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Residual Elements Have Significant Effects on the Elevated-Temperature Properties of Austenitic Stainless Steel Welds

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RESIDUAL ELEMENTS HAVE SIGNIFICANT EFFECTS ON THE ELEVATED-TEMPERATURE PROPERTIES OF AUSTENITIC STAINLESS STEEL WELDS*

D. P. Edmonds, R. T. King, and G. M. Goodwin

ABSTRACT

The influence of various residual elements on the elevated-temperature properties of austenitic stainless steel welds has been investigated at the Oak Ridge National Laboratory (ORNL). Included in this investigation are the effects of B, P, Ti, C, S, and Si. This work is aimed at developing austenitic stainless steel weld materials with enhanced elevated-temperature properties.

The materials investigated in this program include types 308, 316, and 16-8-2 stainless steel weld metals. Processes investigated include shielded metal-arc (SMA), gas tungsten-arc (GTA), and submerged-arc (SA) welding. Early work was done with type 308 and 316 SMA weld metals, where the greatest enhancement of properties resulted from controlled additions of boron, phosphorus, and titanium to the deposits. Significant improvements in the properties of GTA and SA welds also result from the addition of these residual elements. The optimum residual element compositions were determined to be nominally 0.05% Ti, 0.04% P, and 0.006% B for SMA welds and 0.5% Ti, 0.04% P, and 0.006% B for GTA welds. Submerged-arc welds with 0.2% Ti have exhibited improved creep strengths.

INTRODUCTION

A significant problem in the production of fully austenitic stainless steel welds is their tendency for hot-cracking and micro-fissuring. To minimize this tendency, the compositions of welding materials are generally modified to produce small amounts of delta ferrite (usually 3 to 7 vol %) in the as-welded structure.[1] However, when these materials are exposed to elevated-temperatures (500 to 900°C) for extended periods of time, the ferrite transforms to a hard, brittle phase known as sigma phase.[2] This transformation leads to low ductility ruptures (and low strength in some cases) when sufficiently high stresses are applied at elevated temperatures.

*Work performed under ERDA/RDD 189a OH024, Joining Technology Development.

Ruptures generally occur along intersubstructural boundaries between the austenite and sigma phases.[3] This tendency for low ductility ruptures has led to design penalties for welded, austenitic stainless steel structures under certain operating conditions. For example, ASME Boiler and Pressure Vessel Code Case 1592 requires that "... when creep effects are significant...inelastic strains accumulated in the weld region shall not exceed *one-half* the strain values permitted for the parent material... ." For these reasons, we are investigating factors that affect the properties of gas tungsten-arc (GTA), shielded metal-arc (SMA), and submerged-arc (SA) welds.

DEVELOPMENT WORK

Early work[4] on this program revealed that welds made with type 308 SMA electrodes with titania and lime-titania coatings had higher creep strengths than welds made with lime-coated electrodes (Fig. 1). This indicated that titanium from the electrode coating had a major effect on the creep properties of the weld. Electrodes were then made by a commercial manufacturer using standard lime-titania coatings formulated to yield deposits with high and low levels of C, Si, S, P, and B. The following results were obtained from this study.

1. Higher carbon contents (up to 0.074%) markedly increase rupture lives but decrease creep ductilities (Fig. 2).

2. Reducing silicon content (to 0.29%) increases ductility, with negligible effects on rupture life (Fig. 3).

3. Higher levels of phosphorus (up to 0.04%) increase rupture life and ductility (Fig. 4).

4. Variations in sulfur content (0.006 to 0.027%) have negligible effects on creep (Fig. 5).

5. Higher levels of boron (up to 0.06%) increase rupture life and ductility (Fig. 6).

Similar work was done for type 316 stainless steel, SMA weld metals. Results of this study led to the development of SMA types 308 and 316 stainless steel weld metals with enhanced creep strengths and ductilities (type 308 data shown in Fig. 7). These materials are called Controlled

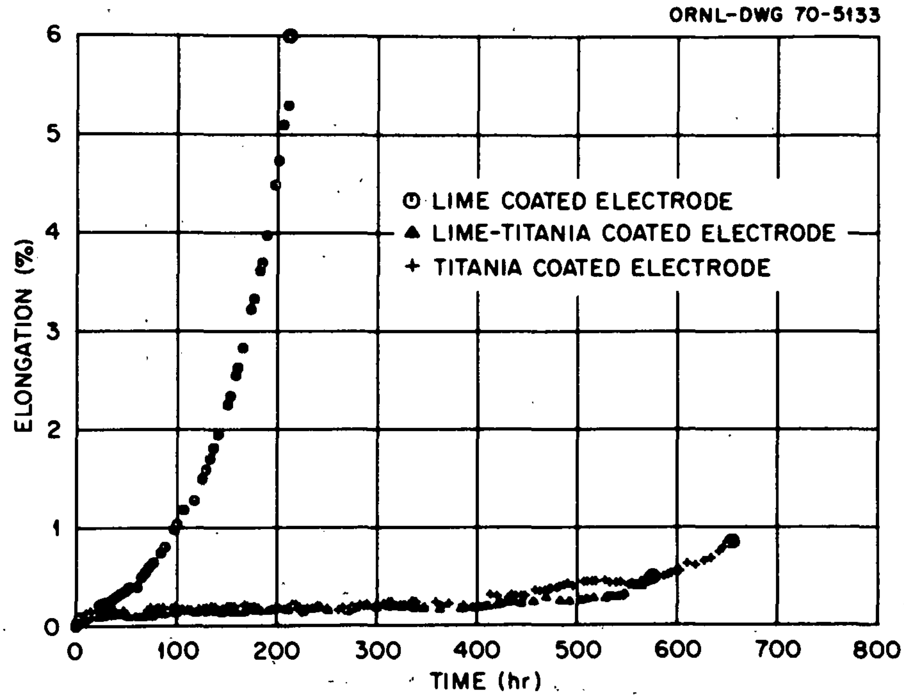

Fig. 1. Comparison of Creep-Rupture Curves for Type 308 Stainless Steel, Shielded Metal-Arc Welds — Tested at 1200°F and 18,000 psi.

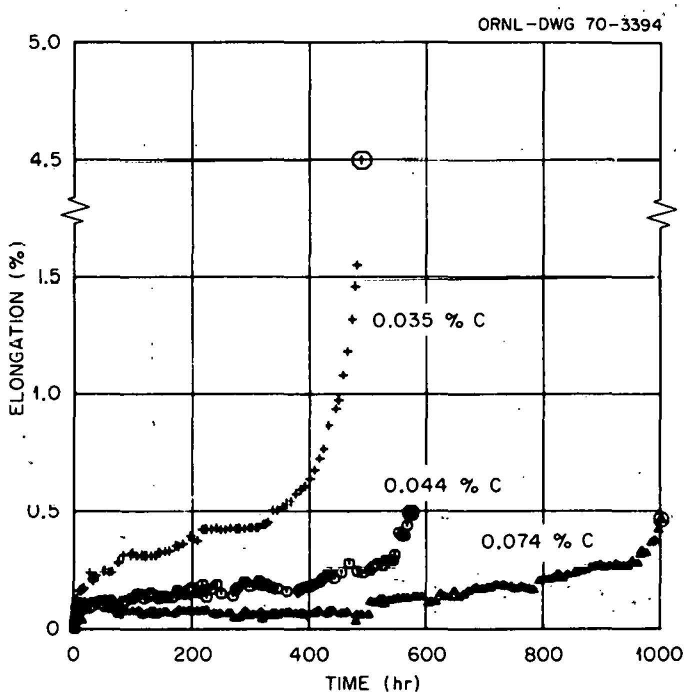

Fig. 2. Effect of Carbon Content on the Creep of Type 308 Stainless Steel, Shielded Metal-Arc Weld Metal at 1200°F and 18,000 psi.

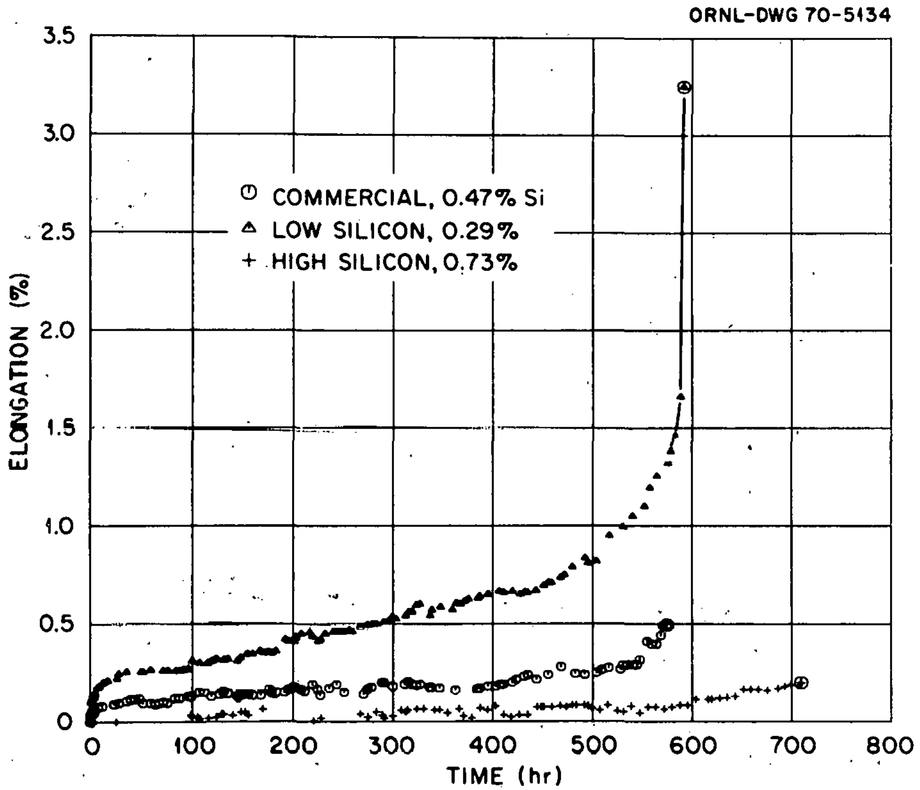

Fig. 3. Effect of Silicon Content on the Creep of Type 308 Shielded Metal-Arc Stainless Steel Weld Metal at 1200°F and 18,000 psi.

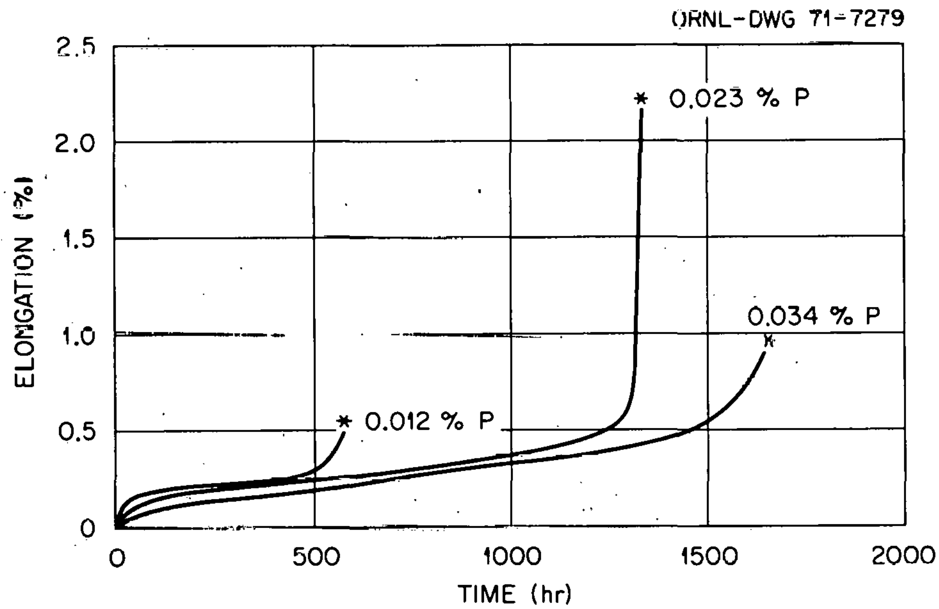

Fig. 4. Effect of Phosphorus Content on the Creep of Type 308 Stainless Steel Shielded Metal-Arc Weld Metal at 1200°F and 18,000 psi.

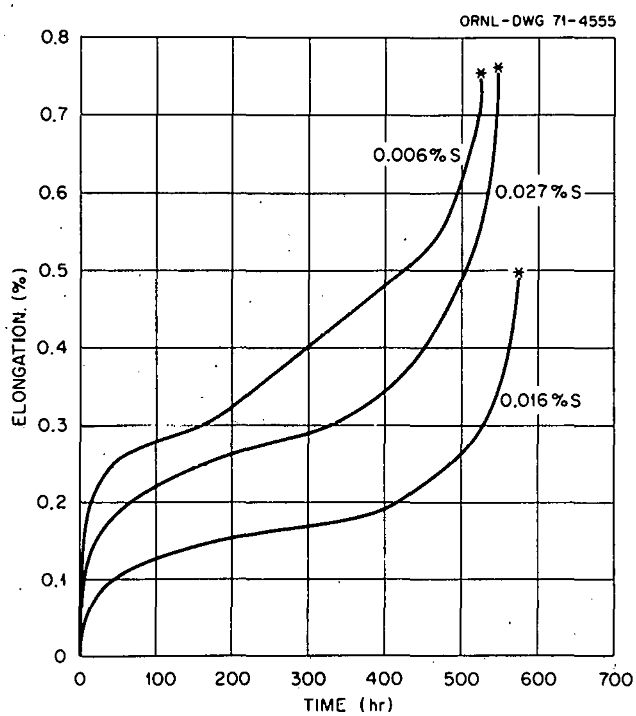

Fig. 5. Effect of Sulfur Content on the Creep of Type 308 Stainless Steel Shielded Metal-Arc Weld Metal at 1200°F and 18,000 psi.

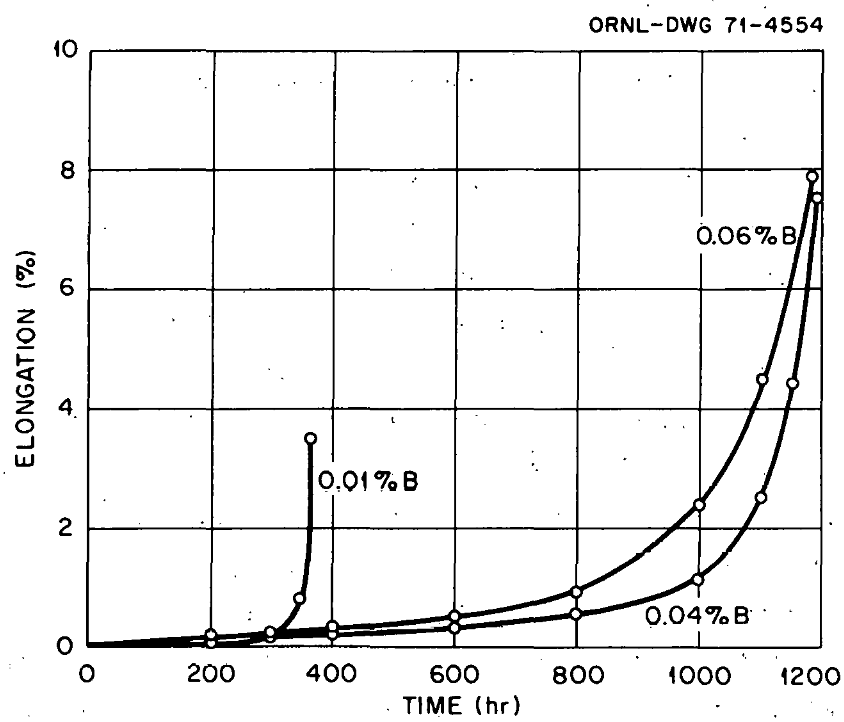

Fig. 6. Effect of Boron Content on the Creep of Type 308 Stainless Steel Shielded Metal-Arc Weld Metal at 1200°F and 20,000 psi.

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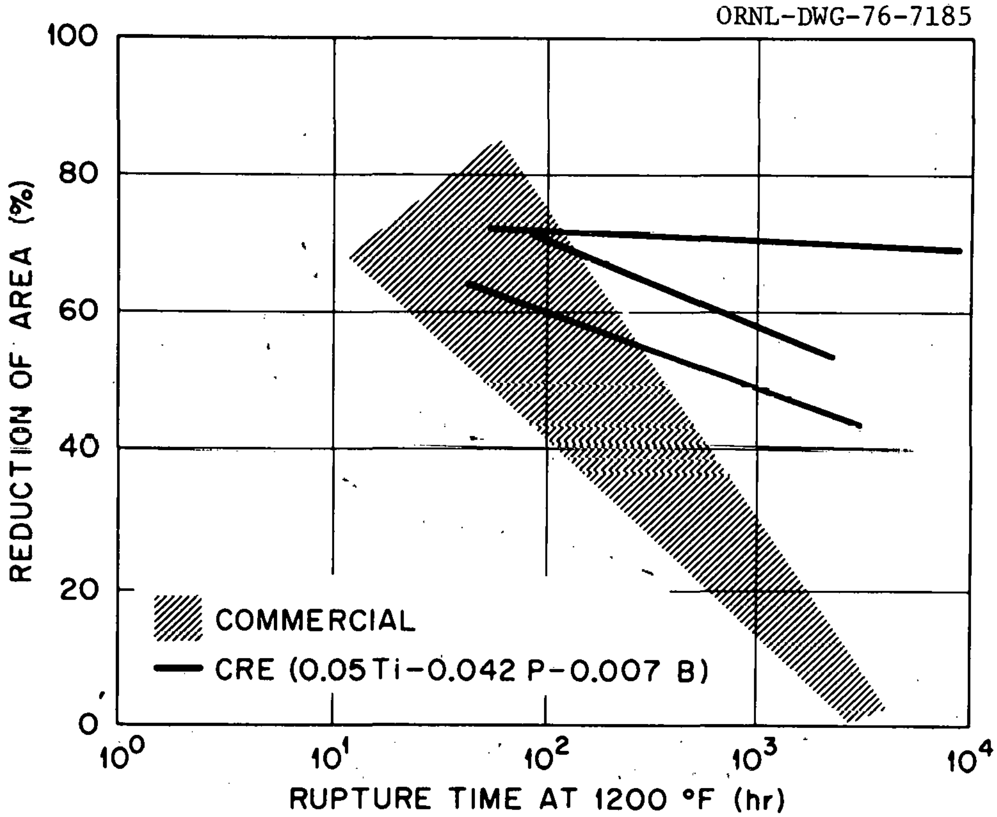

Fig. 7. Creep Rupture Properties of Type 308 Stainless Steel, Shielded Metal-Arc Welds.

Residual Elements (CRE) electrodes and produce nominally 0.05% Ti, 0.04% P, and 0.006% B in the deposit.

We have also investigated types 308, 316, and 16-8-2 GTA welds. Several small heats of GTA welding wire with varying amounts of boron, phosphorus, and titanium were made at ORNL. Results from creep testing of welds made from these heats showed that titanium is the most potent strengthener and produces the greatest increases in ductility. In addition to improving properties, the extra titanium increased the amount of ferrite in the welds without the low ductility ruptures commonly associated with the instability of this phase. It was determined (Figs. 8 and 9) that the best combination of residual elements in the type 308 stainless steel, GTA welds is nominally 0.5% Ti, 0.04% P, and 0.006% B, with the levels of all other residuals as low as possible. Similar results were obtained for type 316 stainless steel, GTA weld metals. These residual element additions did not significantly improve the properties of type 16-8-2 stainless steel, GTA weld metals.

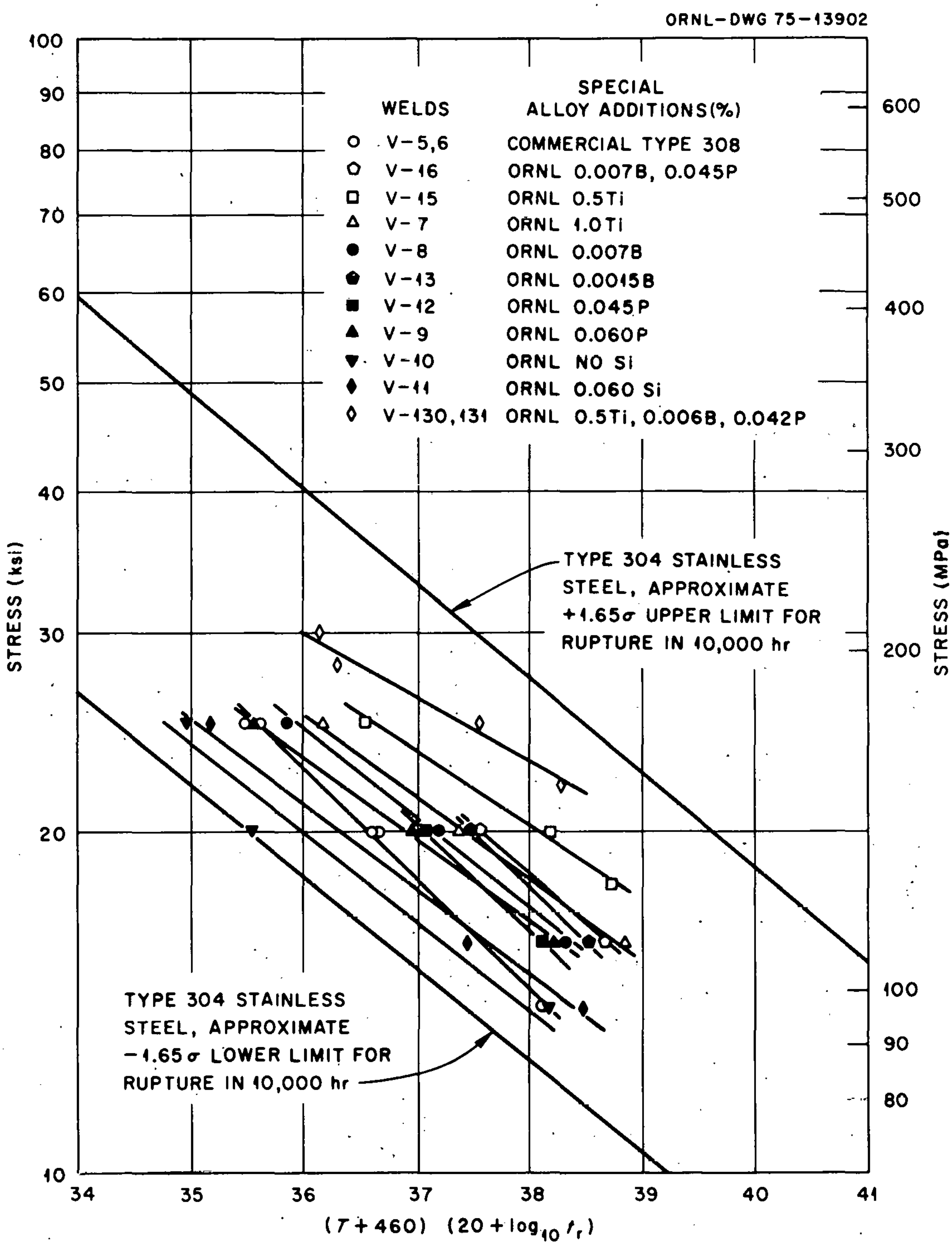

Fig. 8. Creep-Rupture Properties of Type 308 Stainless Steel, Gas Tungsten-Arc Weldments at 649°C (1200°F).

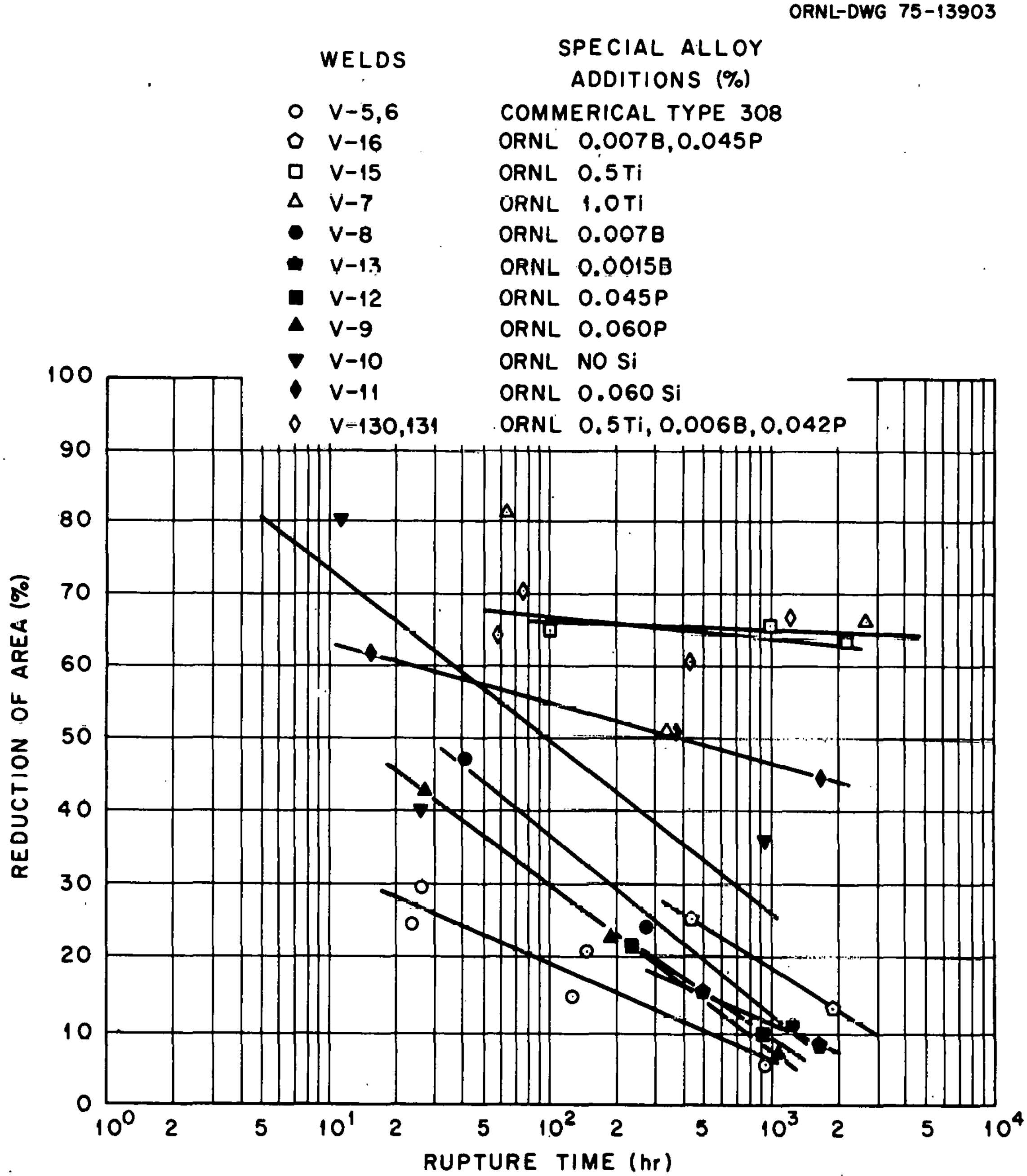

Fig. 9. Creep-Rupture Properties of Type 308 Stainless Steel Manual Gas Tungsten-Arc Weldments at 649°C.

In an attempt to demonstrate commercial capabilities for producing CRE wires, we have procured seveal large (225 kg) stainless steel ingots from four steelmakers. Wires have been drawn from these ingots for GTA and SA welding. Preliminary results from creep testing of GTA welds made from these wires indicate that several of the large heats have properties comparable with the smaller CRE heats described above (type 308 weld metal data are shown in Figs. 10 and 11). Also, SA test welds have been made with these wires using various commercial fluxes. Creep-rupture testing (type 308 weld metal data given in Fig. 12) has shown that higher than normal titanium concentrations (approximately 0.2%) in these SA welds greatly enhance the creep strength. Similar results were obtained for both processes with types 316 and 16-8-2 weld metals.

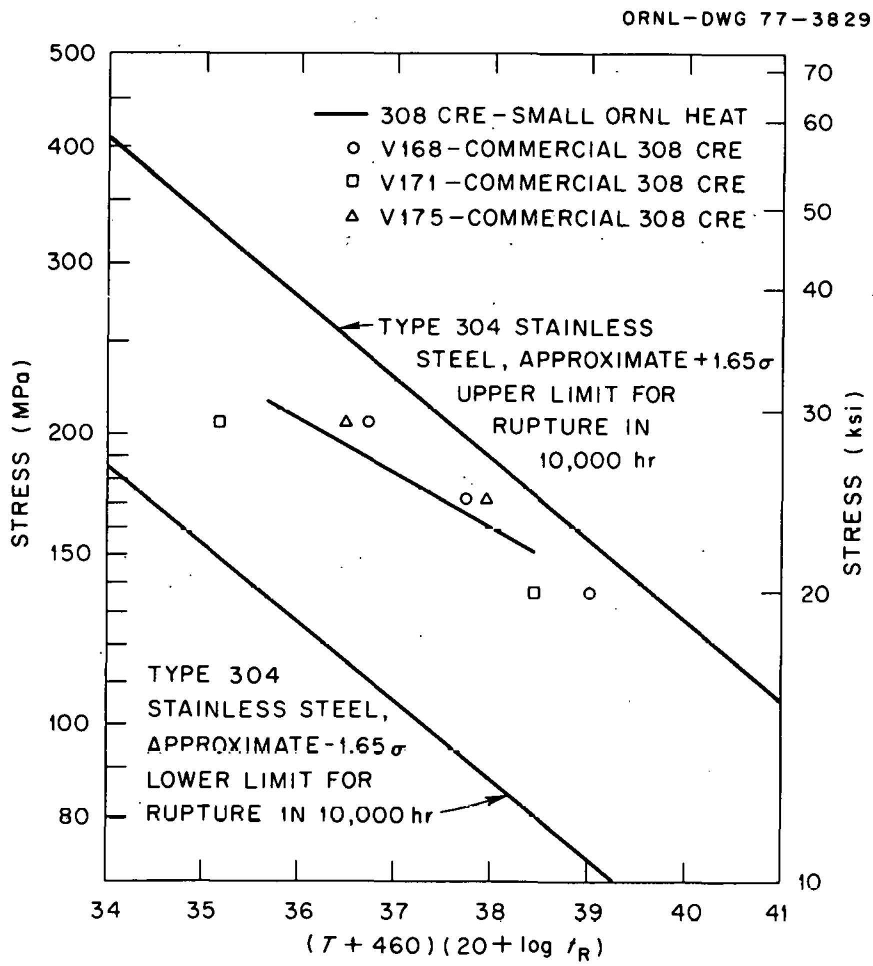

Fig. 10. Creep-Rupture Strength of Type 308 Stainless Steel, Gas Tungsten-Arc Weldments at 649°C (1200°F).

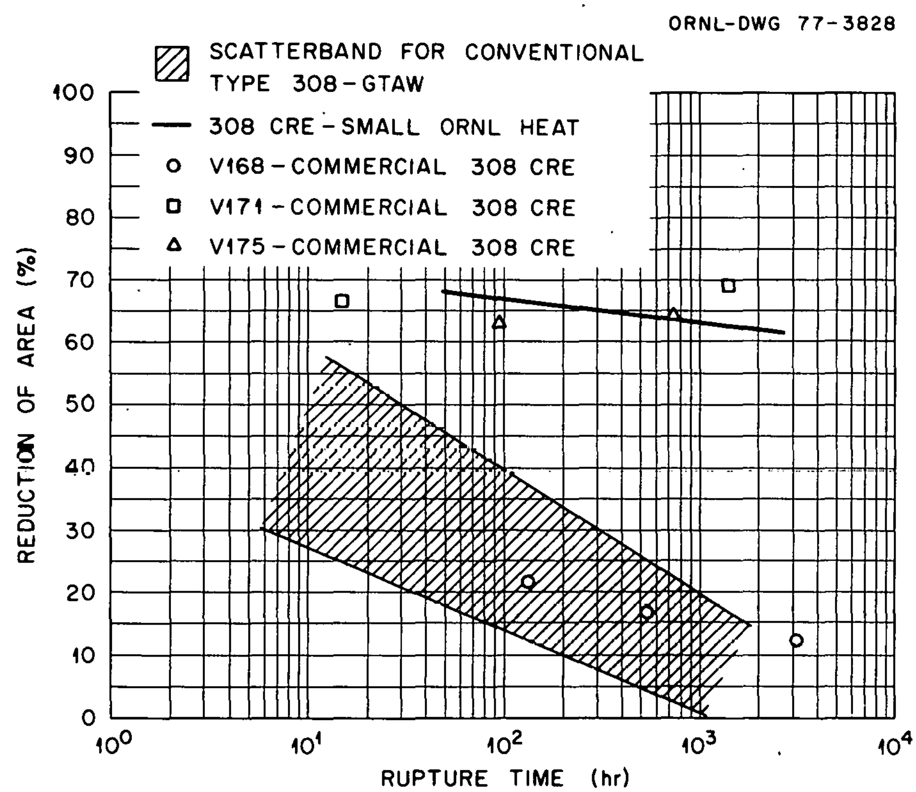

Fig. 11. Creep-Rupture Ductility of Type 308 Stainless Steel, Gas Tungsten-Arc Weldments (GTAW) at 649°C (1200°F).

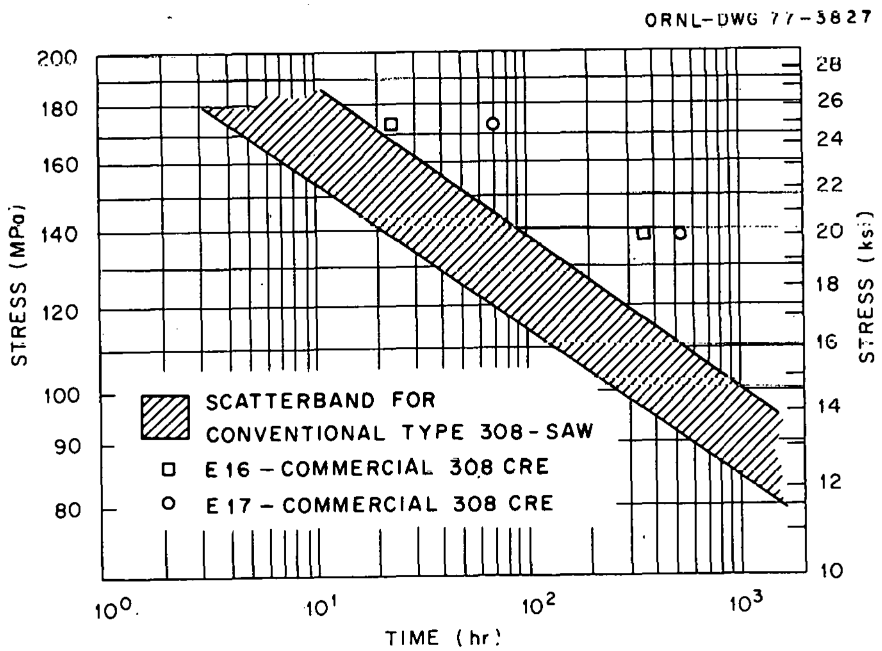

Fig. 12. Creep-Rupture Strength of Type 308 Stainless Steel, Submerged-Arc Weldments (SAW) at 649°C (1200°F).

In summary, we have found that additions of boron, phosphorus, and titanium to types 308, 316, and 16-8-2 stainless steel welds produce enhanced elevated-temperature properties. The optimum residual element compositions were determined to be nomially 0.05% Ti, 0.04% P, and 0.006% B for SMA welds and 0.5% Ti, 0.04% P, and 0.006% B for GTA welds. Submerged arc welds with approximately 0.2% Ti have exhibited improved creep strengths.

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