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PERFORMANCE OF TYPES 304, 316, and 348 STAINLESS STEEL IN NaK AT HIGH TEMPERATURES

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A B S T R A C T

A service test evaluation on Types 304, 316, and 348 stainless steel that were exposed in NaK at 1000-1400°F for 14,200 hours showed no corrosion damage in spite of structural changes in the alloys. At this service time they were found to be equally usable.

SUMMARY

A service test examination has been made on a welded assembly containing Types 304, 316, and 348 stainless steel. This assembly had been in NaK service for 14,200 hours at about 1000°F with the maximum temperature being 1400°F. There was no general corrosion damage on the materials. Appreciable carbide precipitation at the grain boundaries and sigma phase were observed in the Types 304 and 348 stainless steel, but only carbide precipitation in Type 316. These observations plus the results of additional evaluations indicate that the three steels are equally suitable from a corrosion standpoint for service in NaK in the temperature range and for the period reported. Although significant changes were detected in the structure of the alloys, none of these suggested failure in the absence of other factors.

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I. INTRODUCTION

A service test examination was conducted on a pipe-elbow-pipe welded assembly of the NaK transmission return line from the pilot plant calciner operated by the Chemical Technology Branch at ICPP. This assembly was in NaK service for 4,397 hours below 1000°F and for 9,789 hours above 1000°F. The 2-inch OD pipe-elbow-pipe assembly was erected by welding one end of a Schedule 40 Type 348 stainless steel (ss) elbow to a Schedule 40 Type 316 ss nozzle and the other end of the elbow to a Schedule 80 Type 304 ss NaK transmission return line. In this system eutectic NaK (77.2 wt% potassium-22.8 wt% sodium) was heated by an oil-fired furnace through a Type 316 ss metal bundle.

For examination, the assembly was cut from the system and the individual pieces were cut open. A general inspection was made of the inside walls, cross sections were taken for metallographic examination, and pertinent analyses and physical property tests were run.

II. RESULTS

1. GENERAL

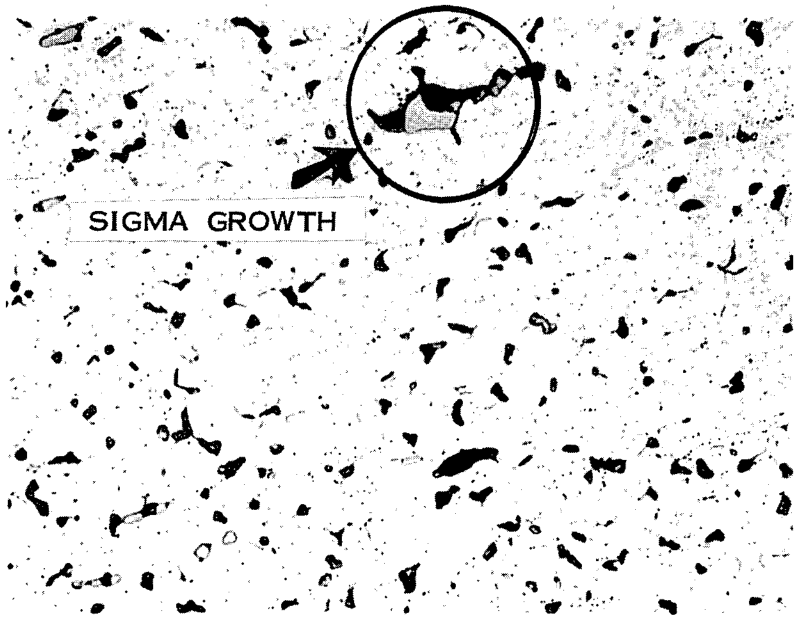
General corrosion damage on the assembly from the 14,200-hour service was nil. Icicles and craters were found in the weld joints. The averages of duplicate carbon analyses were 0.044 percent and 0.051 percent for 5 mil turnings from the inside and outside surfaces of the Type 304 ss pipe, respectively.

2. METALLOGRAPHIC EXAMINATION

A metallographic examination of cross sections of the three stainless steels and their weld joints in the assembly indicated carbide precipitation at the grain boundaries. Type 304 ss appeared to have less carbide precipitation than Type 316 and more than Type 348. The Type 316 alloy exhibited bands of precipitate within the cross-sectional area. Appreciable concentrations of sigma phase (hard intermetallic compound of the general formula Fe_mCr_n) were found in Type 348, and only trace amounts in Type 304. Sigma was sought-for but not found in the Type 316 section. Figures 1, 2, and 3 are micrographs at 750X of Types 348, 304, and 316, respectively. Near the left edge of Figure 1 is a large grain which is a growth of sigma phase in the complex chromium-nickel-columbium austenite matrix of the Type 348 alloy. Another example of sigma growth is located at the lower right-center in the micrograph of the Type 304 wrought pipe, Figure 2. The micrograph of the Type 316 alloy, Figure 3, shows no sigma phase.

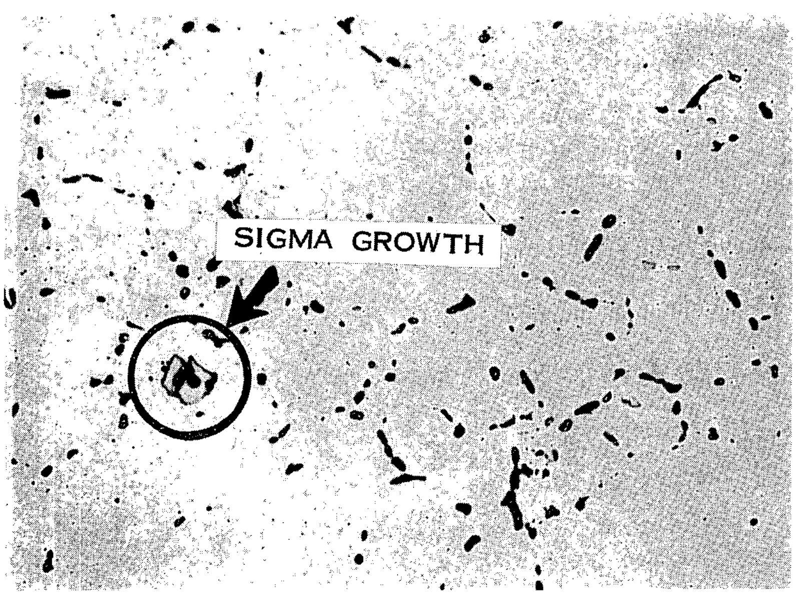
3. HARDNESS

Using a Clark diamond pyramid hardness tester on polished cross sections, hardness traverses were taken on the elbow assembly. The results of this hardness survey are shown in Table I. The only particularly hard spot was on the weld joining Types 304 and 348 ss.



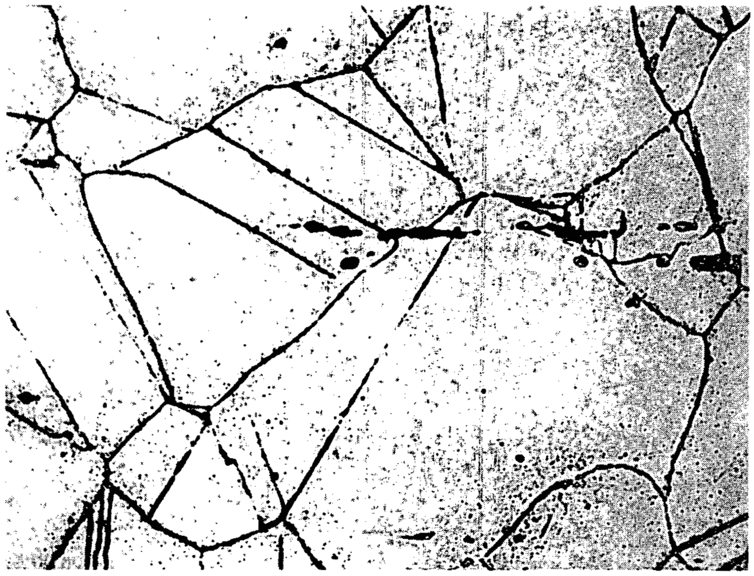
Stainless Steel Type 348 750X
Etch: 10% Oxalic Acid

Fig. 1 Cross Section of 90° Elbow
After 14,186 Hours in NaK Service



Stainless Steel Type 304 750X
Etch: 10% Oxalic Acid

Fig. 2 Cross Section of Wrought Pipe
After 14,186 Hours in NaK Service



Stainless Steel Type 316 750X
Etch: 10% Oxalic Acid

Fig. 3 Cross Section of Wrought Pipe
After 14,186 Hours in NaK Service

TABLE I

HARDNESS SURVEY OF AN AUSTENITIC STAINLESS STEEL ELBOW ASSEMBLY
AFTER 14,186 HOURS IN NaK SERVICE

Alloy	Rockwell Hardness Number
304 - Wrought	91.5 R_b
348 - Wrought	96.4 R_b
316 - Wrought	90.2 R_b
304-348 Weld	24.8 R_c
316-348 Weld	95.0 R_b

4. STRENGTH

Three ½-inch wide semi-circular strips were machined from one of the halves of the Type 348 elbow for physical testing. Two strips were flattened, and the third strip was bent until the tips met each other. Unexposed wrought 2-1/3-inch OD pipe specimens of Type 347 (Cb and Ta) ss were similarly prepared, flattened, or bent. On the inside surfaces of the two flattened specimens exposed to NaK, very shallow tear-like fissures or cracks were observed. On the outside surface of the exposed specimen that was bent, cracking was not apparent at 5X or 15X. The cracks that were observed on the NaK side of the elbow specimens were generally perpendicular to the loading axis. One or two of these fissures was about 40 mils deep, but tbe others were 15 to 20 mils deep. All of the unexposed Type 347 (Cb and Ta) pipe specimens were bent or flattened without developing fissures or cracks that could be observed at either 5X or 15X.

One of the flattened strips was machined into a tensile test specimen and tested at 1400°F in air. This test temperature was selected because it was near the upper service limit of the elbow. The ultimate tensile strength was 40,700 psi with a 40 percent elongation. This value is very close to the published value for Type 347 ss at 1400°F.[1]

III. DISCUSSION OF RESULTS

The precipitation of carbides at the grain boundaries and sigma phase formation, with the accompanying embrittlement and cracking, are deleterious effects of exposure of stainless steels to NaK at elevated temperatures. In austenitic stainless steels sigma phase usually does not form a continuous envelope around individual grains and lead to massive failure. Rather, in the stainless steels where the sigma particles are small and dispersed, as in the present case, some embrittlement results. At points of high stress this can lead to brittle fractures. Although sigma phase was not found in the Type 316 in these studies, it was found in the same steel exposed under similar conditions for a somewhat longer period of 15,174 hours above 1100°F in the NaK system of the Waste Calcining Facility at ICPP. Similar observations have been made in other studies.[2] These essentially thermal effects may be accelerated by the migration of carbon to the NaK surface and mass transfer of carbon, but they appear to be primarily associated with aging of the steel at elevated temperatures. The sigma phase itself is hard, but at these low concentrations no hardening of the metal surface was detectable in the standard test. Although there have been significant changes in the structure of the alloys, the tensile strength remains normal. These observations are in complete agreement with those made on Type 316 ss after 15,174 hours service in NaK at temperatures above 1100°F. The absence of corrosion damage of the steel surface by NaK appears to be typical of NaK systems where stringent efforts are made to control the oxygen content.

Obviously, there is a rather close association of carbide precipitation and sigma phase formation. In unexposed stainless steel, carbon in solid solution is an austenitizing agent, and as such, decreases the tendency to form sigma phase. With exposure at 1400°F carbon always precipitates with a ferritizing agent such as chromium, columbium, molybdenum, etc, as a carbide within a ferrite phase. After prolonged exposure, the presence of precipitated carbides decreases the time for sigma phase formation in 18-8 austenitic steels by acting as nucleating agents. Since carbides usually are precipitated at a lower temperature than sigma, it follows that heating to 1400°F will lead first to carbide formation, then sigma phase nucleation, then sigma phase precipitation.

Based upon existing technology,[3] the use of fully austenitic stainless steel low-carbon alloy is suggested in applications where sigma phase inhibition is highly desirable. Type 316 ss has significantly greater yield and ultimate tensile strengths than Types 304 and 348 ss after exposure at 1200°F; Type 304 steel has by far the highest impact strength after such exposure.

IV. CONCLUSIONS

Types 304, 316, and 348 stainless steel served for 14,200 hours in NaK at 1400° maximum temperature without failure. Under these conditions and at this exposure time, these three alloys appear to be equally serviceable from a corrosion standpoint. The appearance of sigma phase, which is probably the most significant deleterious effect, does not appear to affect the serviceability of the steel as long as the sigma phase particles are small and the concentration small. Currently the use of a fully austenitic stainless steel with low carbon content is suggested in applications where sigma phase growth is undesirable.

V. REFERENCES

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