

# Tensile properties of strontium metal

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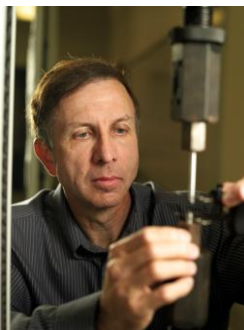
## ABSTRACT

The yield strength, ultimate tensile strength, elastic modulus, and strain rate sensitivity of pure Sr metal in the as-extruded condition were determined by tensile testing and compared with the properties of other alkaline metals. Two strain rates were used for testing. At a strain rate of  $6.5 \times 10^{-4} \text{ s}^{-1}$ , Sr has a 0.2% offset yield strength of 71.6 MPa, an ultimate tensile strength of 88.1 MPa, and 10.4% elongation at fracture. At a strain rate of  $6.3 \times 10^{-3} \text{ s}^{-1}$ , Sr has a 0.2% offset yield strength of 81.9 MPa, and ultimate tensile strength of 101.5 MPa, and 5.0% elongation at fracture. The strain rate sensitivity was determined to be 0.059. Copyright © 2012 VBRI press.

**Keywords:** Strontium metal; tensile strength; tensile elongation; strain rate sensitivity.



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## Introduction

The heavy alkaline metals (Ca, Sr, Ba, Ra) are not used for structural applications because their moduli and strengths are fairly low and they react rapidly with water. Some of these elements are used as alloying additions to Al, Be, Cu, Mg, and Pb, but the mechanical properties of pure, heavy alkaline metals have received little study. As-cast Ca metal is reported to have an ultimate tensile strength of 55 MPa with 55% tensile elongation [1]. Cold-rolled Ca's tensile yield strength has been reported to be 84.5 MPa with an

ultimate strength of 115 MPa [2]. Although no quantitative tensile data were found in the literature for Sr, Ba, and Ra, they are known anecdotally among metallurgists to possess mechanical properties somewhat similar to those of Ca with the metals becoming progressively softer as atomic number increases. This qualitative observation is consistent with the decreasing elastic moduli of these elements (i.e., Ca: 20.7 GPa, Sr: 17.2 GPa, and Ba: 12.4 GPa, as measured by ultrasound [3]). Both Ca and Sr are face-centered cubic, so one might expect the mechanical properties of Sr to be roughly similar to those reported for Ca, though Sr's strength might be expected to be somewhat lower since the Sr atom radius (215 pm) is larger than the Ca atom radius (197 pm). Recent work on Al-Ca and Al-Sr metal-metal nanocomposites for high-voltage electric power transmission [4] has prompted renewed interest in the mechanical properties of Ca and Sr and motivated this study of Sr mechanical properties.

## Experimental

As-extruded, technical-grade purity Sr metal was provided by the Materials Preparation Center of the Ames Laboratory of the U.S. Department of Energy [5]. Accurate analysis of impurity content is difficult in heavy alkaline earth metals due to their reactivity. The extruded Sr rods were cleaned in an inert atmosphere glovebox with fine abrasive paper to remove surface oxide. Upon removal from the glovebox, the Sr metal rods were quickly immersed in mineral oil to minimize oxidation. The Sr metal was then machined on a lathe to form cylindrical tensile test specimens with 11mm gauge diameters; other dimensions were in accordance with the ASTM-E8 standard [6]. A mineral oil film was maintained over the Sr

metal during machining and served as a cutting lubricant for the machining operation. The tensile specimens were stored in mineral oil prior to tensile testing.

The tensile tests were performed with an Instron 3367 machine using a 30 kN load cell and a knife-edge extensometer to measure strain. Clamp-type grips were utilized to grasp the tensile specimen ends. A thin film of mineral oil was periodically "painted" onto the Sr metal as tensile testing progressed. Crosshead displacement control was used to control the deformation of the metal. Two strain rates were used,  $6.5 \times 10^{-4} \text{ s}^{-1}$  and  $6.3 \times 10^{-3} \text{ s}^{-1}$ .

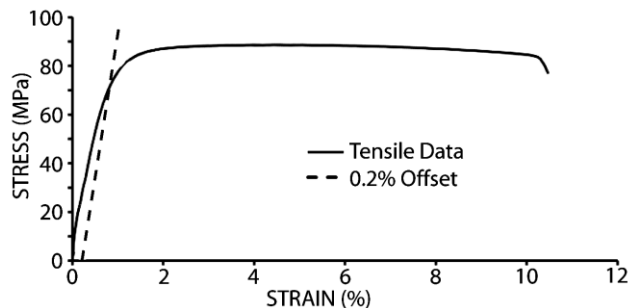


Fig. 1. Engineering stress-strain plot of pure Sr metal (strain rate =  $6.5 \times 10^{-4} \text{ /sec}$ ).

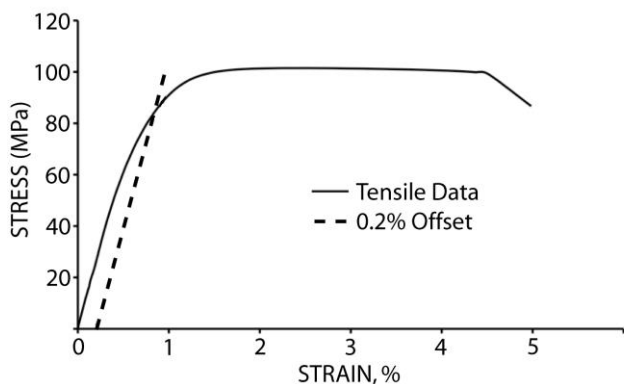


Fig. 2. Engineering stress-strain plot of pure Sr metal (strain rate =  $6.3 \times 10^{-3} \text{ /sec}$ ).

## Results and discussion

Engineering stress-strain plots generated by these tensile tests are shown in Fig. 1 and 2. The measured engineering stress as a function of engineering strain is shown as the solid line, with the 0.2% offset shown as a dotted line.

Values for elastic modulus (E), yield strength ( $\sigma_{y,0.2\%}$ ), ultimate tensile strength ( $\sigma_{UTS}$ ), and elongation at fracture are shown in Table 1. Note that the elastic modulus values differ by more than 10% between the two tests, and both modulus values are smaller than the published Young's modulus value (17.2 GPa). Elastic modulus normally does not change appreciably with strain rate; the differing E values shown in Table 1 presumably result from deviation from linearity in the elastic regime seen in both stress-strain plots (Fig. 1 and 2), which necessitated use of curve fitting to determine the positions of the 0.2% offset lines. Thus, the Young's modulus values shown in Table 1 should be considered approximate.

Table 1. Mechanical properties of Sr metal at two strain rates.

Strain rate ( $10^{-3} \text{ s}^{-1}$ )	Young's modulus (GPa)	0.2% offset yield stress (MPa)	Ultimate stress (MPa)	Elongation (%)
0.65	11.7	71.6	88.1	10.4
6.30	13.1	81.9	101.5	5.0

The strain rate sensitivity,  $m$ , was determined by  $\sigma_y = C \dot{\epsilon}^m$ , where  $C$  is a constant,  $\sigma_y$  is the yield strength, and  $\dot{\epsilon}$  is the strain rate. The strain rate sensitivity for Sr was determined to be 0.059, and the empirically determined constant,  $C$ , was calculated to be 110 MPa.

Table 2. Tensile properties of cold-worked Ca and cold-worked Sr.

Property	Ca [2]	Sr (this study)
$\sigma_y$ (MPa)	84.5	77
$\sigma_{UTS}$	115	95
Elongation (%)	7	8

The measured properties of extruded Sr are similar to those of cold-rolled Ca metal [2]. Table 2 shows a comparison of the measured tensile properties for work-hardened Ca and Sr metals. The Sr values in Table 2 are averages of the two tests performed. The yield strengths of both elements are similar, while the ultimate tensile strength difference between Ca and Sr suggests that Sr metal may have a lower work-hardening coefficient than Ca. It should be noted that the exact purities of both the Ca and Sr specimens in Table 2 are unknown. Since impurity elements typically have a large effect on a metal's mechanical properties, these comparisons should be considered as preliminary guidance only for others working with these metals.

## Conclusion

The tensile properties of (cold worked) Sr metal were measured at two strain rates and the mechanical properties constants calculated. It was observed that pure, cold-worked Sr metal had limited ductility. Tensile testing showed that the yield strength, ultimate strength, and elastic modulus of pure Sr are 71.6 MPa, 88.1 MPa, and 11.7 GPa at a strain rate of  $6.5 \times 10^{-4} \text{ s}^{-1}$ . The strain rate sensitivity of the Sr metal was measured to be 0.059. These values are similar to those for as-rolled Ca metal [2].

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