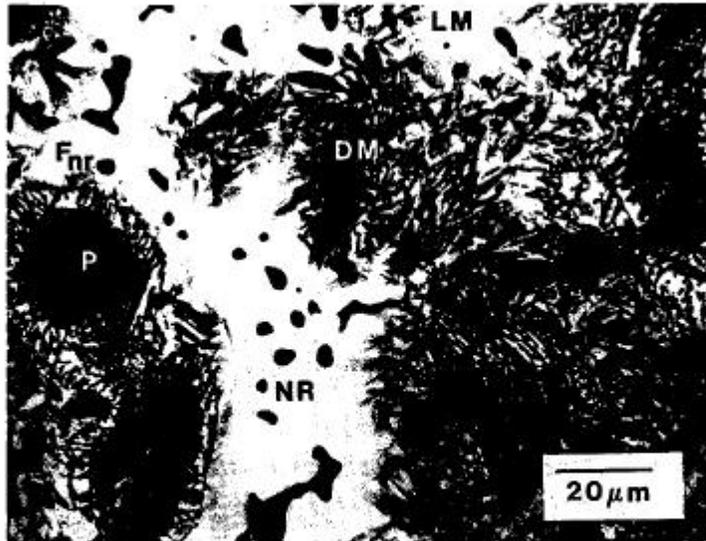


Figure 1: Photomicrograph of sample B2 (0.8% graphite, sinter-hardened, 37 minutes at 2050°F, tempered at 375°F). Etched with a combination of 2% nital/4% picral. Original magnification 750X.

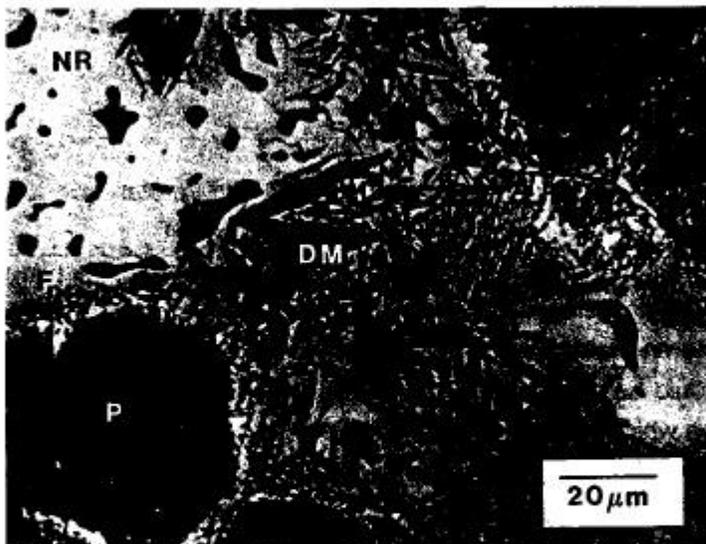
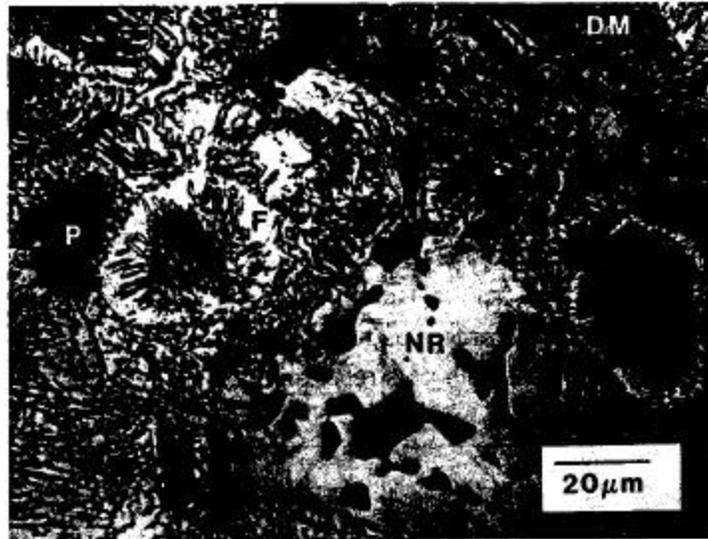
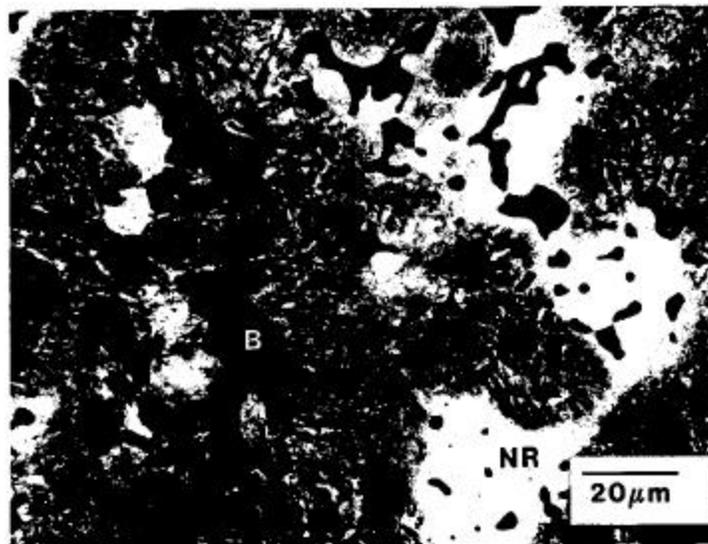


Figure 2: Photomicrograph of sample B6 (0.8% graphite, sinter-hardened, 37 minutes at 2150°F, tempered at 375°F). Etched with a combination of 2% nital/4% picral. Original magnification 750X.



**Figure 3:** Photomicrograph of sample D2 (no additional nickel, 0.8% graphite, sinter-hardened, 37 minutes at 2050°F, tempered at 375°F). Etched with a combination of 2% nital/4% picral. Original magnification 750X.



**Figure 4:** Photomicrograph of sample E7 (0.3% graphite, quench-hardened, 20 minutes at 2050°F, tempered at 375°F). Etched with a combination of 2% nital/4% picral. Original magnification 750X.

**Table IV: Mechanical Properties (Premixes A, B, C and Processes 1, 2, 3)**

Premix	Process No.	Tensile Yield (ksi)	UTS (ksi)	Elong. (%)	Charpy Impact (ft.lbf)	TRS (ksi)	Hardness Tensile Specimen (HRC)	Hardness Charpy Specimen (HRC)
A (0.75% gr)	1	66.4	117.3	3.1	31.5	254	22	22
	2	74.5	125.6	3.1	34.8	272	25	22
	3	74.9	126.4	3.4	34.0	273	24	24
B (0.80% gr)	1	82.7	122.6	3.2	36.6	265	25	26
	2	84.3	133.8	3.4	37.0	266	27	26
	3	83.5	134.6	3.3	35.0	263	28	26
C (0.85% gr)	1	78.6	122.2	3.2	29.3	256	25	23
	2	81.7	126.3	3.2	33.8	263	27	24
	3	90.4	128.2	3.2	34.0	276	26	24

**Table V: Results for Selected Premix/Process Combinations**

Premix/Process	Tensile Yield (ksi)	UTS Tensile (ksi)	Elong. (%)	Hardness (HRC)	Density (g/cm <sup>3</sup> )	Charpy Impact (ft.lbf)	TRS (ksi)
B2	84.3	133.8	3.4	27	7.38	37.0	266
B4	82.2	133.6	3.5	26	7.36	37.1	281
B5	86.9	131.4	3.4	25	7.40	32.2	262
B6	78.4	134.9	3.8	25	7.43	40.0	NA
D2	96.0	124.8	2.5	26	7.37	26.0	269
E7	131.8	142.3	1.3	38	7.37	22.0	290

Table VI: Metallographic Estimate of the Percentage of Different Microstructural Constituents in Selected Samples

Sample	Microstructural Constituents (%)									
	Pearlite P	Coarse Pearlite Pc	Ferrite F	Nickel-rich Ferrite F <sub>nr</sub>	Bainite B	Nickel-rich Non-Etching NR	Dark Etching Martensite DM	Light Etching Martensite LM	Martensite (from Quench Hardening) M	Porosity
A2	24	--	1	18	1	5	13	32	--	6
B1	30	--	--	11	--	8	29	18	--	4
B2	20	--	--	17	--	8	26	24	--	5
B3	25	--	--	16	--	6	24	24	--	5
B6	21	--	--	15	--	13	19	27	--	5
C2	29	--	--	12	--	10	19	24	--	6
D2	24	17	3	15	--	2	11	22	--	6
E7	--	--	--	--	6	19	--	--	69	6

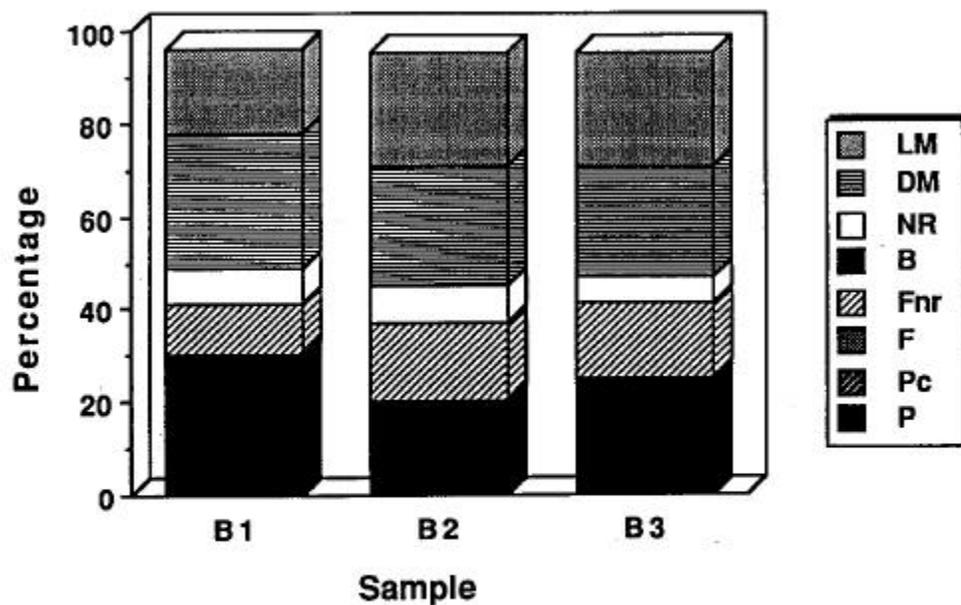


Figure 5: The percentage of different microstructural constituents in samples B1, B2 and B3 as determined by point count analysis - see Table VI.

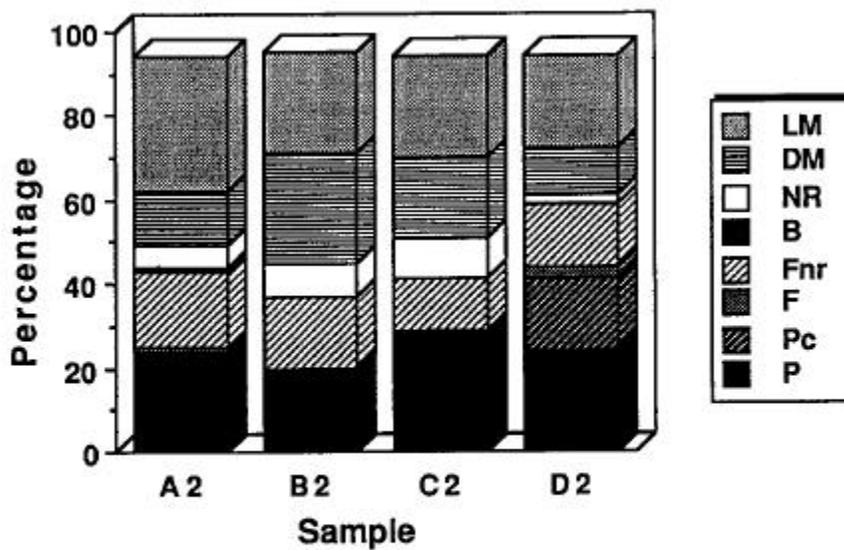


Figure 6: The percentage of different microstructural constituents in samples A2, B2, C2 and D2 as determined by point count analysis - see Table VI.

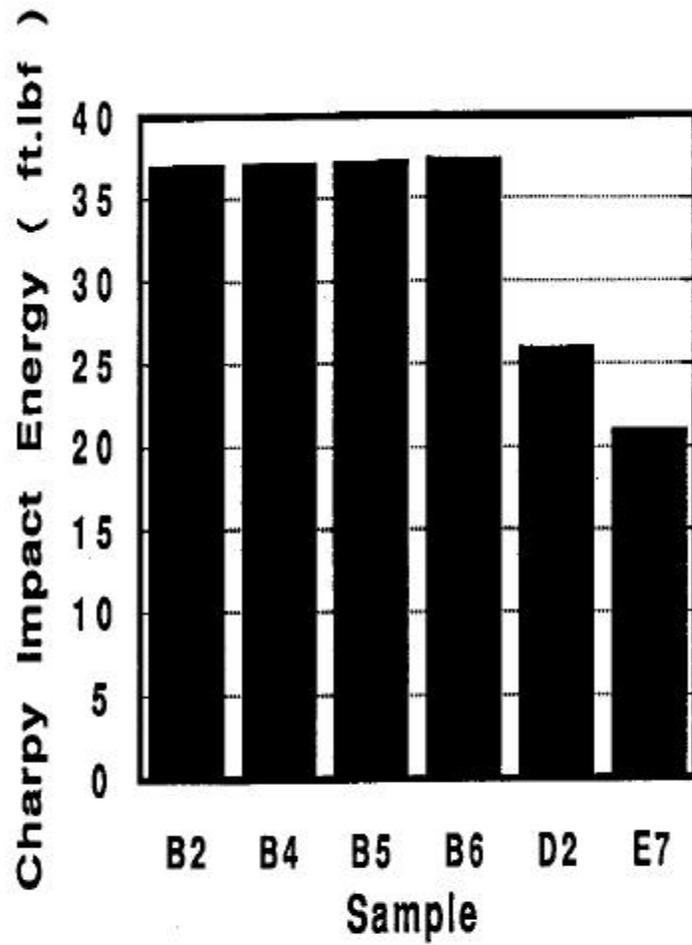


Figure 10: Unnotched Charpy impact energy of samples B2, B4, B5, B6, D2 and E7 - see Table V.

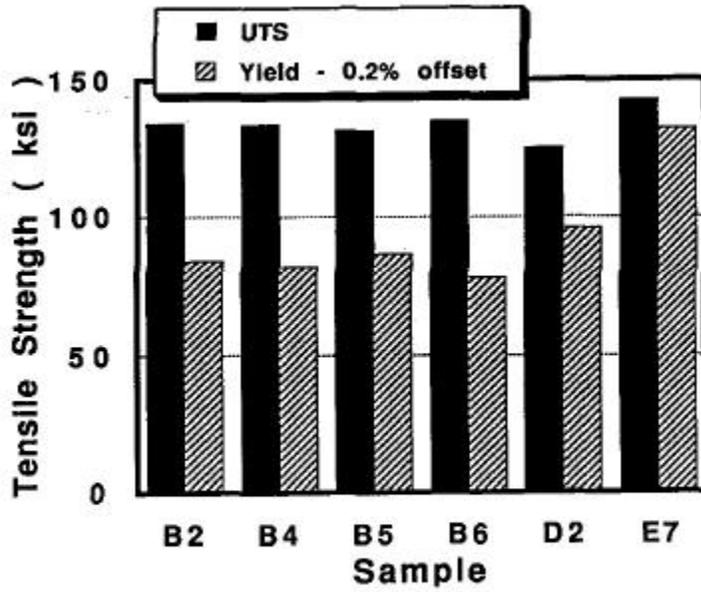


Figure 8: Tensile strength of samples B2, B4, B5, B6, D2 and E7 - see Table V.

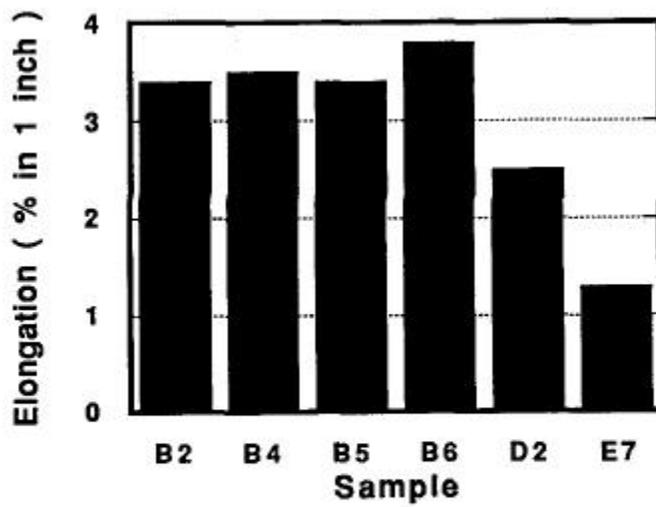


Figure 9: Tensile elongation of samples B2, B4, B5, B6, D2 and E7 - see Table V.

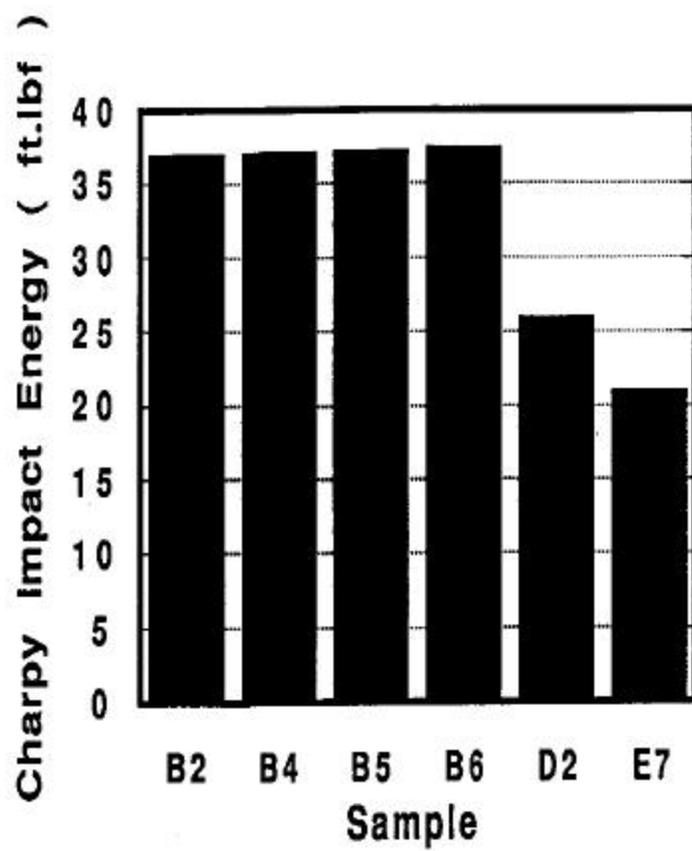


Figure 10: Unnotched Charpy impact energy of samples B2, B4, B5, B6, D2 and E7 - see Table V.