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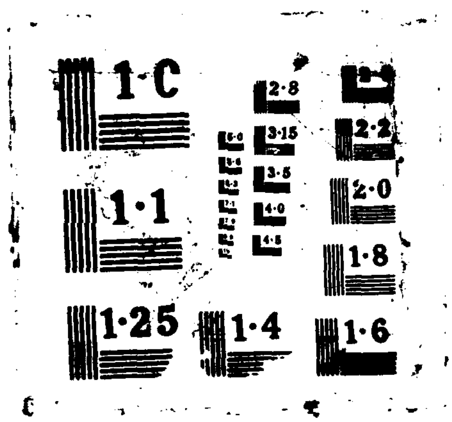
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MEMORANDUM REPORT BRL-MR-3606

MECHANICAL PROPERTY EVALUATION OF A SERIES OF COMMERCIAL TUNGSTEN ALLOYS

WILLIAM J. BRUCHEY, JR.
DENISE M. MONTIEL

JUNE 1987

US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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A series of commercially available tungsten alloys ranging in tungsten content from 75% to 95% were evaluated. Typical tensile and compressive engineering properties are reported. These tests were conducted in support of penetrator ballistic test programs.

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I. INTRODUCTION

During the conduct of a kinetic energy penetrator design study, the Penetration Mechanics Branch experienced unexpected ballistic performance variations from a series of tungsten materials. These materials contained 75% to 95% tungsten in a nickel-iron matrix. Examination of the firing data records did not reveal any unusual behavior which could be associated with either the penetrator design or the impact geometry. It was decided that the mechanical properties of the material should be determined independently of the manufacturer's advertised data.

Because there was some concern that the materials were actually at fault, the manufacturer agreed to supply a replacement material at no charge. Mechanical property tests were run on both the new and original batches of material to determine if the material had been improperly processed, or whether the manufacturer had changed the processing history for the material between the time of the last tests and the present ones.

This report covers the mechanical property data gathered by the Solid Mechanics Branch. At a later date, these results will be combined with ballistic performance data to determine the extent that the materials accounted for test variations.

II. EXPERIMENTAL PROCEDURES

The mechanical tests were conducted using an Instron electromechanical testing machine, with a load cell calibrated for a 10,000 Kg maximum load. The data was collected onto magnetic tapes with the aid of a Hewlett Packard data logger; programs written for the data logger were utilized to further reduce, analyze and plot the data.

All tensile specimens were of the SMB-1 type, illustrated in Figure 1. Two rosette strain gages were bonded to the center of the specimen, 180 apart. A one-inch extensometer was also incorporated into the setup to measure the strain-to-failure as accurately as possible. The crosshead speed used in every case was a rate of .02 cm/minute.

The compression specimens were all configured as shown in Figure 1. Three rosette strain gages were used in each instance, bonded with a 120 separation at the center of the specimen. Six of the specimens, Test Nos. 336-341, were tested at a crosshead speed of .005 cm/min, and four tests, Nos. 361-364, were run at a rate of .01 cm/min.

III. RESULTS

Following are the tensile and compressive properties of various tungsten materials supplied to the Solid Mechanics Branch for evaluation. Table I is a summary of the measured engineering properties for each of the materials tested. In the table, the abbreviation "SW" refers to the percent swaging to which the material was subjected. Figures 2-24 are the actual engineering stress-strain curves for each of the materials listed in Table I. All of the test specimens were provided by the AAI Corporation.

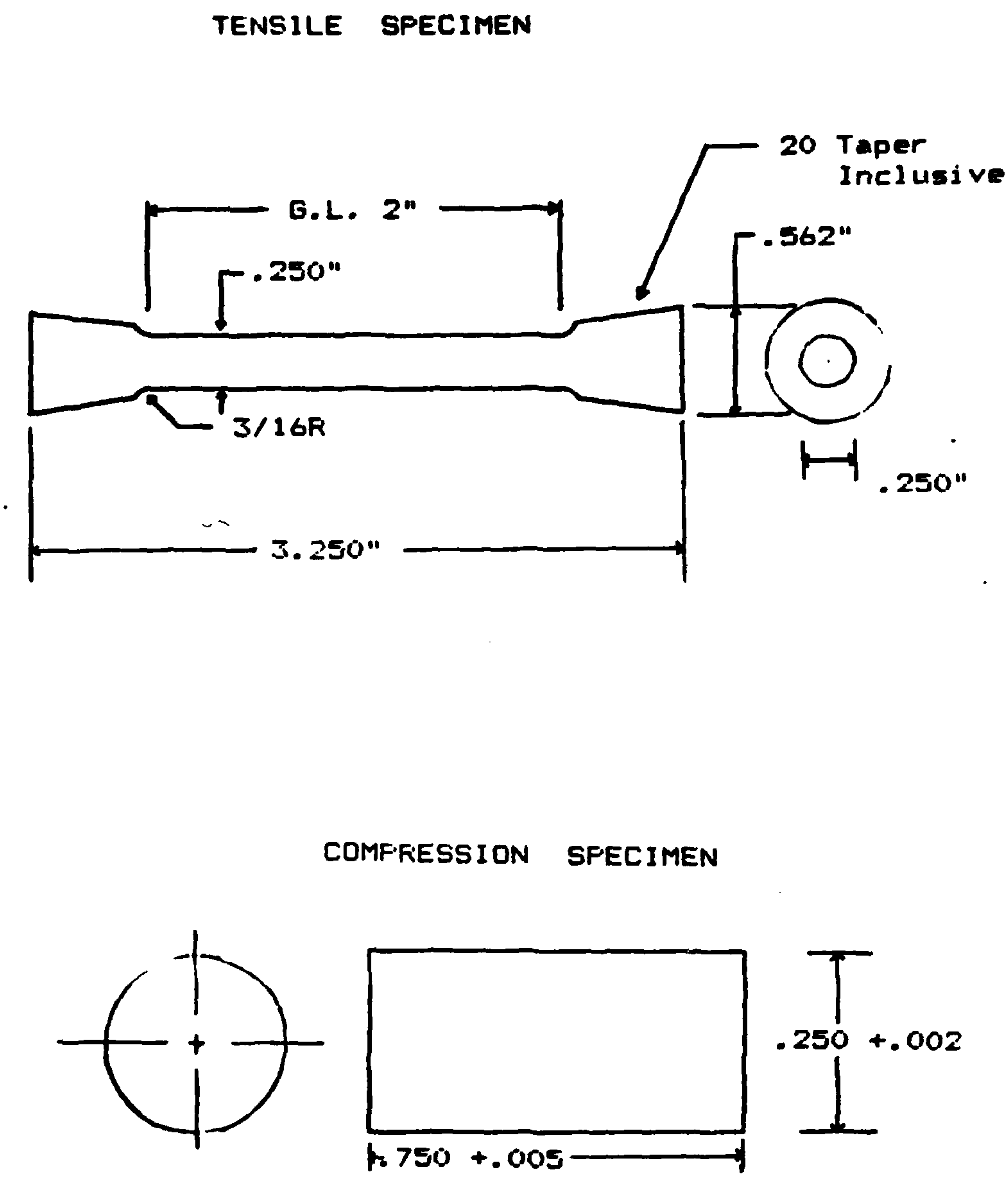

Figure 1. Test Specimen Configurations

(AAI) SPECIMEN REFERENCE NO.	TEST NO.	TENSILE	COMPRESSION	YIELD MPa .2%	YOUNG'S MODULUS GPa	BULK MODULUS GPa	POISSON'S RATIO	PLASTIC POISSON's RATIO	ULTIMATE STRESS MPa	ULTIMATE STRAIN %	FRACTURE STRESS MPa	FRACTURE STRAIN %
376 #1	324	X			298	278	.323	.465	830	14.28	825	15.71
376 #2	325	X			302	276	.319	.481	833	13.89	828	15.28
Tungsten 75% WA #1	326	X		507	267	230	.309	.449	764	14.96	764	14.96
75% WA #2	327	X		510	248	277	.351	.490	765	15.63	765	15.63
75% WA #3	334	X		493	244	275	.354	.456	738	18.20	738	18.20
75% WA 14% SW	357	X		907	260	260	.334	.491	960	6.98	950	6.98
"	358	X		924	275	261	.324	.466	970	5.12	960	7.40
75%	337		X	523	303	255	.303	.520				
"	340		X	517	291	226	.287	.479				
75% WA 21% SW	359	X		1,023	285	242	.304	.441	1,043	4.42	1,030	6.33
"	360	X		1,014	281	243	.308	.478	1,044	3.79	1,015	7.05
75% WA 14% SW	361		X	772	299	252	.303	.514				
"	362		X	724	287	220	.283	.455				
Tungsten 90% (R) WA #1	331	X		587	280	291	.341	.473	834	9.97	834	9.97
90% (R) WA #2	335	X		590	313	338	.347	.475	784	7.20	784	7.20
75% WA 21% SW	363		X	749	270	269	.334	.546				
"	364		X	707.	266	234	.313	.520				
Tungsten 90% (R) WA	336		X	578	340	294	.313	.515				
"	339		X	578	344	274	.294	.454				
Tungsten 95% WA #1	332	X		1,093	316	270	.305	.464	1,118	2.54	1,098	6.24
"	333	X		1,107	305	272	.314	.458	1,117	3.50	1,106	4.76
95%	338		X	820	343	263	.284	.545				
95%	341		X	810	345	267	.286	.493				

Table I. Tensile and Compression Data

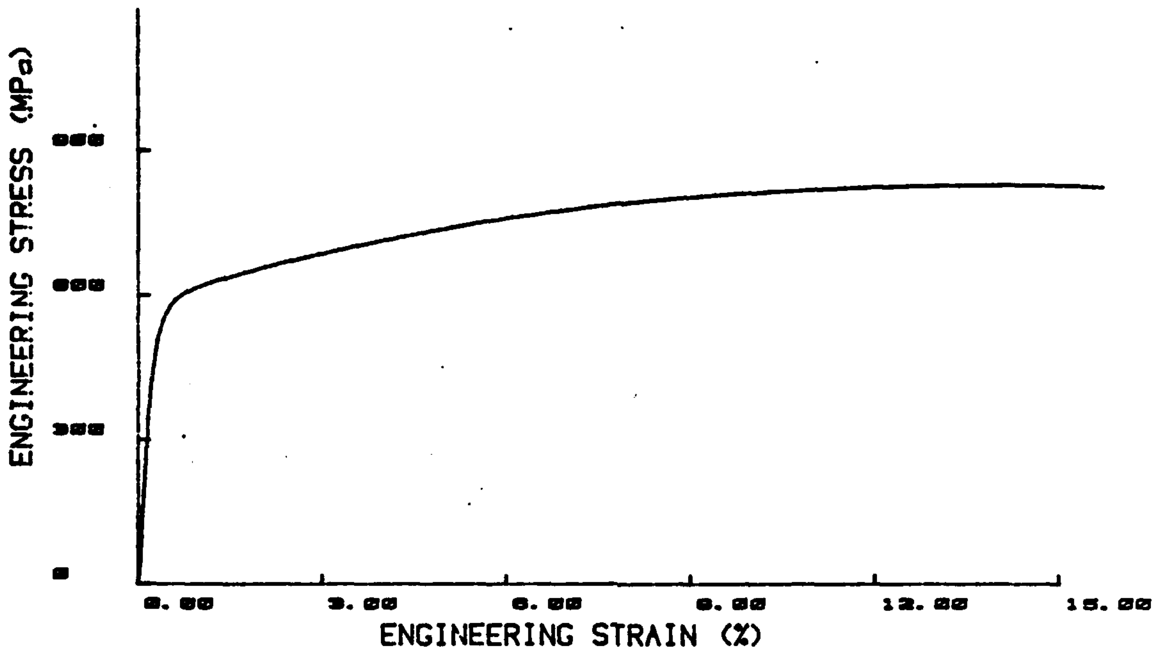

Figure 2. Uniaxial tensile stress-strain curve for initial lot 90% tungsten alloy, Specimen No. 324.

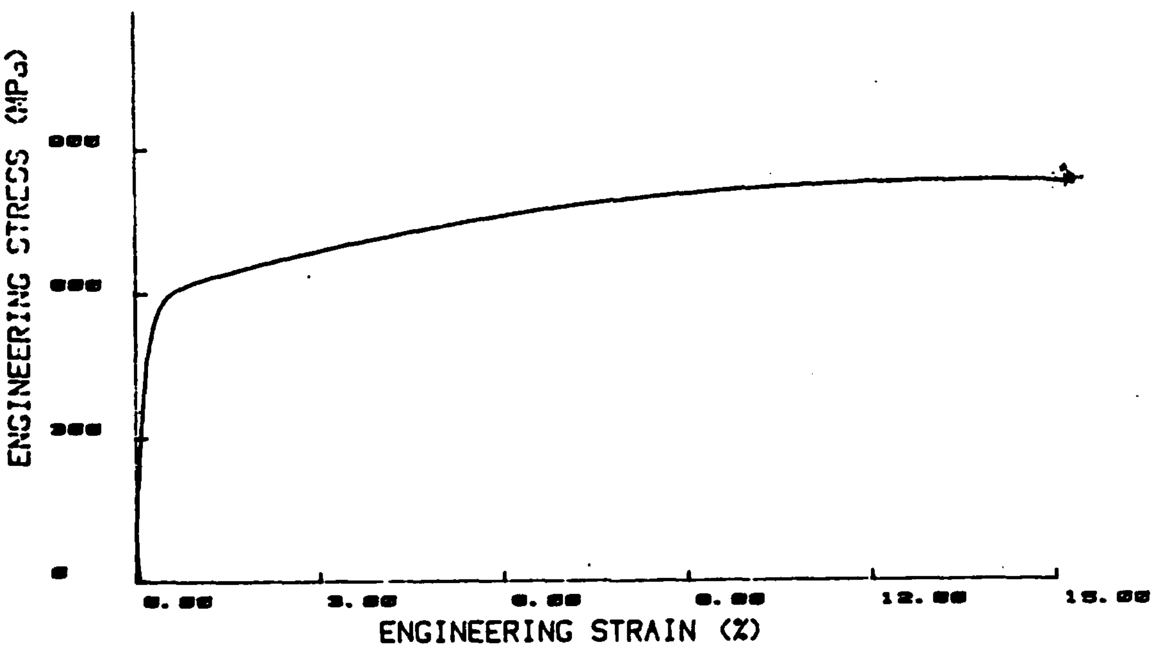

Figure 3. Uniaxial tensile stress-strain curve for initial lot 90% tungsten alloy, Specimen No. 325.

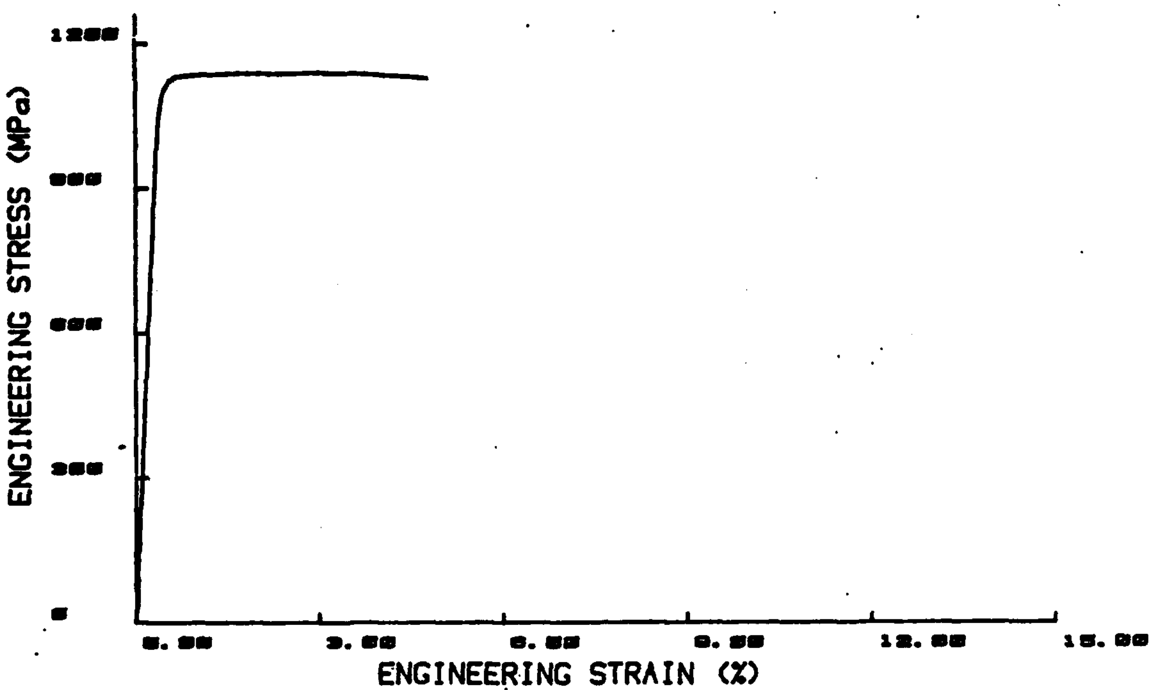

Figure 4. Uniaxial tensile stress-strain curve for a 95% tungsten alloy, Specimen No. 333.

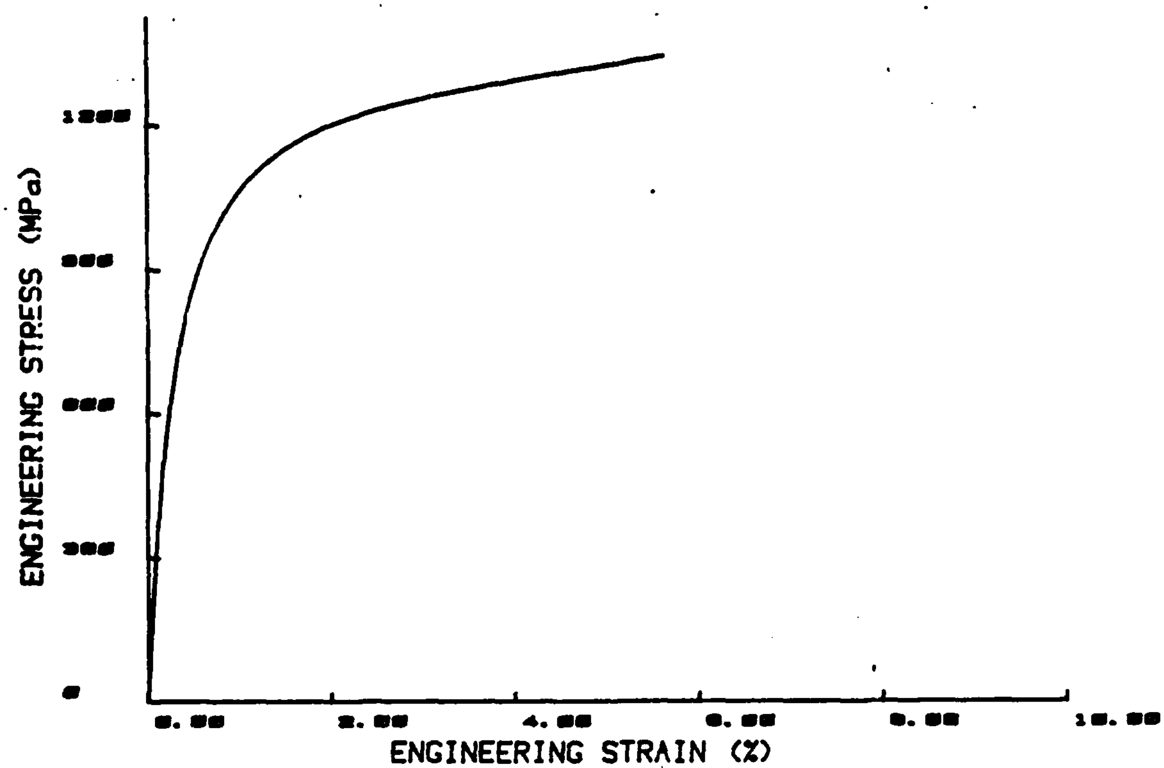

Figure 5. Uniaxial compressive stress-strain curve for a 95% tungsten alloy, Specimen No. 338.

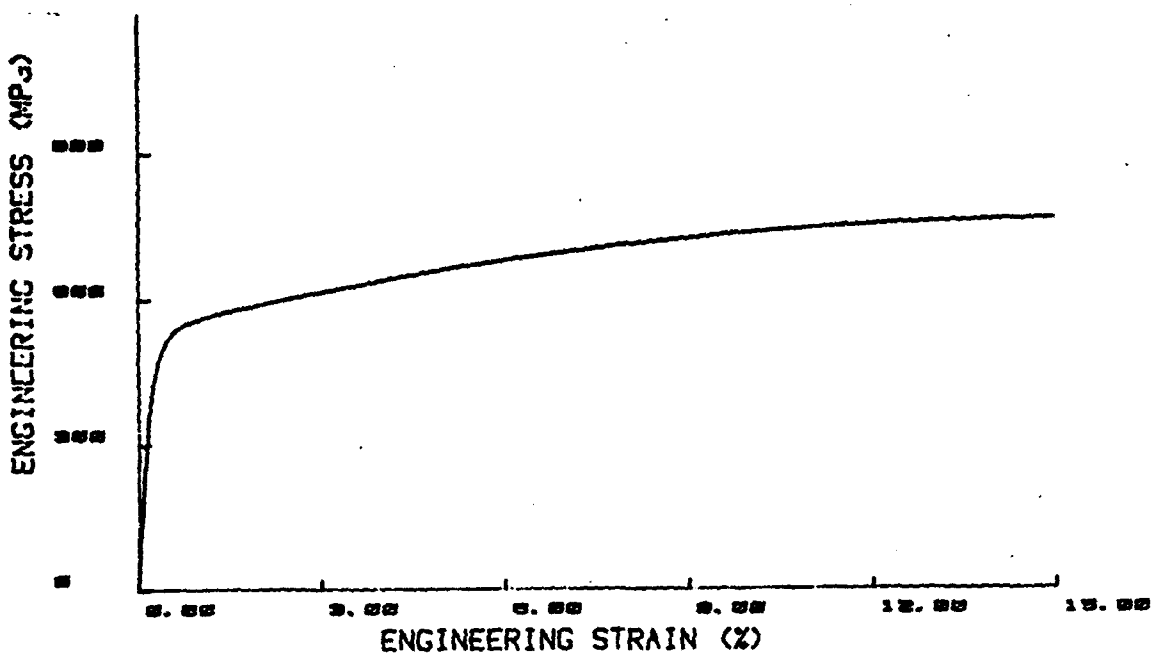

Figure 6. Uniaxial tensile stress-strain curve for an unswaged 75% tungsten alloy, Specimen No. 326.

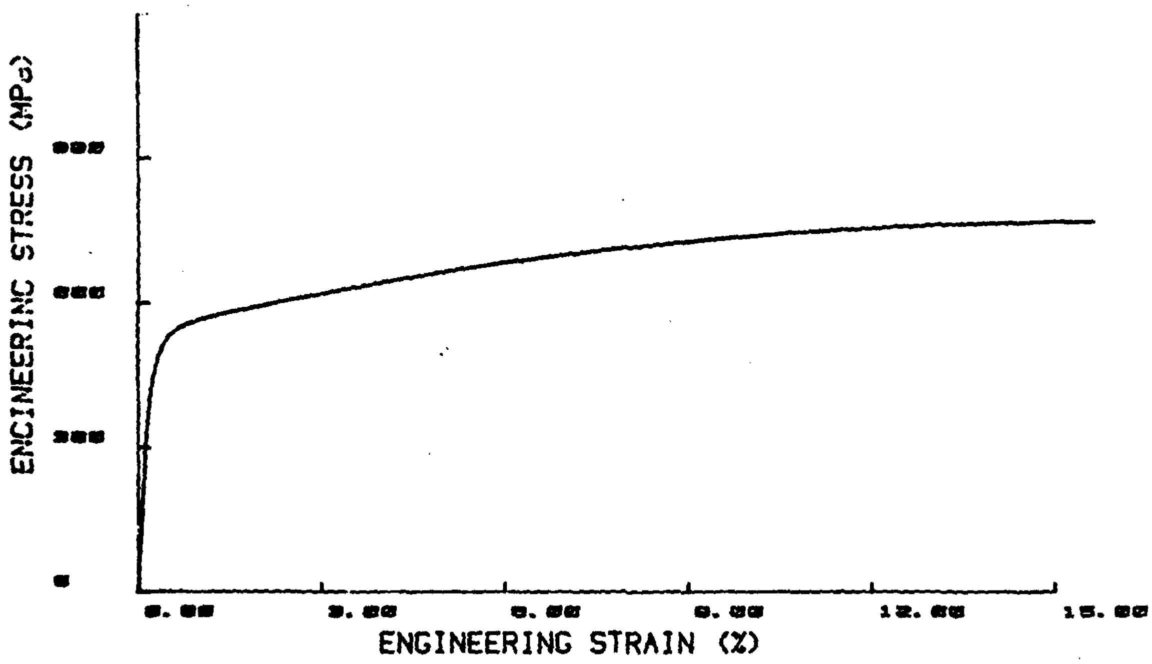

Figure 7. Uniaxial tensile stress-strain curve for an unswaged 75% tungsten alloy, Specimen No. 327.

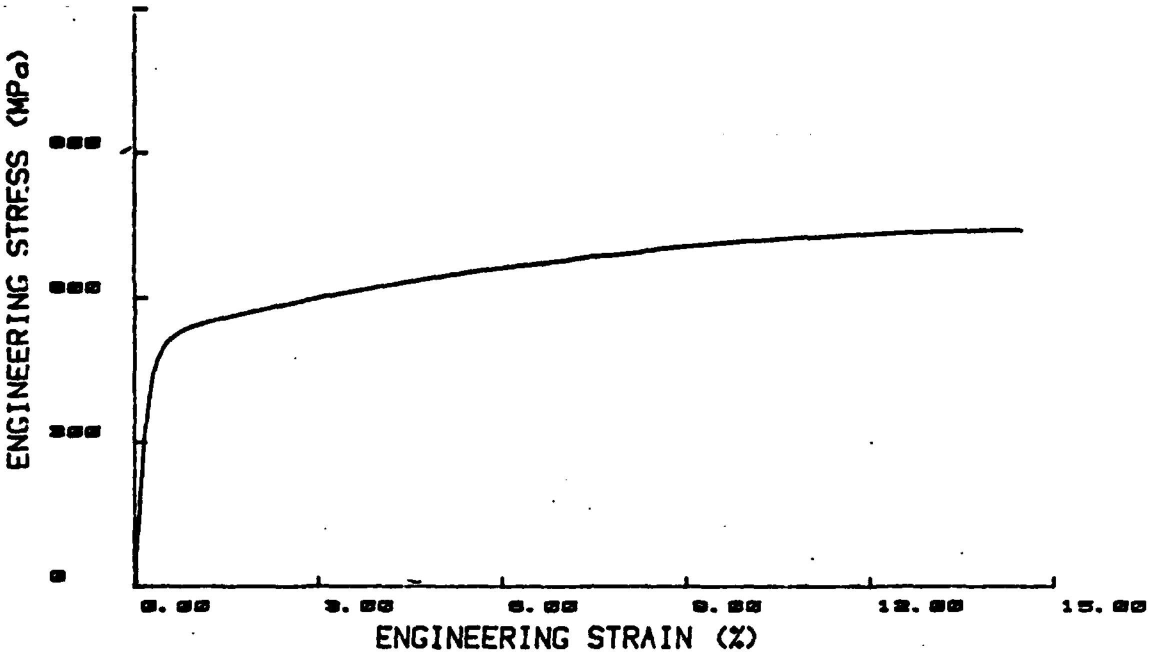

Figure 8. Uniaxial tensile stress-strain curve for an unswaged 75% tungsten alloy, Specimen No. 334.

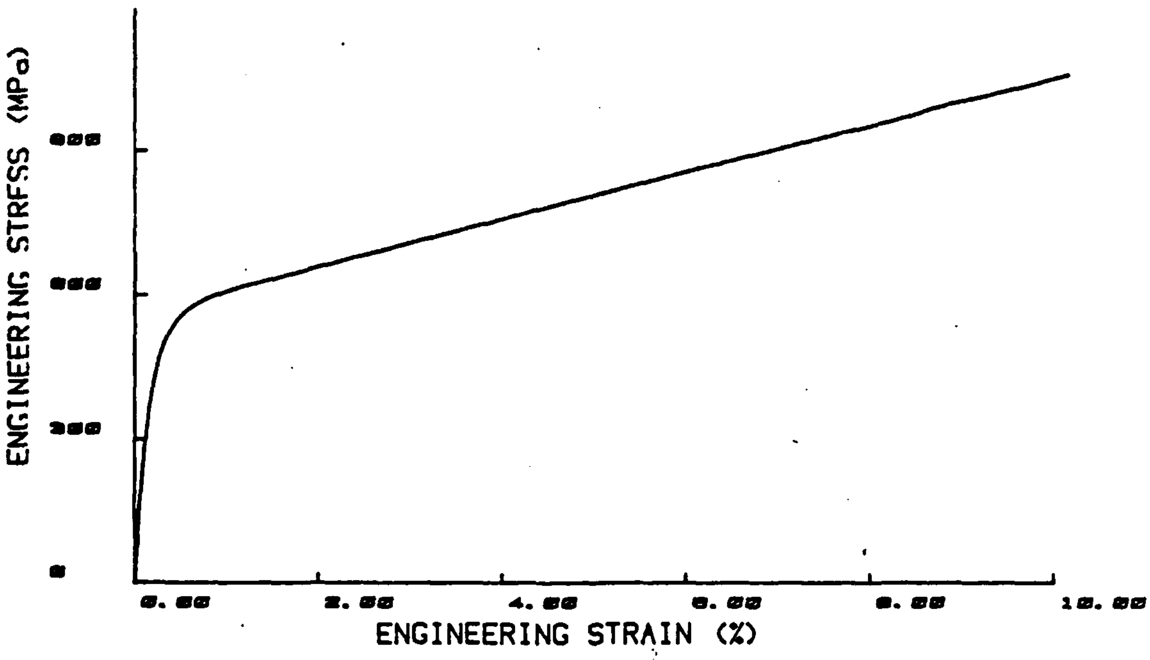

Figure 9. Uniaxial compressive stress-strain curve for an unswaged 75% tungsten alloy, Specimen No. 337.

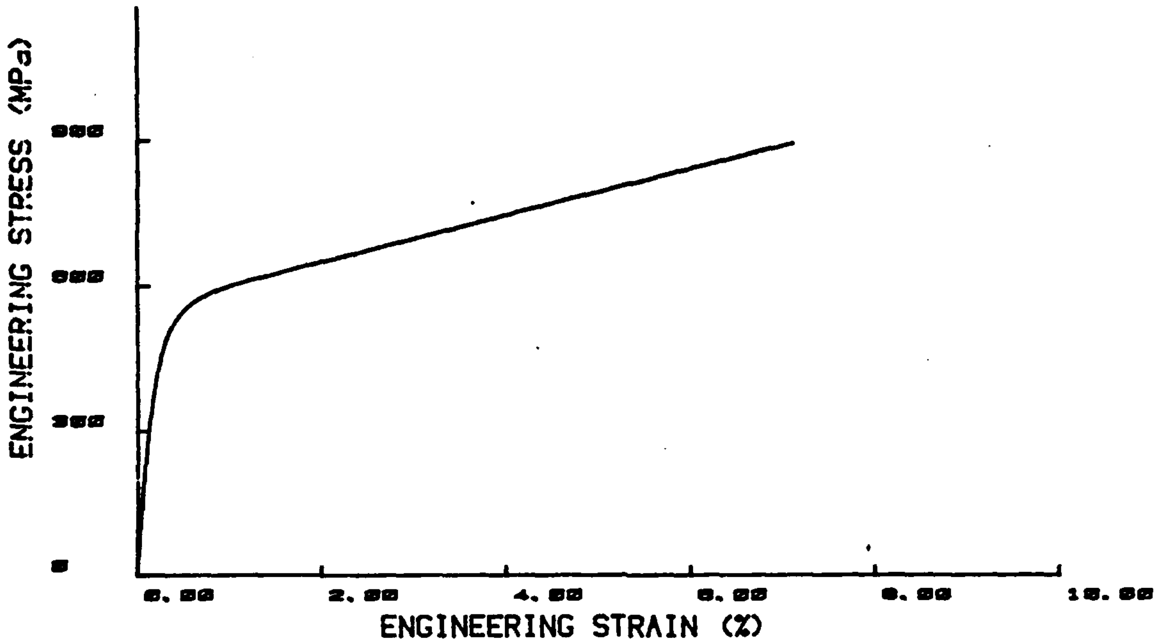

Figure 10. Uniaxial compressive stress-strain curve for an unswaged 75% tungsten alloy, Specimen No. 340.

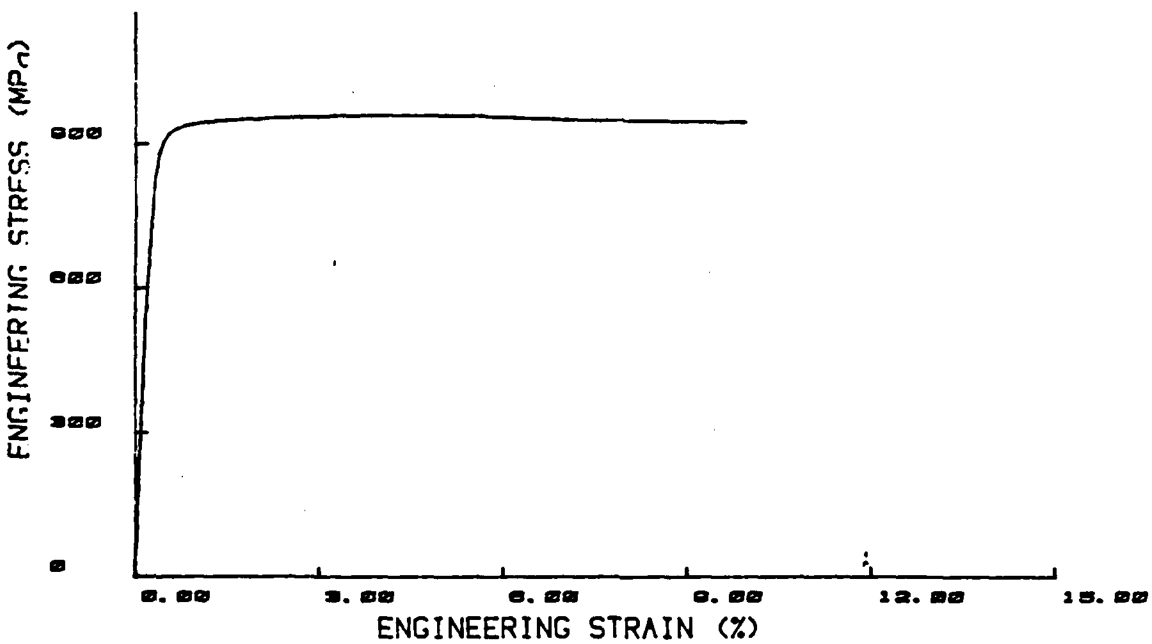

Figure 11. Uniaxial tensile stress-strain curve for a 75% tungsten alloy swaged 14%, Specimen No. 357.

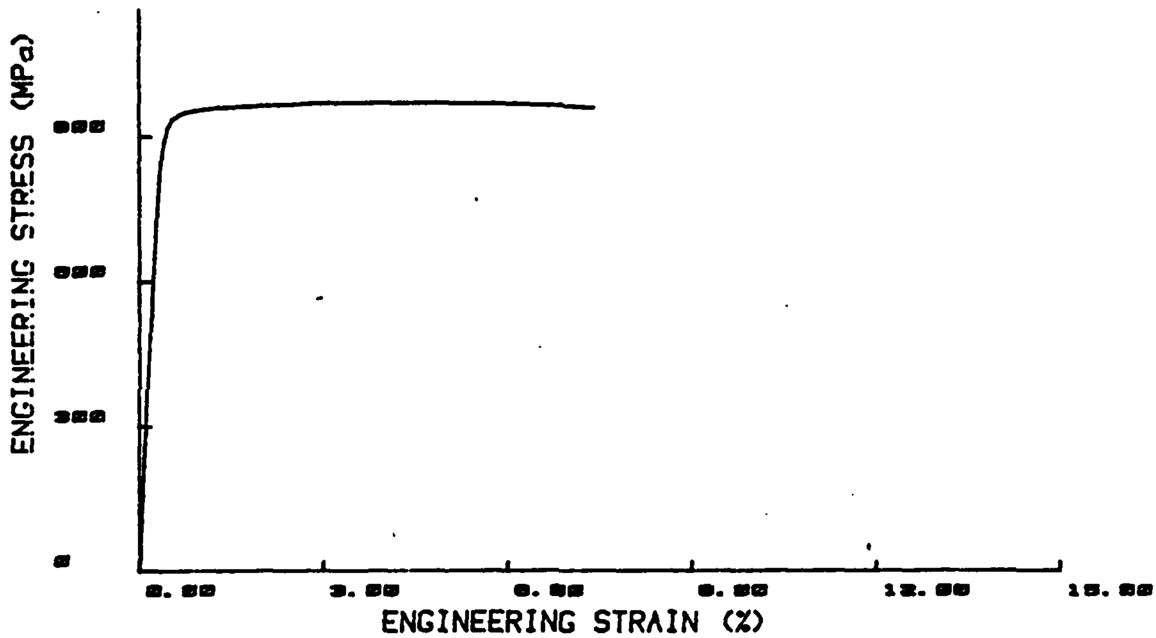

Figure 12. Uniaxial tensile stress-strain curve for a 75% tungsten alloy swaged 14%, Specimen No. 358.

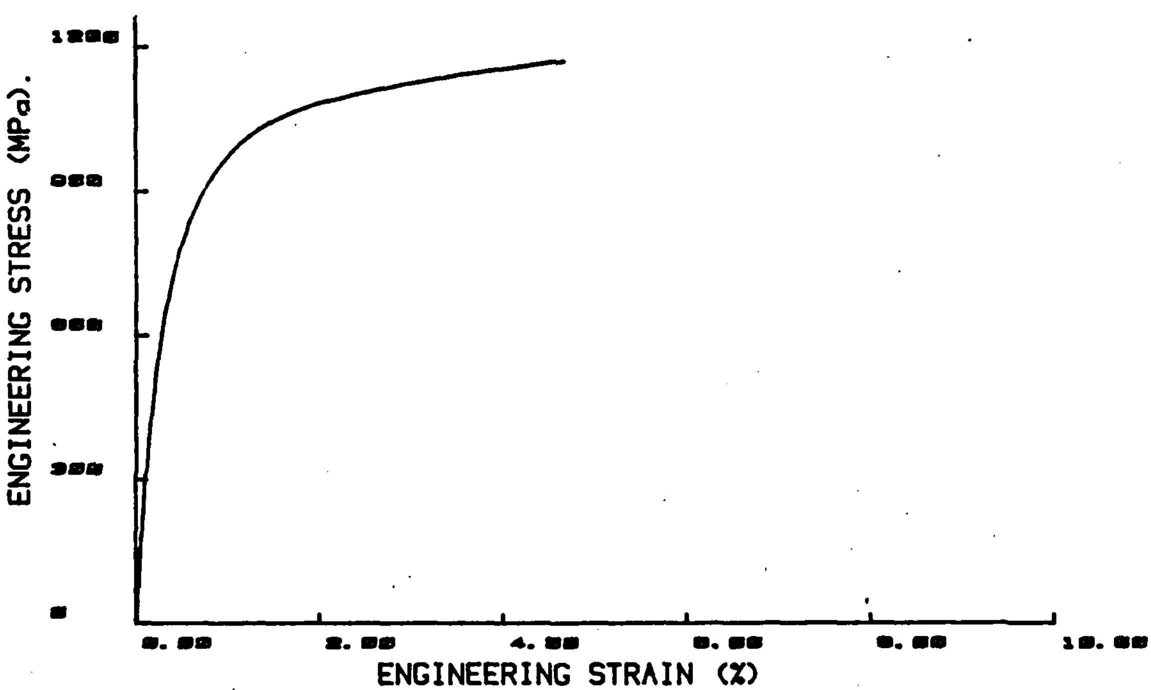

Figure 13. Uniaxial compressive stress-strain curve for a 75% tungsten alloy swaged 14%, Specimen No. 361.

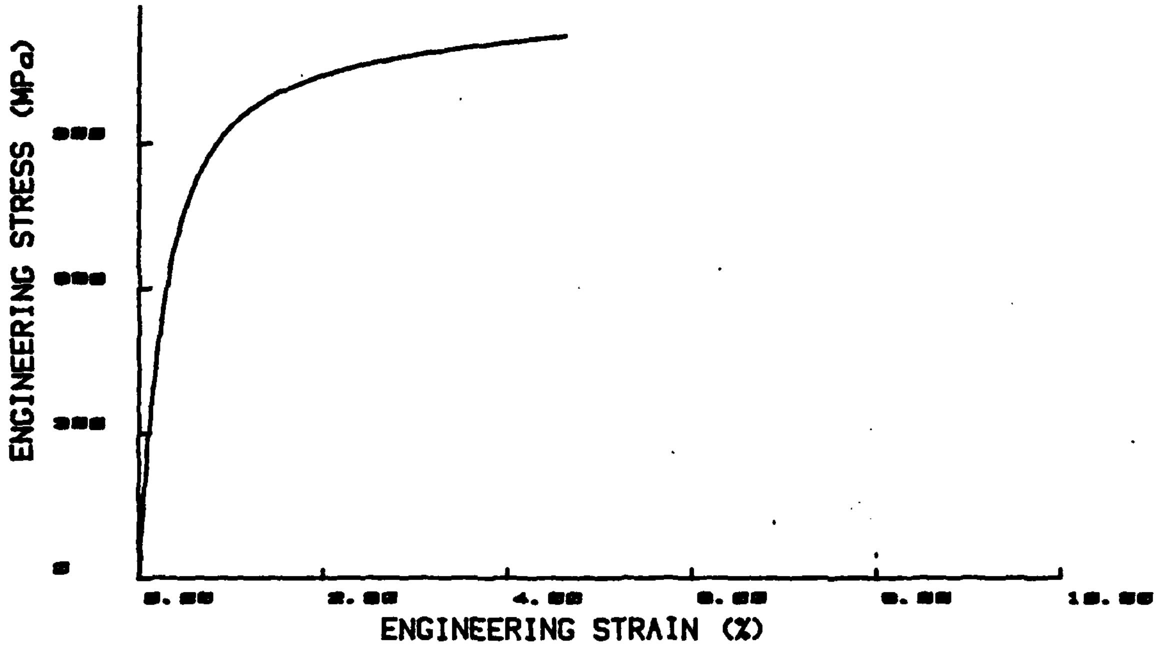

Figure 14. Uniaxial compressive stress-strain curve for a 75% tungsten alloy swaged 14%, Specimen No. 362.

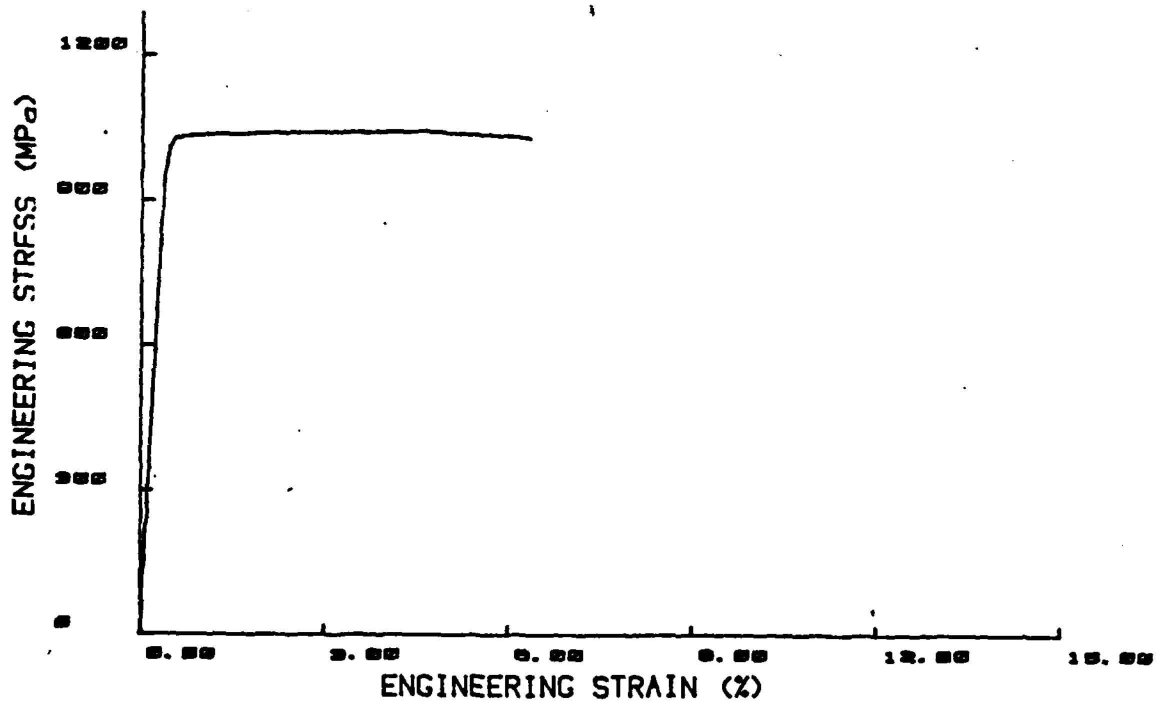

Figure 15. Uniaxial tensile stress-strain curve for a 75% tungsten alloy swaged 21%, Specimen No. 359.

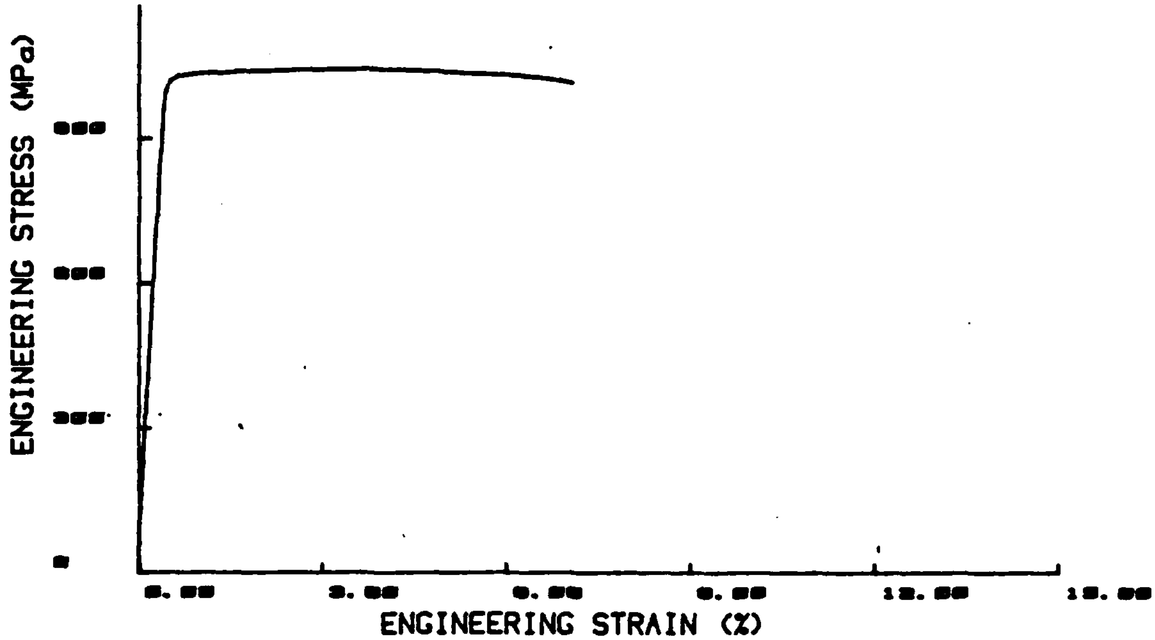

Figure 16. Uniaxial tensile stress-strain curve for a 75% tungsten alloy swaged 21%, Specimen No. 360.

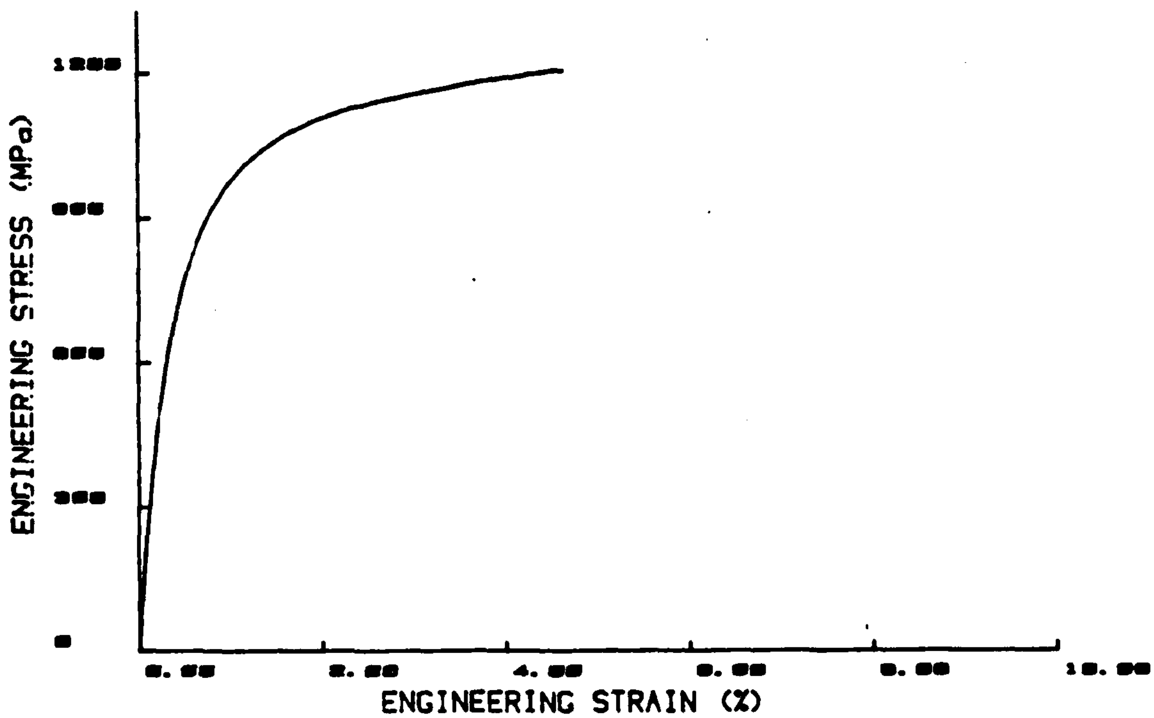

Figure 17. Uniaxial compressive stress-strain curve for a 75% tungsten alloy swaged 21%, Specimen No. 363.

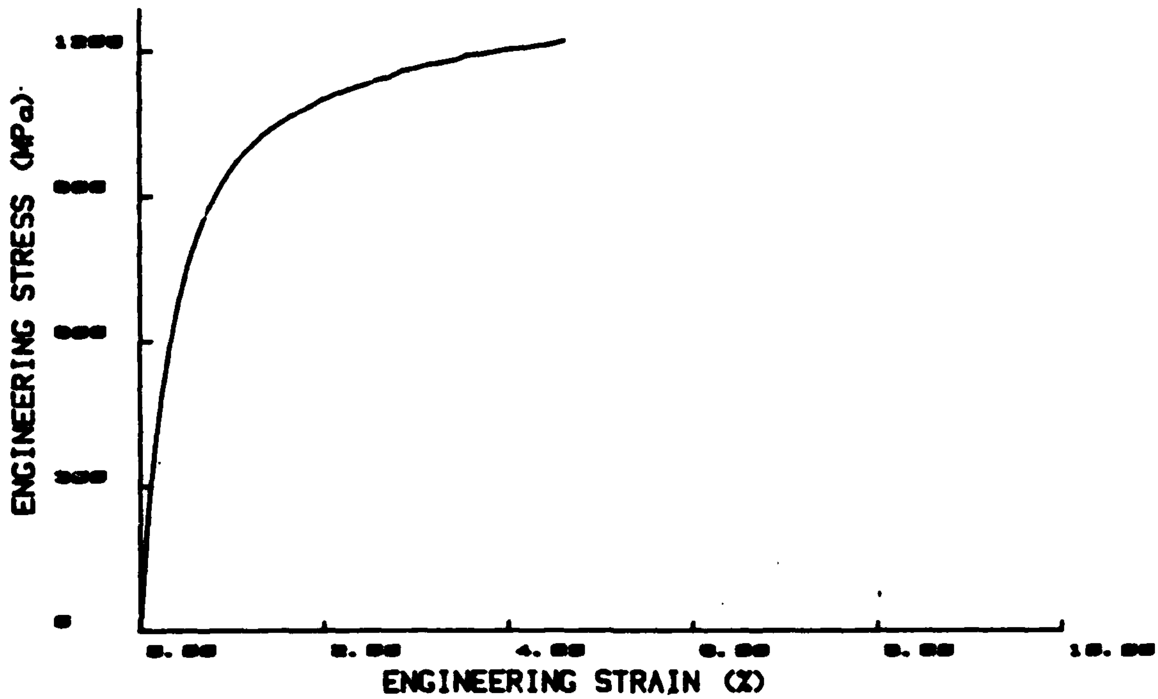

Figure 18. Uniaxial compressive stress-strain curve for a 75% tungsten alloy swaged 21%, Specimen No. 364.

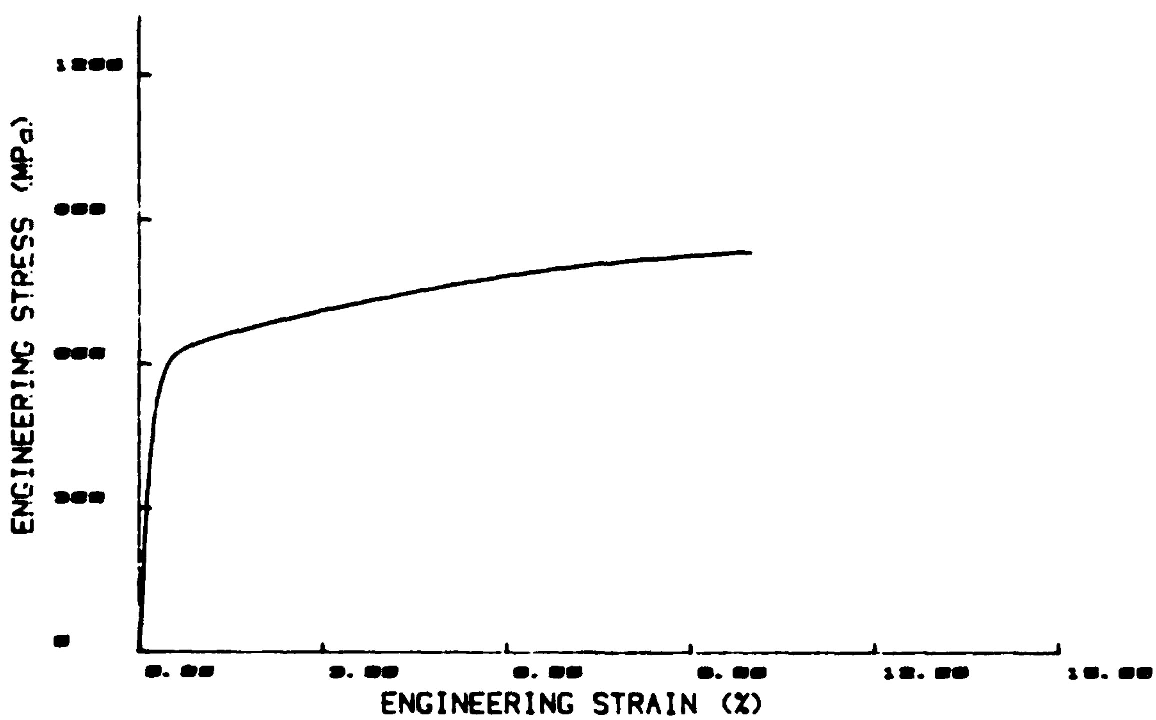

Figure 19. Uniaxial tensile stress-strain curve for a 90% tungsten alloy, double sintered, Specimen No. 331.

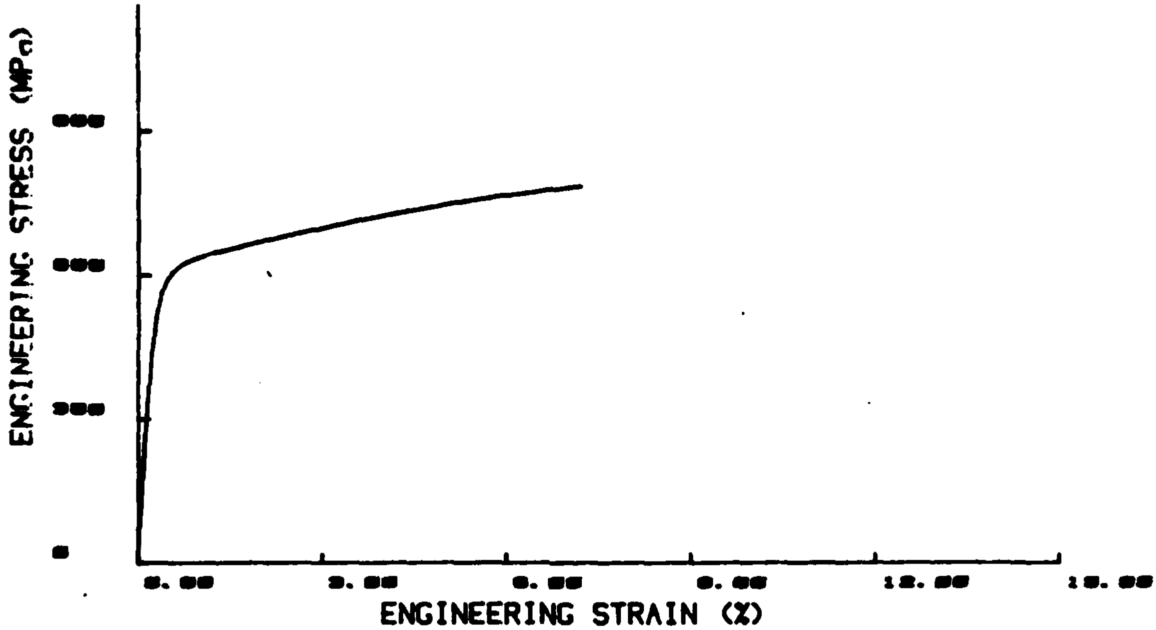

Figure 20. Uniaxial tensile stress-strain curve for a 90% tungsten alloy, double sintered, Specimen No. 335.

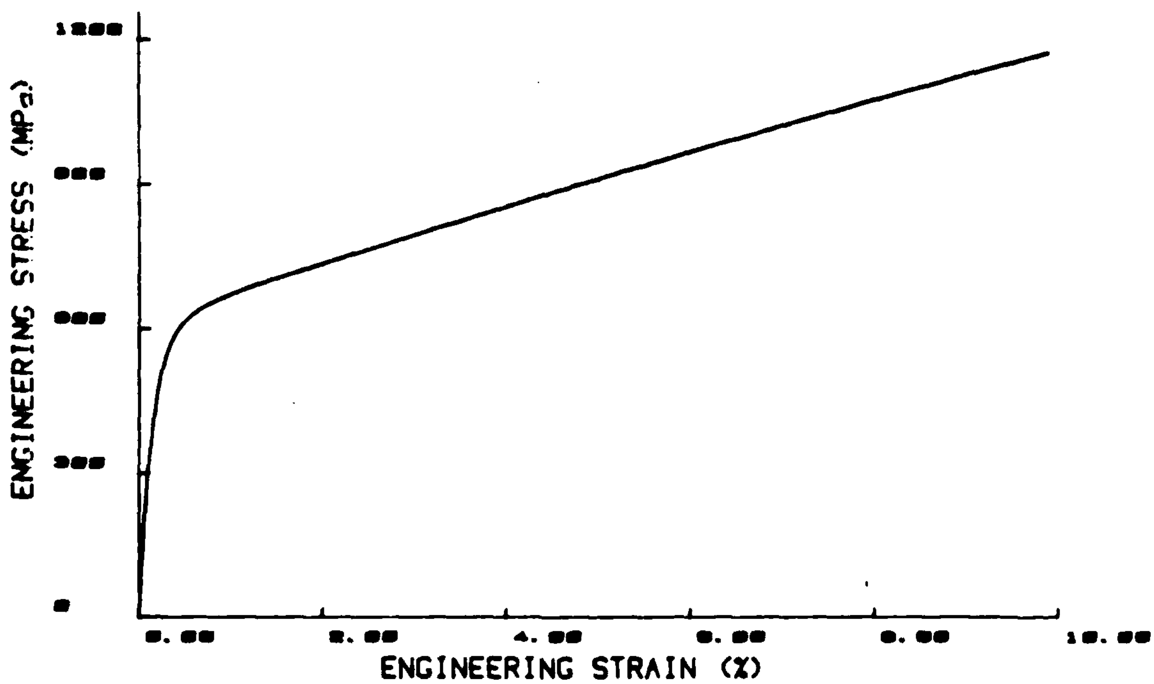

Figure 21. Uniaxial compressive stress-strain curve for a 90% tungsten alloy, double sintered, Specimen No. 336.

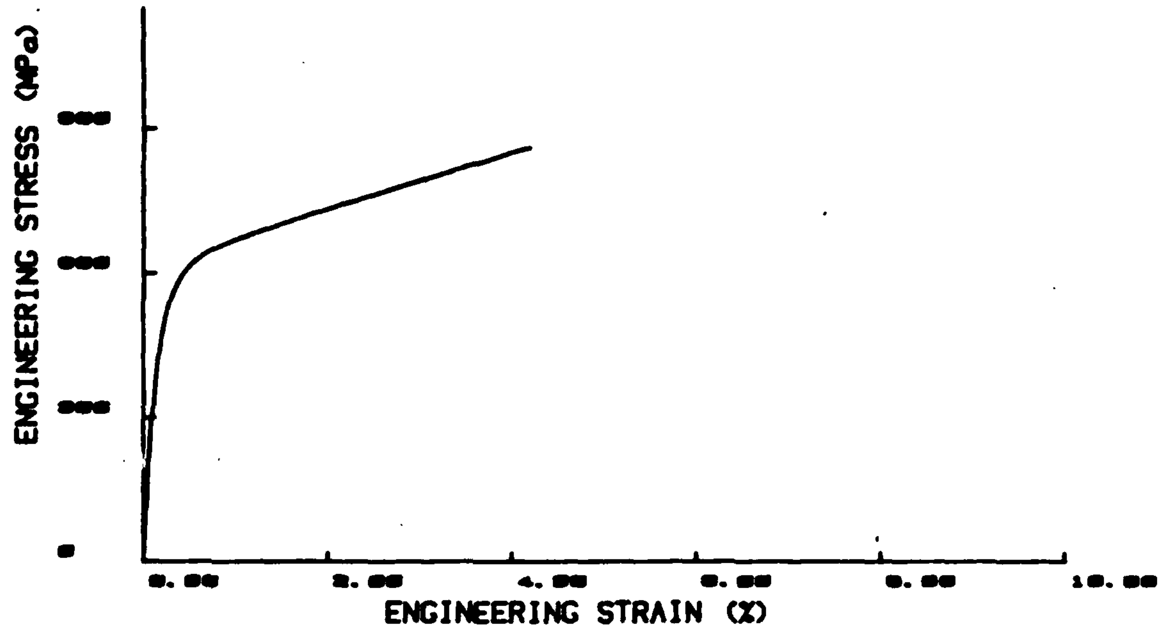

Figure 22. Uniaxial compressive stress-strain curve for a 90% tungsten alloy, double sintered, Specimen No. 339.

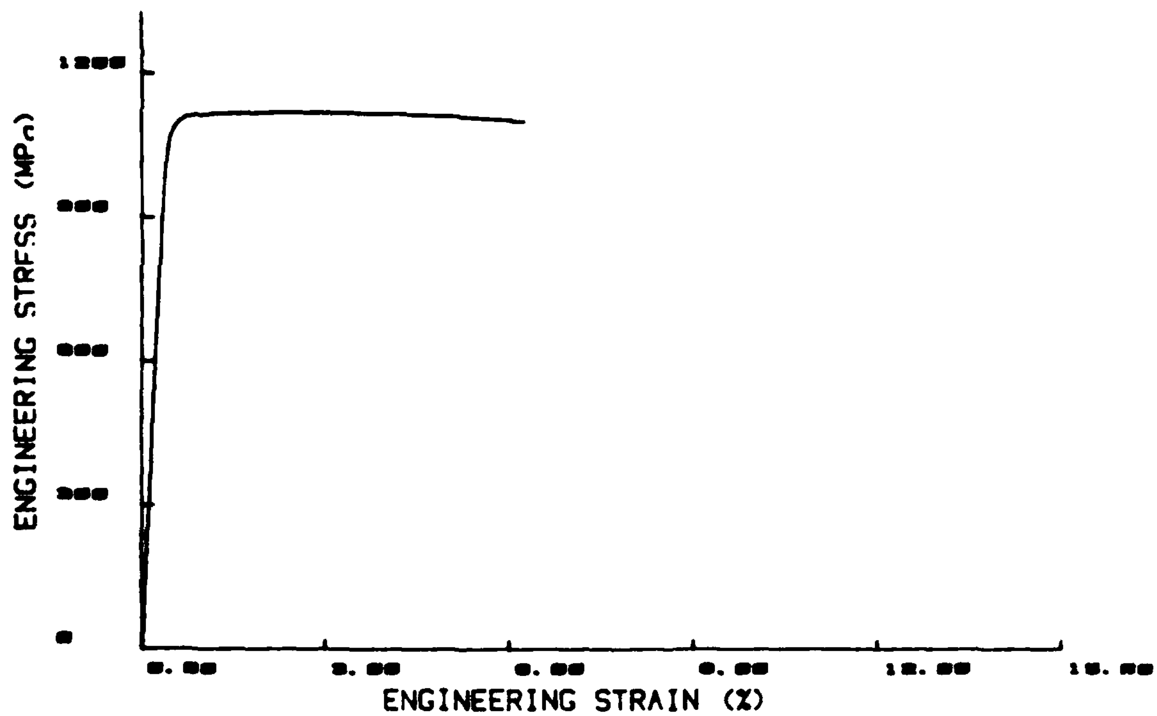

Figure 23. Uniaxial tensile stress-strain curve for a 95% tungsten alloy, Specimen No. 332.

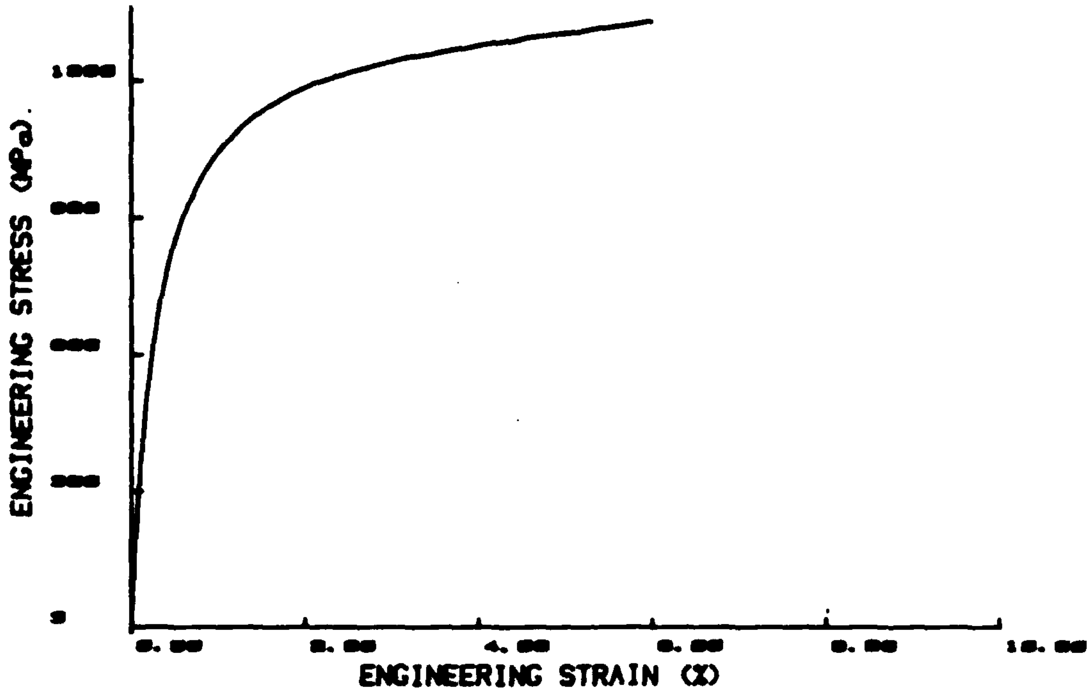

Figure 24. Uniaxial compressive stress-strain curve for a 95% tungsten alloy, Specimen No. 341.

The original material used in the penetrators was a 90% tungsten alloy as supplied by Teledyne Firth-Sterling Co. As stated, the motivation for conducting these tests was the unexpected performance observed during the early stages of the program, when the penetration test results for this material began to show unacceptable variations in the ballistic limits for the penetrator.

Engineering data on the replacement material that was supplied by the manufacturer is given in Table I as Test Nos. 331, 335, 336, 339, and in Figures 19-21. The only known change in the processing history of this material as compared to the original material was a double sinter step.

Comparing the original material and it's replacement, one sees very little difference in the mechanical properties. Only enough material was available to conduct tensile tests on the original material. The only differences that appear are in the ultimate stress and strain, and the fracture strain. The ultimate strain is the strain at the ultimate stress, or maximum load. The fracture stress is the load at failure, divided by the cross-sectional area of the specimen at failure.

A brief look was taken at the fracture surfaces of the tensile specimens for both the original and replacement material. Typical electron micrographs of the fractures are shown in Figures 25 and 26. No significant differences were noted in the particle sizes. The most notable difference is in the number of fractured tungsten particles appearing on the fracture surface; the original material reveals a greater number of fractured particles than the replacement material. This differance would account for the higher ultimate stress and strain of the original material. The tungsten particles in the replacement material are not as tightly bound to each other; consequently, failure occurs in an intergranular mode, rather than transgranular. Processing details were not available; a possibility may be that the replacement material was sintered at a lower temperature than the original material.

IV. DISCUSSION

Tungsten alloy is somewhat of a misnomer; the material should be more correctly referred to as a composite, as it is composed of tungsten particles embedded in a metal matrix. Most often for penetrators, this matrix is a nickel-iron material. The material is processed by liquid phase sintering under pressure, i.e. the nickel-iron matrix becomes liquid at the temperature and pressure used during the process. The manufacturer's concern was that the original material had not been fully liquid phase sintered and that it may have contained some porosity. Unfortunately, ballistic testing does not lend itself to valid examination of the small nuances of the material after the test. These penetrators that failed to perform properly could not be examined after the fact to check for porosity. Consequently, the manufacturer decided to resinter the material in an effort to avoid any possible porosity in the penetrators. The material supplied to the Solid Mechanics Branch may or may not have been representative of the entire batch of material.

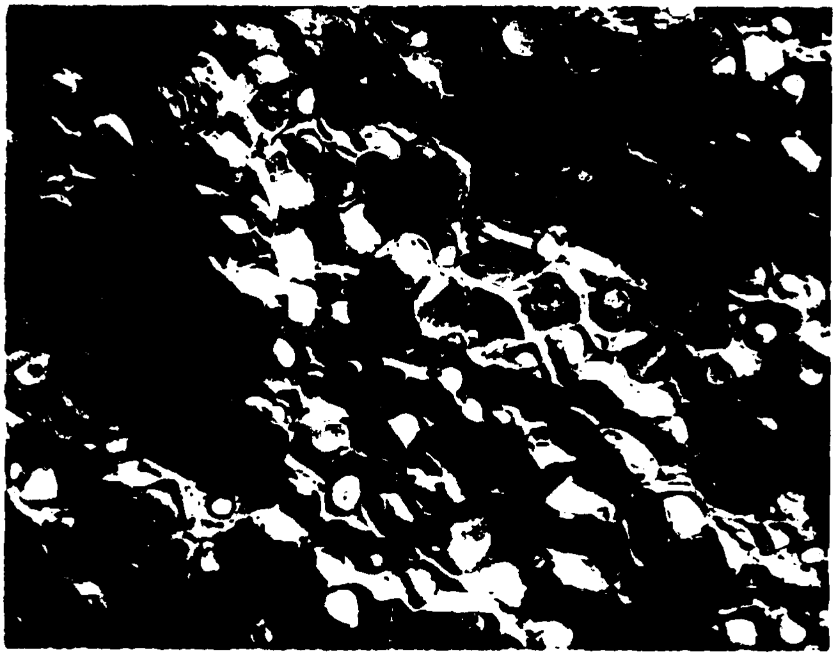

Figure 25. Fracture surface of original material.

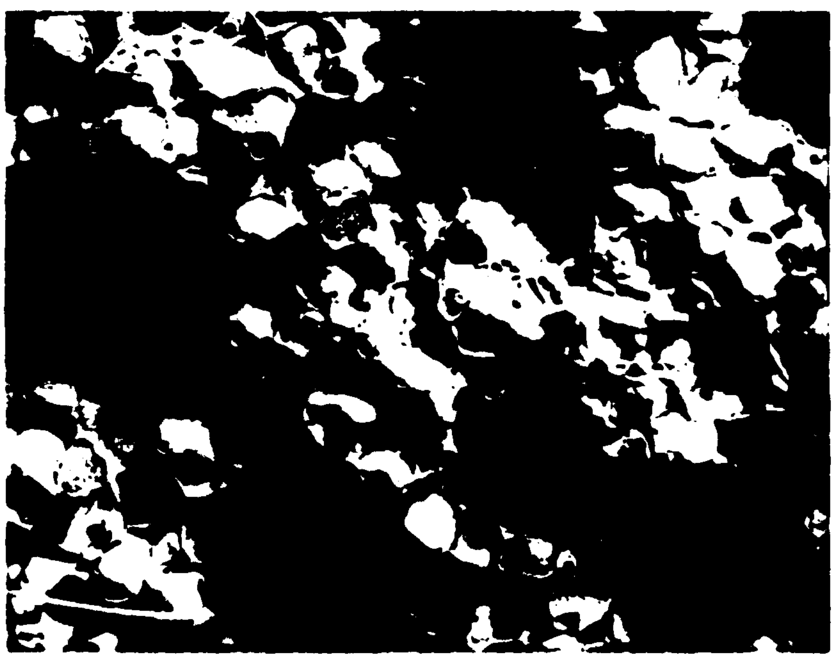

Figure 26. Fracture surface of replacement material.

Test results on a series of tungsten alloys ranging in tungsten content from 75% to 90% are submitted herein. Tensile and compressive data did not reveal unusual variations in material properties. To assess the sensitivity of the small variations observed, it will be necessary to relate the data in this report to the ballistics results as they become available.

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