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A NEW LONG-RANGE-ORDER-STRENGTHENED SUPERALLOY

by
M. F. Rothman & S. K. Srivastava
Haynes International, Inc.

INTRODUCTION:

Age-hardenable alloys have long played an important role in the design of critical gas turbine components. The addition of titanium and aluminum to nickel-base alloys, as well as columbium to iron-nickel-base alloys, has been well exploited in the development of commercial precipitation-strengthened materials over the last 40 years. Such has been the success of these "gamma prime" strengthened alloys as to virtually preclude the development of alternative age-hardening mechanisms for commercial high-temperature materials.

This situation has changed with the recent commercial introduction of HAYNES® alloy No. 242 for gas turbine applications. Consisting essentially of Ni-25%Mo-8%Cr (see Table 1), 242 alloy depends upon a long-range - ordering response to aging treatment for the development of high strength for use at service temperatures up to 1400°F (760°C). The basis for this strengthening is the formation of small long range ordered domains upon aging at 1200°F (650°C). These domains are believed to correspond to an Ni_2 (Mo, Cr) stoichiometry, with a crystal structure of the Pt_2Mo type. An electron micrograph of this type of domain structure is shown in Figure 1. It is interesting to note that the size and distribution of these domain structures are very similar to that typically observed for gamma prime precipitate particles.

As a commercial material, 242 alloy was developed to exploit this new strengthening mechanism, and to take advantage of some additional important factors. First, the ductility accompanying the high strength achieved in the aged condition is quite good. Second, the ordering reaction of interest is quite sluggish, so problems often encountered with strain-age cracking in gamma prime strengthened alloys during welding and fabrication are avoided. Third, and of great importance, 242 alloy exhibits the relatively low thermal expansion characteristics typical of the Ni-Mo system.

Coupled with the high-strength capability, these and other additional attributes make 242 ideally suited for seal ring and other key component applications. It is currently under engine test at major gas turbine manufacturers for both advanced engine and retrofit uses. Some of the advantages exhibited by 242 alloy relative to a number of older, established materials are discussed in the following sections.

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(1297d)

MATERIALS

Compositions of the four seal ring alloys to be considered are given in Table 1. The data presented for 242 alloy are for plate or bar material given a 1950°F (1065°C)/30 minutes/WQ + 1200°F (650°C)/24 hours/AC heat-treatment. That for the widely used alloy 909 is taken from bar and plate heat-treated at 1800°F (980°C)/1 hour/AC + 1325°F (720°C)/8 hours/FC to 1150°F (620°C)/8 hours/AC. Both the alloy N and alloy B data were generated for sheet annealed at 2150°F (1175°C) and 2000°F (1095°C), respectively.

STRENGTH CHARACTERISTICS

A comparison of the 100-hour stress-rupture strengths of the four materials, as a function of temperature, is presented in Figure 2. Both 242 alloy and alloy 909 exhibit considerable strength advantages over the solid-solution-strengthened alloy N and alloy B up to about 1200°F (650°C). Alloy 909's precipitation strengthening, coupled with its excellent thermal expansion characteristics, is largely responsible for its wide usage in seal ring applications. The effectiveness of this strengthening, however, falls off rather rapidly over about 1150°F (620°C). As can be seen from Figure 2, at 1400°F (760°C) the rupture strength of alloy 909 is only marginally higher than that for alloy B.

The rupture strength of 242 alloy, on the other hand, is still considerably higher than that for alloy B at 1400°F (760°C) and only begins to see an accelerated rate of decrease as temperatures exceed 1350°F (730°C). This is ascribable to the unique nature of the long-range-order strengthening mechanism, which provides effective strength even as the temperature approaches 1500°F (815°C).

The comparison between the rupture strengths of alloy 909 and 242 alloy is particularly interesting considering their tensile properties. These are shown in Figure 3 and Figure 4, together with corresponding properties for alloy B and alloy N. From room temperature to about 1200°F (650°C), 242 alloy has ultimate tensile strength slightly below that of alloy 909. At the same time, alloy 909 exhibits yield strengths significantly higher than that of 242 alloy, with correspondingly lower ductility. Looking at the 1200°F (650°C) data, it can be seen that the 100-hour stress rupture stress given in Figure 2 for alloy 909 is below its yield strength at that temperature. By the same token, 242 alloy's 100 hour stress rupture stress is above its yield strength at 1200°F (650°C). This all suggests that 242 alloy strain hardens to a significantly greater degree, even at the slow strain rates associated with creep deformation.

Coupled with the ductility advantage that 242 alloy has over alloy 909, as shown in Table 2, the propensity for greater strain hardening in 242 alloy suggests that it will have superior low-cycle fatigue properties. Indeed, preliminary cyclic stress-controlled LCF tests indicate at least an order of magnitude improvement in life for 242 alloy over alloy 909 at 1200°F (650°C).

THERMAL EXPANSION

Thermal expansion characteristics are a particularly important consideration in qualifying materials for seal ring component applications. Fe-Ni-Co-type materials, such as alloy 909, are well known for exhibiting the lowest expansion behavior up to about 1000°F (540°C). Although the expansion characteristics of Ni-Mo alloys such as alloy B are higher, they are still low enough to be of use for seal rings, particularly at somewhat higher temperatures.

Normally, adding chromium to alloys used for seals is avoided as a consequence of the significant increase in expansion coefficient. As shown in Figure 5, however, 242 alloy with 8% chromium has total expansion behavior similar to that for alloy B up to about 1200°F (650°C). From 1200°F (650°C) to 1800°F (980°C), 242 alloy expands only slightly more than alloy B, which in turn is only slightly more than alloy 909. This small debit in expansion behavior is more than offset by the benefit the chromium content in 242 alloy brings in terms of oxidation resistance, as will be discussed later.

THERMAL STABILITY

Another important consideration for seal ring applications is material thermal stability. Loss of ductility in service due to microstructural degradation can shorten component life, by promoting susceptibility to fatigue, for example. The response of 242 alloy and alloy 909 to 1000-hour exposure at 1200°F (650°C) is shown in Table 2. Even after this exposure, 242 alloy still has more than twice the room-temperature tensile elongation of alloy 909. Compared with alloy B in terms of residual impact resistance after 4000 hours at 1200°F (650°C), 242 alloy exhibits a Charpy V-Notch value of 32 ft-lbs. (43 joules) against only 6 ft-lbs. (8 joules) for alloy B. This high retained ductility and impact strength bodes very well for 242 alloy's capability to function in a containment as well as seal-ring type application.

OXIDATION-RESISTANCE

With all of their other desirable characteristics, one significant disadvantage of the Fe-Ni-Co and Ni-Mo alloys is their intrinsic lack of oxidation-resistance. For usage up to about 1000°F (540°C), this is not a key factor; however, for higher application temperatures it is necessary to employ protective coatings, often at significant expense. The need for coatings is clearly apparent from the 1500°F (815°C) flowing air oxidation data presented in Figure 6.

After 1008 hours exposure at 1500°F (540°C), with daily cycles to room temperature, alloy 909 had nearly 20 mils (500 microns) of combined metal loss and internal penetration. Alloy B is not as bad, but still significantly oxidized. In the case of alloy N. (7% Cr) and 242 alloy (8% Cr), the oxidation damage was only minimal, illustrating the value in trading off some increased thermal expansion for oxidation-resistance by adding chromium.

FABRICATION

A full comparison of the fabrication characteristics of these alloys is too large an issue to consider here. Suffice it to say that 242 alloy, as well as the other materials, is readily manufacturable in a variety of forms, and capable of being used to produce complex components. One area of key importance is weldability, which is worth considering separately.

Since most seal ring applications involve relatively heavy sections, one of the most pertinent aspects of welding to examine is the susceptibility of these materials to weld metal hot cracking. Data generated utilizing standard Varestraint test methodology for thick sheet product are shown in Figure 7. These data show that 242 alloy and alloy N are superior to alloy 909 and alloy B in resisting hot cracking.

SUMMARY

HAYNES alloy No. 242 represents a new superalloy for high stress applications in the temperature range from 1000 to 1400°F (540 to 760°C). Strengthened by a unique long-range-ordering response to heat treatment, 242 alloy possesses a desirable combination of properties well suited to gas turbine applications such as seal rings. Advantages compared to other established seal ring alloys include superior strength, thermal stability, and oxidation-resistance, among others. Engine tests at major gas turbine manufacturers for both advanced engine and retrofit uses are in progress.

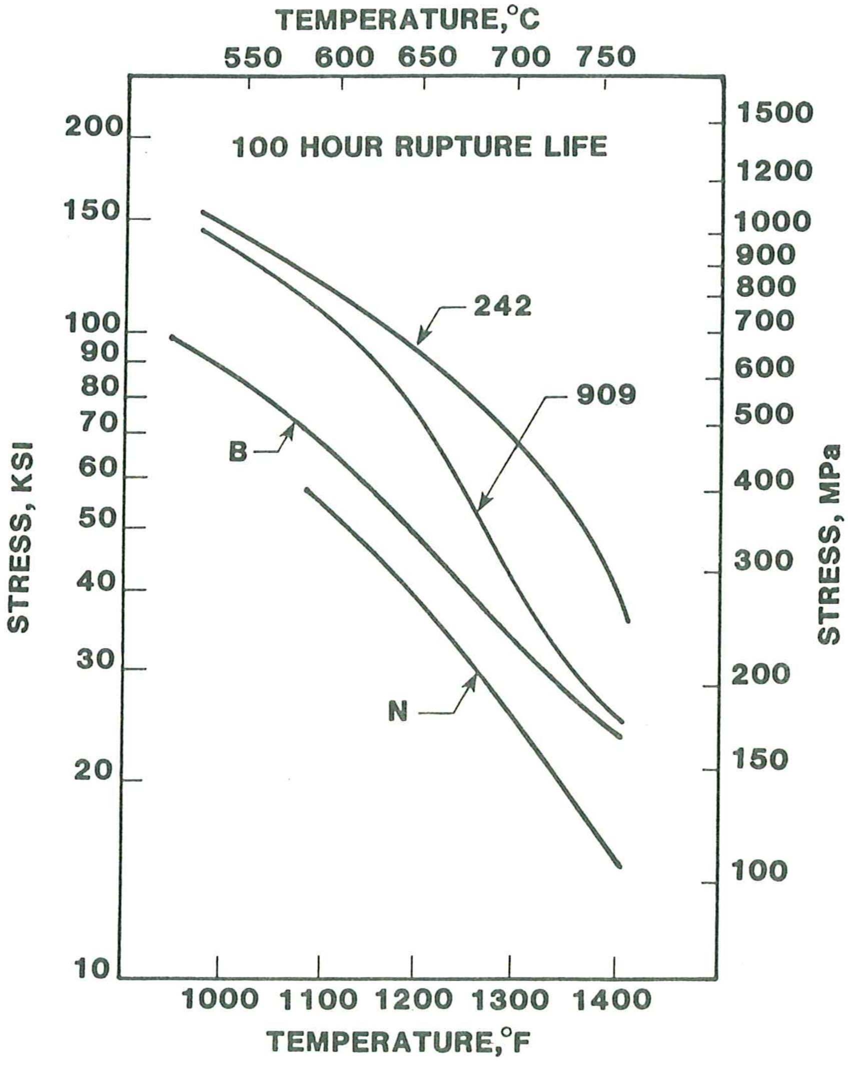

FIGURE 2: APPROXIMATE STRESS REQUIRED TO PRODUCE RUPTURE IN 100 HOURS AT VARIOUS TEMPERATURES FOR VARIOUS SEAL RING ALLOYS.

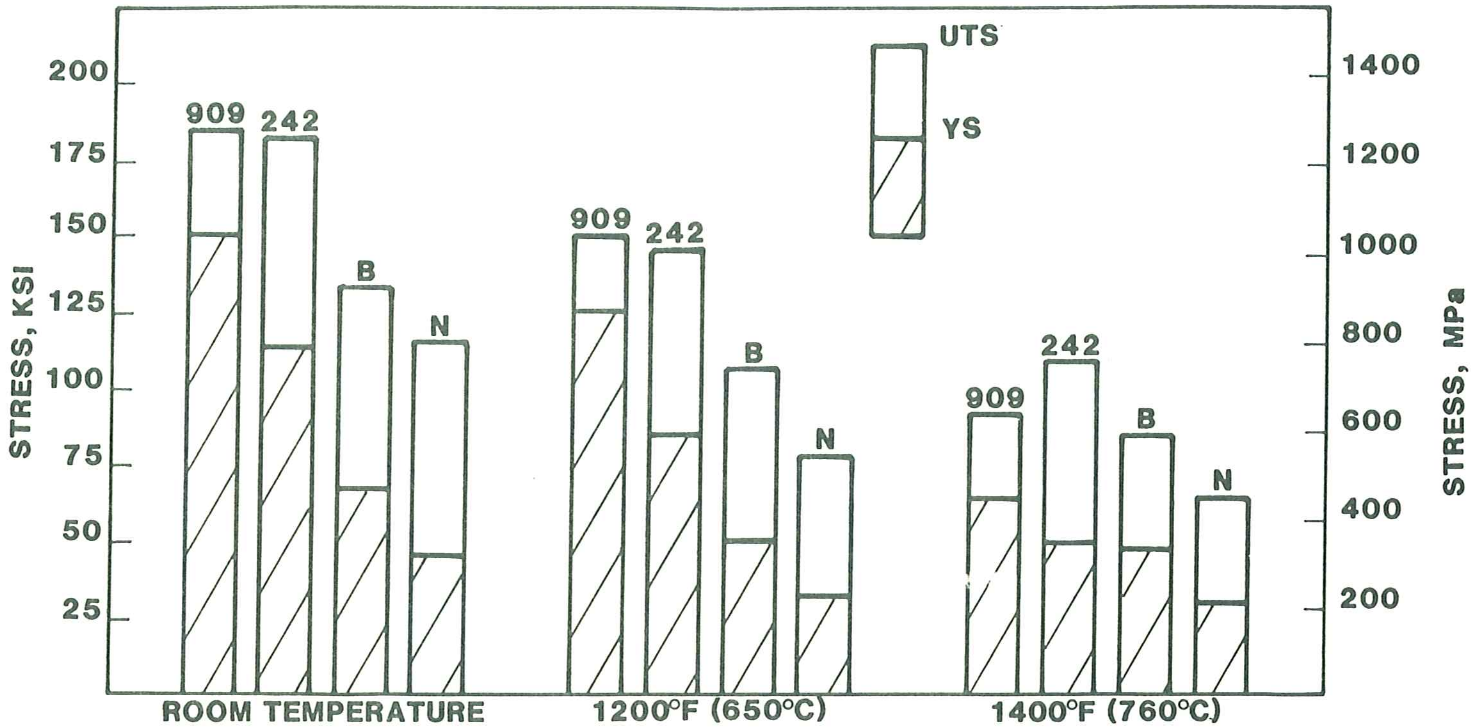

FIGURE 3: COMPARATIVE TENSILE STRENGTHS FOR VARIOUS HIGH-TEMPERATURE SEAL RING ALLOYS.

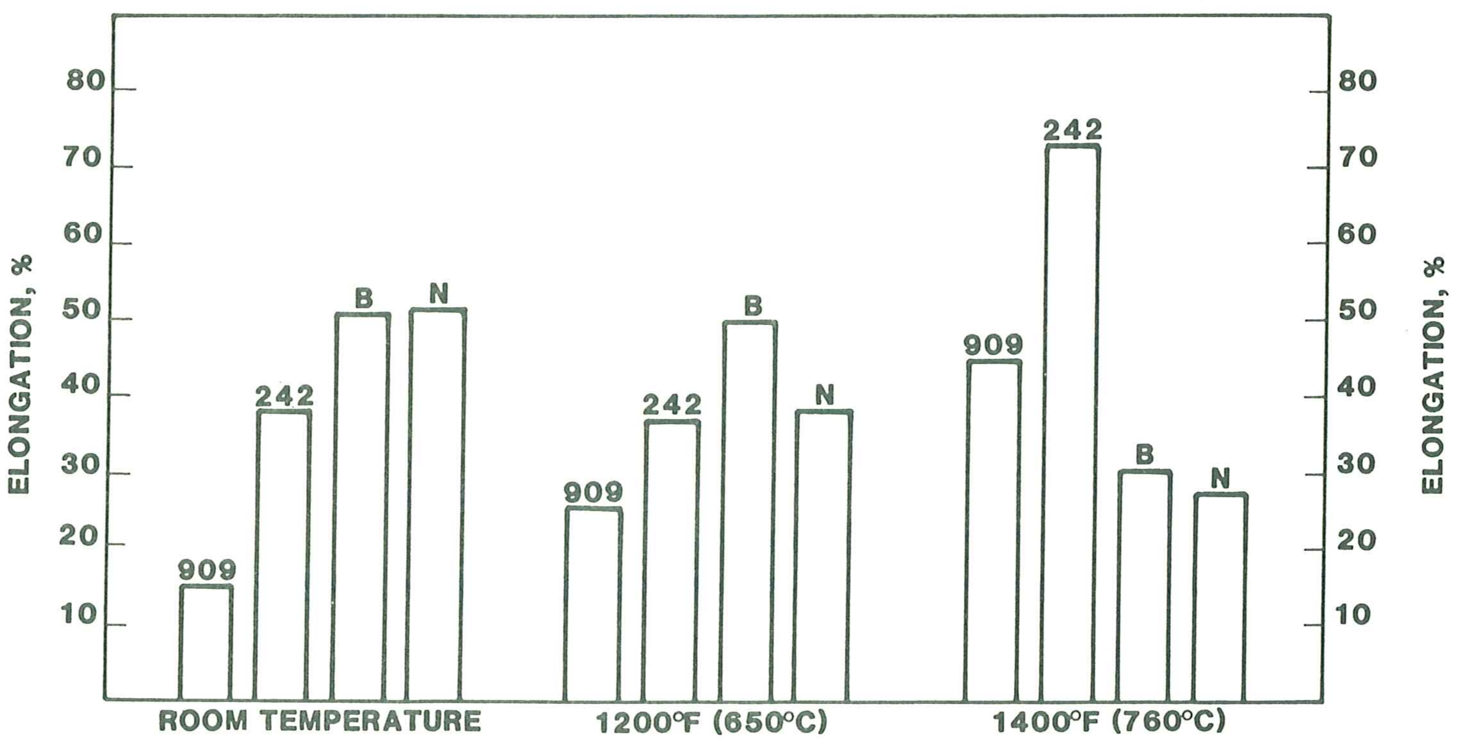

FIGURE 4: COMPARATIVE TENSILE ELONGATION FOR VARIOUS HIGH-TEMPERATURE SEAL RING ALLOYS.

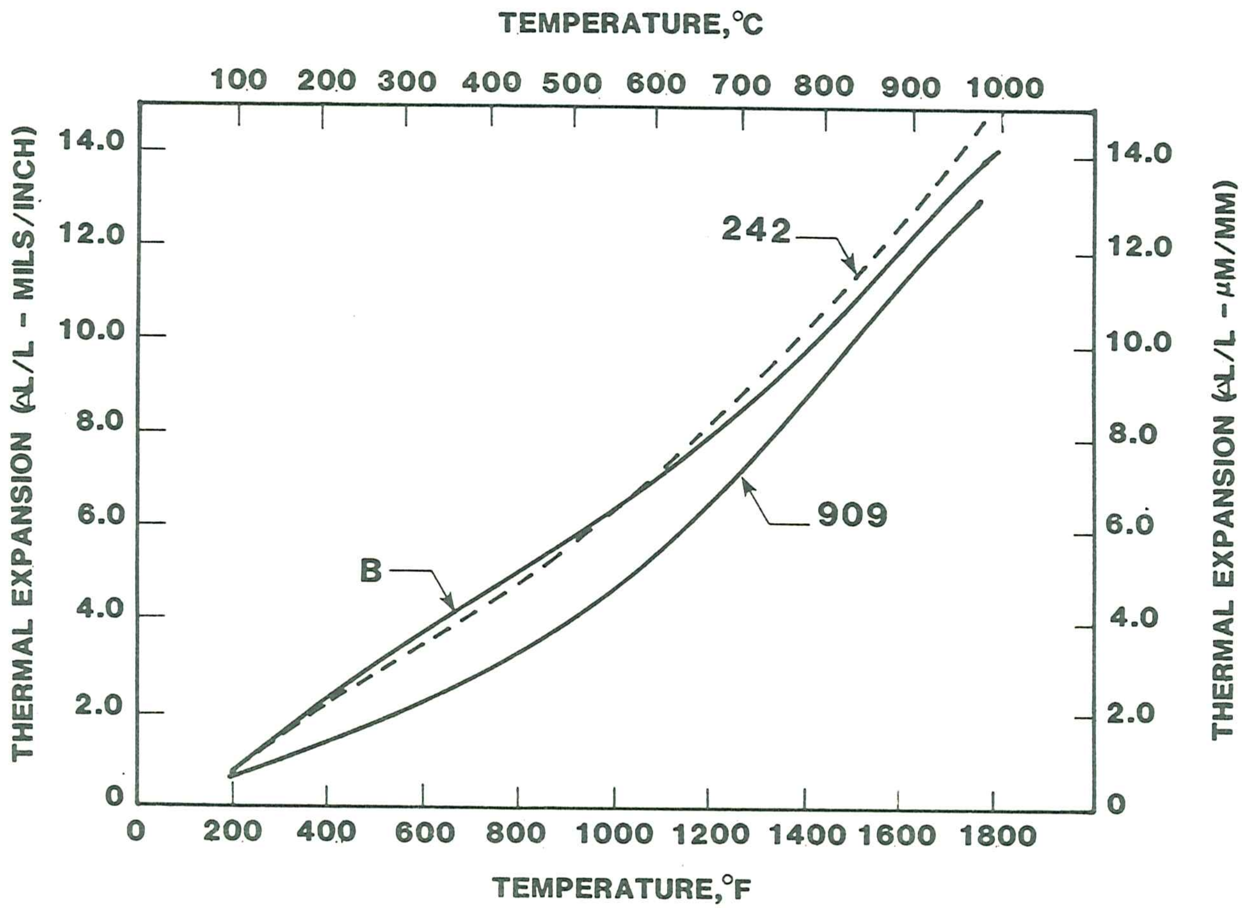

FIGURE 5: COMPARATIVE THERMAL EXPANSION CHARACTERISTICS OF VARIOUS SEAL RING MATERIALS.

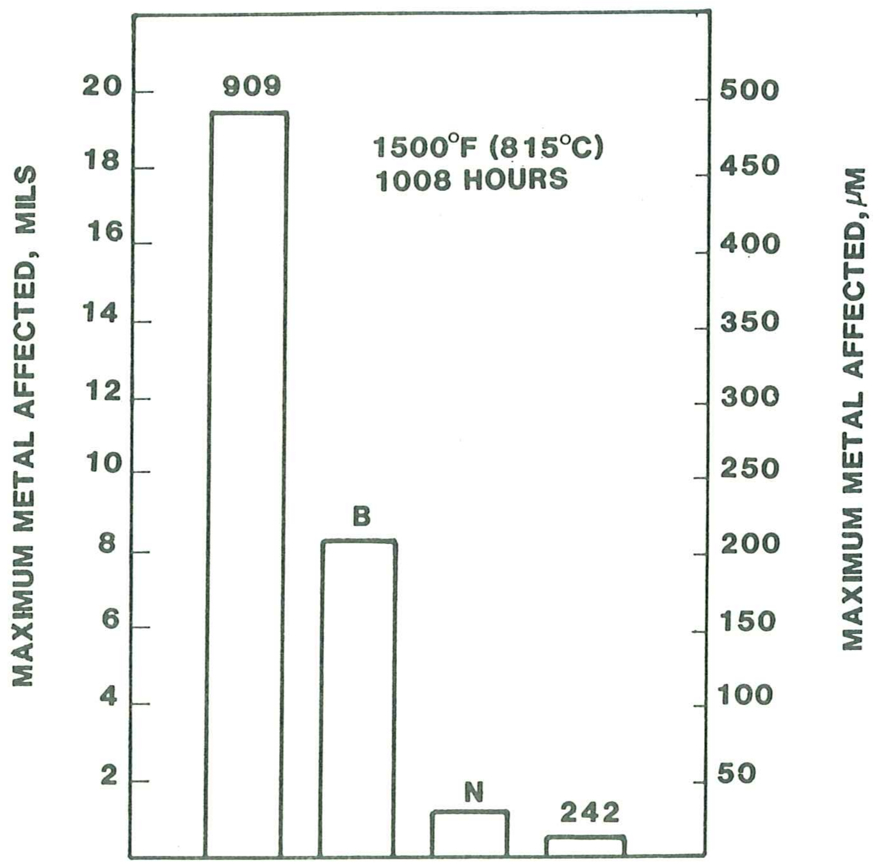

FIGURE 6: OXIDATION DAMAGE FOR VARIOUS SEAL RING ALLOYS EXPOSED 1008 HOURS AT 1500°F (815°C). SAMPLES CYCLED TO ROOM TEMPERATURE EVERY 24 HOURS.

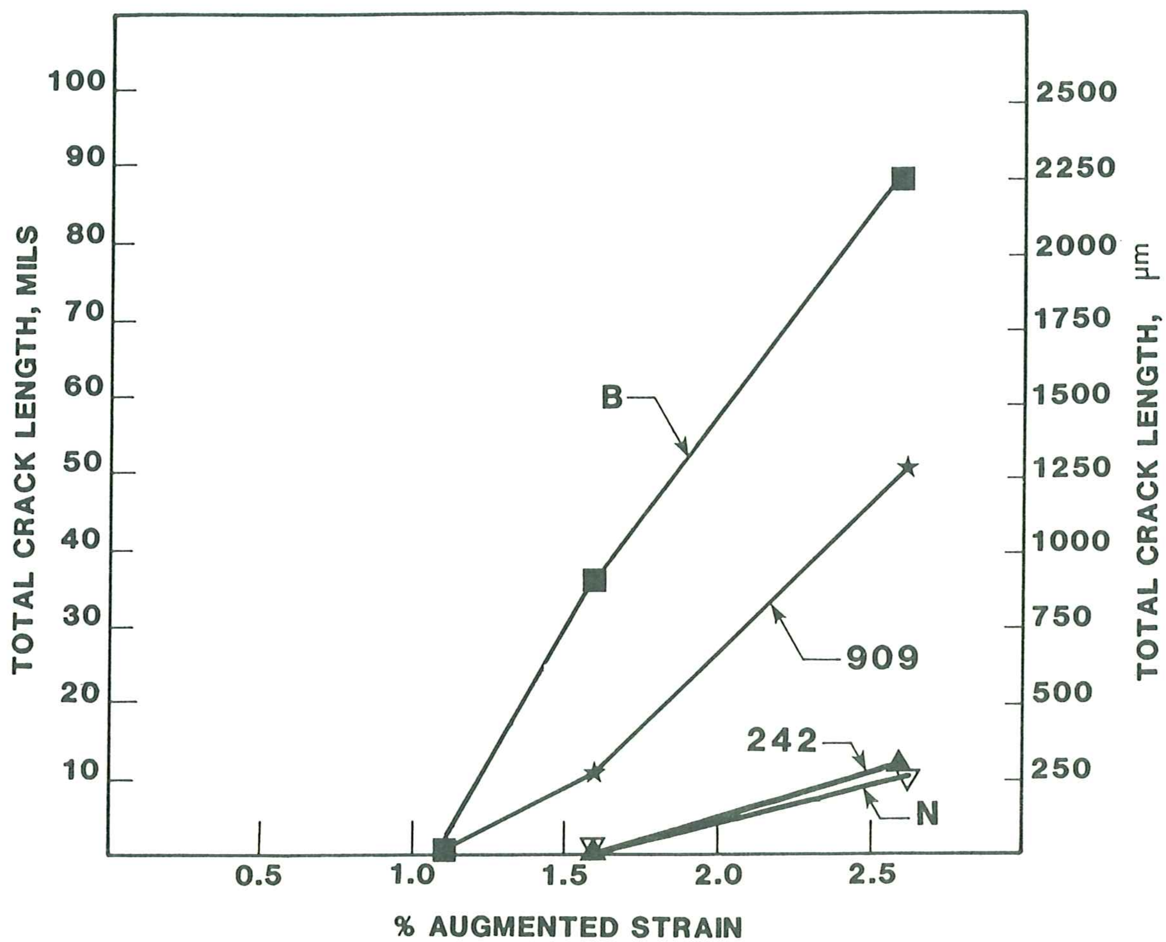

FIGURE 7: VARESTRAINT TEST RESULTS FOR VARIOUS SEAL RING MATERIALS SHOWING SUSCEPTIBILITY TO WELD METAL HOT CRACKING UNDER RESTRAINT.

HAYNES

International

Haynes International, Inc.
1020 West Park Avenue, P.O. Box 9013
Kokomo, Indiana 46904-9013

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FORMS

Sheet	Strip	Seamless Pipe and Tubing
Plate	Billet	Welded Pipe and Tubing
Coils	Wire	Bar

PROPERTIES DATA

The properties listed in this publication are average values based on laboratory tests conducted by the manufacturer. They are indicative only of the results obtained in such tests and should not be considered as guaranteed maximums or minimums. Materials must be tested under actual service conditions to determine their suitability for a particular purpose.

For More Information Contact:

Kokomo, Indiana 46904-9013
1020 W. Park Avenue
P.O. Box 9013
Tel: 317-456-6612
800-354-0806
Telex: 272280
FAX: 317-456-6905

Anaheim, California 92806
Stadium Plaza
1520 South Sinclair Street
Tel: 714-978-1775
800-531-0285
TWX: 910 591 1884
FAX: 714-978-1743

Arcadia, Louisiana 71001-9701
(Tubular Products Only)
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Route 1 Box 8
Tel: 318-263-9571
Telex: 588427
FAX: 318-263-8088

Windsor, Connecticut 06095
430 Hayden Station Road
Tel: 203-688-7771
800-426-1963
FAX: 203-688-5550

Houston, Texas 77041
The Northwood Industrial Park
12241 FM 529
Tel: 713-937-7597
800-231-4548
Telex: 225465
FAX: 713-937-4596

Brazil
Avenida Paulista 2001
Conj 1704, 01311 Sao Paulo-SP
Tel: 289-0900 and 289-0622
Telex: 11 22510

Canada
189 Hymus Boulevard,
Suite 308
Pointe Claire
(Montreal) Quebec H9R 1E9
Tel: 514-694-8303
Telex: 05822530
FAX: 514-694-8166

England
Haynes International, Ltd.
P.O. Box 10
Parkhouse Street
Openshaw
Manchester, M11 2ER
Tel: (061) 223-5054
Telex: 667611
FAX: 061-223-2412

France
Haynes International, S.A.R.L.
43 Rue de Bellevue
Boite Postale No. 47
92101 Boulogne Cedex
Tel: (01) 48 25 22 76
Telex: 631417
FAX: (01) 48250251

Switzerland
Nickel Contor, AG
Gotthardstrasse 21
CH-8022 Zurich
Tel: (01) 201 73 22
Telex: 815-601
FAX: (01) 201 73 33

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