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Nanotensile Characteristics of Metal Wires

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Introduction

Tensile testing is a standard method used to obtain important mechanical properties of materials. As technology has advanced, however, component size has drastically decreased, which may hinder the ability to obtain accurate material properties using the conventional tensile test machine on such specimens.

This study demonstrates the ability of the nanoTensile™ 5000 to measure tensile properties of two metal wires with relatively small diameters.

Experimental Procedure

Specimens used in this study included 99.99% copper wire with diameters of 77 µm, 100 µm, 132 µm, and type 302/304 stainless steel wire with diameters of 125 µm. All the wires were cold-drawn with a soft temper treatment.

Tensile tests were performed using a Hysitron nanoTensile™ 5000 with a 10 N maximum load head. The nanoTensile™ 5000 instrument has two operating modes: Small Displacement mode with a maximum extension range of 80 µm, and Large Displacement mode with a maximum extension range of 150 mm. Specimens were tested using both Small and Large Displacement modes.

Wire specimen gauge lengths range from 25 – 30 mm. Constant test velocities of 5 and 80 µm/s were used for tensile tests performed in Small and Large Displacement modes, respectively.

Results

Figure 1 is a plot of engineering stress versus engineering strain from a tensile test on a 100 µm copper wire. From such a plot, the mechanical properties of the metal wire specimen can be deduced. Table 1 summarizes the experimental results obtained from tensile tests on all wire specimens. The mechanical properties listed in this table include Young's modulus (E), yield stress (σ_y), ultimate tensile strength (σ_{ult}), ultimate strain (ε_{ult}), and toughness (U_f). As expected, Young's modulus values measured using Small Displacement and Large Displacement modes are consistent.

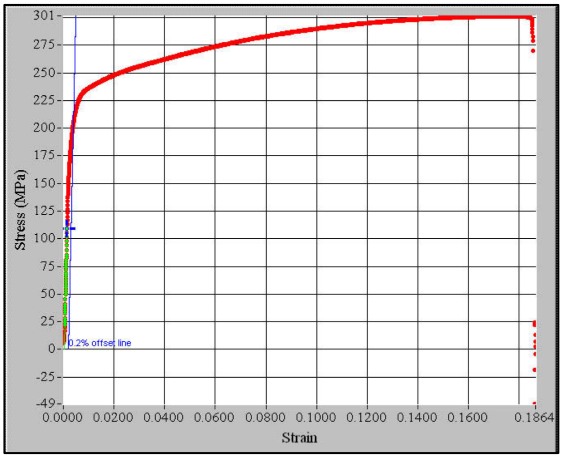

Figure 1. *Representative plot of engineering stress vs. engineering strain from a tensile test on a copper wire.*

Table 1. *Results from tensile tests on copper and stainless steel wire*

Specimen	E (GPa)				σ_y (MPa)		σ_{ult} (MPa)		ε_{ult} (%)		U_f (J/cm^3)	
	Small Disp. Mode		Large Disp. Mode		Large Disp. Mode		Large Disp. Mode		Large Disp. Mode		Large Disp. Mode	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
77 µm Ø Cu Wire	106.24	0.63	105.03	3.45	195.98	7.96	279.52	3.88	20.43	0.70	52.06	2.30
100 µm Ø Cu Wire	108.71	2.13	109.11	4.62	206.14	8.85	297.09	3.76	19.90	0.96	54.17	1.86
132 µm Ø Cu Wire	98.39	1.76	99.68	2.74	191.73	3.27	258.03	4.80	20.27	1.81	48.42	5.25
125 µm Ø T302/304 SS Wire	199.29	3.26	198.82	2.68	379.61	21.94	753.00	9.86	46.57	1.08	296.84	5.75

An optical micrograph of a fractured copper wire is shown in Figure 2. Necking is visible near the fracture surface.

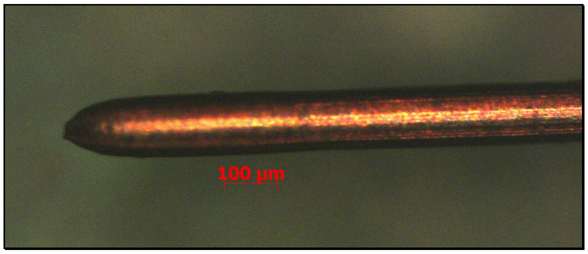

Figure 2. *10X optical micrograph of fractured copper wire after tensile test.*

A 1.5 µm topographical AFM image of the fracture surface of a copper wire is shown in Figure 3. The uneven fractographic characteristics shown in the image indicate severe plastic deformation and ductile final fracture of the copper wire.

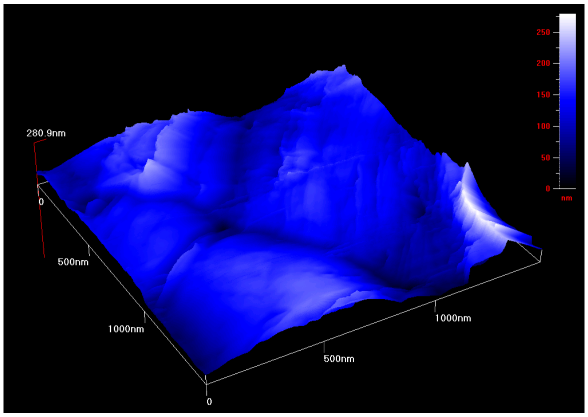

Figure 3. *1.5 µm topographical AFM image of copper wire fracture surface after tensile test.*

Discussion

As can be seen in Table 2, the mechanical properties of the metal wires obtained in this study are very close to those reported in literature [1, 2] and to the results obtained through quasi-static nanoindentation. The excellent precision in the nanotensile results are obvious in comparison to the nanoindentation results. This can be explained by the large difference in sampling material volumes between these two testing techniques. Where nanoindentation tests an extremely small volume of material and may get a single grain property each time, nanotensile testing measures the overall response of one specimen with a relatively larger volume.

It is understandable that the nanotensile test results are more representative of the specimen than the results obtained from nanoindentation. Meanwhile the sensitivity of the nanoTensile^{TM} 5000 is sufficient in discerning the properties of the copper wires when diameters of wire change.

Table 2. *Young's modulus of copper and T302/304 stainless steel wires listed in literature and as determined by nanotensile testing and nanoindentation*

Source	E (GPa), Copper		E (GPa), T302/304 Stainless Steel	
	Avg.	Std. Dev.	Avg.	Std. Dev.
Literature [2]	110	-	193	-
Nanotensile	105.03 (77 µm)	3.45	199.1 (125 µm)	3.00
	109.11 (100 µm)	4.62	-	-
	99.68 (132 µm)	2.74	-	-
Nanoindentation*	97.3 (132 µm)	12.0	194.4 (125 µm)	15.3

** = E converted from E_r using v_{Cu} = 0.35 and v_{Steel} = 0.30*

Summary

In this study, tensile mechanical properties of copper and stainless steel wires with relatively small diameters were successfully measured through nanotensile testing using the nanoTensile^{TM} 5000 Automated Test Instrument. While the mechanical properties determined for copper and stainless steel wires by nanotensile testing agree well with those listed in literature and those determined by nanoindentation, the excellent measurement repeatability and the capability of resolving the size effect of properties are evident of nanotensile tests.

References:

[1]. http://www.key-to-metals.com/Article98.htm.
[2]. William D. Callister. Jr., An Introduction, Materials Science and Engineering (Wiley, 2003).

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