NBSIR 85-3103

Metallurgical Evaluation of Type 304 Stainless Steel Exposed to Woodburning Stove Flue Gases

John H. Smith

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Center for Materials Science
Metallurgy Division
Gaithersburg, MD 20899

January 1985

Issued February 1985

Final Report

Prepared for
U.S. Consumer Product Safety Commission
Washington, DC 20207

NBSIR 85-3103

METALLURGICAL EVALUATION OF TYPE 304 STAINLESS STEEL EXPOSED TO WOODBURNING STOVE FLUE GASES

John H. Smith

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Center for Materials Science
Metallurgy Division
Gaithersburg, MD 20899

January 1985

Issued February 1985

Final Report

Prepared for
U.S. Consumer Product Safety Commission
Washington, DC 20207

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Introduction

Background: Metallic chimneys used for wood burning stoves have recently been identified by the Consumer Product Safety Commission as the cause of numerous house fires. These chimneys are presently constructed according to Underwriters Laboratory (UL) Standard 103. Presently used chimneys are constructed of either AISI (American Iron and Steel Institute) type 304 or type 430 stainless steel and are either a double walled or triple walled design.

To evaluate the design of metallic chimneys and to determine the extent of degradation of the materials of construction used in these chimneys, the Consumer Product Safety Commission has conducted laboratory and field investigations of metallic chimneys. The laboratory investigations consist of controlled tests in which test coupons of sections from metallic chimneys are exposed to typical wood burning stove flue gas environments and temperature cycles. The field investigations consist of the examination of selected chimney sections that have been removed from service after normal operation or after being involved in chimney fires.

Present Investigation: The objectives of this investigation were to determine the extent of degradation in mechanical properties, to identify any microstructural changes, and to determine the amount of corrosive attack of austenitic stainless steels (types 304 and 321) exposed to flue gas environments and temperatures from wood burning stove fires. In this phase of the investigation, coupons taken from sections of new, unused metallic chimneys were exposed to flue gases generated by wood burning stoves in controlled tests that lasted up to six months. Selected coupons were heat treated prior to exposure to the flue gas environment to produce a fully "sensitized" condition in the austenitic stainless steel. A limited number of chimney sections made from type 304 stainless steel that had been removed from field service or that were used in the laboratory test program were also examined to assess the extent of any degradation during use.

Experimental Procedures

Materials Examined: Test coupons were cut from new, unused sections of double walled and triple walled chimneys made from AISI type 304 stainless steel. The test coupons were approximately 3-inches wide by 18-inches long and were roll formed into rings approximately 5 1/2-inches in diameter for use in the laboratory environmental exposure tests. The test coupons from the double walled chimney sections were approximately 0.018-inch thick and the test coupons from the triple walled chimney sections were approximately 0.015-inch thick. Additional material of a stabilized grade of austenitic stainless steel (AISI type 321) was purchased for making test coupons. These test coupons were 0.050 inch thick. This material is not currently used in the manufacture of metallic chimneys but was included in this study to evaluate the significance of the sensitization phenomenon in contributing to the degradation of chimneys. The chemical composition of all material was checked and is shown in Table I. All materials used in this test program satisfied the chemical composition specifications for type 304 or type 321 as given by the appropriate AISI specification.

The test coupons were evaluated in the following conditions: 1) as received (cut from new chimney sections), 2) after a sensitization heat treatment in air in an accurately controlled furnace for 100 hours at 1000°F, 3) after sensitization plus exposure to wood burning in a stove environment for periods of 3, 4, or 6 months. The test cycle for the wood burning stove environment exposure consisted of starting a new fire each day, initially allowing it to burn hot with full air supply for approximately 15 minutes and then controlling the temperature of the test coupon to approximately 400°F for the remainder of the cycle. Test coupons of type 304 stainless steel from both double walled and triple walled chimneys were exposed to the wood burning stove environment for 3 or 6 months after the test coupons had been sensitized in the heat treatment furnace. Test coupons of type 321 stainless steel were exposed to the wood burning stove environment both in the as received and in the sensitized conditions. In addition, test coupons of type 304 stainless steel from triple walled chimneys and test coupons of type 321 stainless steel were evaluated after being sensitized in a chimney by heating with propane for 100 hours to a temperature (measured in the test coupon) of 1000°F.

Five sections of each of two chimneys, constructed of type 304 stainless steel, that had been in normal service for an extended time but which had not experienced a chimney fire, were acquired for examination. In addition, sections of the double walled chimney and of the triple walled chimney that were used in the laboratory tests for exposing the test coupons for three and six months were evaluated after the completion of the laboratory tests.

Description of Experimental Tests

Metallographic Examination: Specimens were taken from all test coupons and chimney sections to evaluate the general microstructure, to determine the presence of sensitization, and to determine the extent of surface attack due to exposure to the flue gases. Metallographic specimens were mounted so that the microstructure in the through thickness direction could be examined. Additional specimens were mounted in the more conventional manner so that the surface of the test coupons could be examined. In addition, selected specimens were mounted as taper sections to better identify the degree of attack approaching the surface that was exposed to the flue gas environment. Optical metallographic analysis was performed after polishing and etching the specimens. Most of the optical metallographic analysis was performed at magnification of 500X, but selected examinations were done at

100X, 250X, and 1250X as appropriate.

To examine the general microstructure, the specimens were etched with glyceria (20ml HCl/5ml HNO_3/20ml glycerin) or with an etch of 15ml HCl/10ml HNO_3/ 15ml acetic acid. These etches were used to show the general microstructural features such as grain size, grain shape, and the presence of cold work. Selected specimens were etched with Nital (5ml HNO_3/95ml alcohol) to identify the presence of any small amounts of ferrite in the predominantly austenitic microstructure. The glyceria etch was also used on the edge mounted specimens to show the depth and location of attack at the surface of specimens that had been exposed to the flue gas environments. To identify the presence and degree of sensitization, an electrolytic etching procedure using an oxalic acid etch (10% oxalic acid in water) was used. This etching procedure attacks only the carbide microconstituent in the specimens and clearly shows the existence of sensitization by showing the presence of carbide precipitates at the austenite grain boundaries.

Mechanical Properties Tests: Tensile test specimens were taken from the test coupons and from the test chimneys. Tests were conducted following the ASTM standard test method E-8-81 for Tension Testing of Metallic Materials. The tensile test specimens had a gage section of 0.5 inches wide by 2.0 inches long and were the thickness of the test coupons (0.015 to 0.018- inch). The 0.2% offset yield strength, ultimate tensile strength, and percent elongation to fracture were determined at room temperature for each test specimen. Selected specimens were tested for hardness using the Knoop microhardness test with a 50 gram load.

Corrosion Tests: To evaluate the susceptibility to intergranular attack, specimens were taken from the test coupons and were tested by the oxalic acid etch test (the Streicher test) and by the ferric sulfate-sulfuric acid test (the Huey test) according to procedures given by the ASTM standard practice methods A-262-81. The oxalic acid etch test (Streicher test) is a rapid test used for austenitic stainless steel to identify specimens that are free from susceptibility to rapid intergranular attack caused by the presence of carbide precipitation at grain boundaries (sensitization). Evaluation is based on the classification of etched grain structures in the test specimen after controlled etching with oxalic acid. The ferric sulfate-sulfuric acid test (Huey test) is used to detect the susceptibility of austenitic stainless steels to intergranular attack by determining the weight loss (corrosion rate) of specially prepared specimens that are immersed in a boiling solution of ferric sulfate and sulfuric acid. This test detects the susceptibility to intergranular attack associated with the precipitation of chromium carbide (sensitization) in unstabilized austenitic stainless steel. The corrosion rates measured and the presence or absence of intergranular attack in this test is not necessarily a measure of the performance of the material in other corrosive environments, such as the flue gases.

Experimental Results

Evaluation of "As-Received" Material:

Chemical Composition: Specimens from new, doubled walled and triple walled chimneys, and from sections of AISI type 321 material in the "as received" condition were analyzed for chemical composition. The chemical compositions are shown in Table I. In all cases, the composition satisfied the required composition for AISI type 304 or type 321 stainless steel.

Metallographic Analysis: All materials were examined by optical metallographic techniques in the "as received" condition. Examination of each material was made using aqua regia etch and a magnification of 500X to determine the general microstructure, microconstituants, and grain size. An electrolytic oxalic acid etch was used on separate specimens to determine the presence of carbides precipitated at the grain boundaries which is indicative of sensitization. A typical microstructure of the "as received" material taken from the double walled chimney made from type 304 stainless steel is shown in Figure 1. This material was fully austenitic with no evidence of residual ferrite or other microconstituants. The grains were predominantly equiaxed with a grain size of ASTM No. 9 (approximately 0.0006 in. diameter). Annealing twins were present in many of the grains. The oxalic acid etch did not reveal any evidence of carbide precipitation at the grain broundaries indicating that no sensitization had occurred in the as received material as fabricated into a typical double walled chimney. The structure indicated that the stainles steel was in the annealed condition and had not been significantly cold worked.

Specimens taken from sections of triple walled chimney made from 304 stainless steel showed a generally similar microstructure to those taken from doubled wall chimney sections. As shown in Figure 2, the microstructure consisted entirely of equiaxed austenitic grains containing many annealing twins. No evidence of significant cold work was observed. The grain size of the material taken from the triple walled chimney sections was ASTM grain size No. 8 (approximately 0.0009 in. diameter) which is somewhat larger than the grain size of the material from the double walled chimney sections. The oxalic acid etch did not reveal the presence of any carbides at the grain boundaries which indicates that the material in the typical triple walled chimney section had not been sensitized.

The stabilized grade of stainless steel (type 321) was examined in the "as received" condition. As shown in Figure 3, this material had a microstructure similiar to the material taken from the double walled and triple walled chimney sections made from type 304 stainless steel. The microstructure consisted entirely of equiaxed austenitic grains showing a substantial amount of annealing twins. No evidence of significant cold work was present in the microstructure indicating that the material was fully annealed in the "as-received" condition. The material was fine grained with a grain size of ASTM No. 9 (approximately 0.0006 in. diameter). The oxalic acid etching procedure did not reveal the presence of any grain boundry carbides indicating the absence of sensitization in the material.

Mechanical Properties Tests: The results of the tensile tests performed on the "as received" material from double walled and triple walled chimney sections are shown in Table II. No tensile tests were performed on the stabilized stainless steel (AISI type 321). The results show that the yield strength, tensile strength, and percent elongation to fracture of material from both the double walled and triple walled chimney sections fall within the normally expected range for annealed type 304 stainless steel. The yield strength and tensile strength of the material from the triple walled chimney section were slightly lower that the same properties for material from double walled chimney sections. This small effect may be due to the somewhat larger grain size in the triple walled material than in the double walled material.

Corrosion Tests: Specimens of all "as received" materials were tested using the Streicher test (ASTM method A-262-81, practice A) which is an oxalic acid etch test for classification of austenitic stainless steels to determine their susceptibility to intergranular corrosion. The three materials tested, which were from double walled and triple walled chimneys and from type as received 321 stainless steel, all showed a satisfactory etched structure classified as a "step" structure.

On the basis of the Streicher test these materials are not susceptible to intergranular attack due to carbide precipitation (sensitization) at the grain boundaries.

Additional corrosion tests were conducted on material from the double walled and triple walled chimney sections using the ferric sulfate-sulfuric acid (Huey) test (ASTM method A-262-81 Practice C) for determining the susceptibility to intergranular attack. This procedure determines the corrosion rate of stainless steel in boiling sulfuric acid. The measured corrosion rate for both materials was 26 to 29 mpy (mils per year) which indicates that the stainless steels were not susceptible to intergranular attack in the sulfuric acid environment.

Evaluation of Sensitized Material:

Test coupons of type 304 stainless steel from both double walled and triple walled chimney sections and of type 321 (stabilized) stainless steel were heat treated in a furnace for 100 hours at 1000°F to cause carbide precipitation at the grain boundaries (sensitization) prior to being exposed to wood burning stove environments. In addition, selected coupons from a triple walled chimney and from sections of type 321 stainless steel were heated in a wood burning stove chimney for 100 hours at a controlled temperature of 1000° F to cause sensitization.

Metallographic Analysis: As shown in Figure 4, the sample of material from the double walled chimney section showed severe sensitization after the heat treatment as indicated by the carbide precipitation completely surrounding the grains. The degree of sensitization was most extreme at the surface of the specimen and decreased somewhat in the interior (mid thickness) of the specimen. As shown in Figure 5, at a magnification of 500X the surface of the test coupon is slightly rough after the completion of the heat treatment, but no evidence of grain boundary attack is apparent. The features of this micrograph (Figure 5) will be compared with similar micrographs taken after exposure of the specimens to the wood burning stove environment. No changes in the microstructure, other than the carbide precipitation at the grain boundaries, were found after the sensitization heat treatment (for example, compare Figure 1 and 4).

As shown in Figure 6, samples taken from triple walled chimney sections showed evidence of extreme sensitization after the heat treatment at 1000° F for 100 hours in the furnace. The degree of sensitization in this material was more extreme at the surface of the specimen than of the mid-thickness of the specimen as shown in Figure 7. Complete sensitization was also observed in the test coupons that were heated in the wood burning stove chimney for 100 hours at 1000° F, as shown in Figure 8. The surface of the test coupons were only slightly roughened and no grain boundary attack was observed after the furnace heat treatment, as shown in Figure 9. The carbide precipitation due to sensitization was the only microstructural change observed in the material from the triple walled chimney sections after the heat treatment.

Samples of the type 321, stabilized grade of stainless steel were examined after heat treating for 100 hours at 1000° F in both the heat treating furnace and in the wood burning stove chimney. As shown in Figure 10, the type 321 stainless steel was not sensitized by this heat treatment as indicated by the lack of carbide precipitation at the grain boundaries. This is in contrast to the samples of type 304 stainless steel (unstablized) that were heavily sensitized after the same heat treatment.

Mechanical Properties Tests: Tensile tests were conducted on samples of materials from double walled and triple walled chimney sections after the materials were heat treated in the furnace for 100 hours at 1000° F. The results of these tests, given in Table II, show that no significant change occurred in the yield strength, tensile strength, or percent elongation to fracture as a result of this sensitization heat treatment. The mechanical properties of the sensitized 304 stainless steel were with the normally expected range of property values for annealed type 304 stainless steel.

Corrosion Tests: The samples of materials from both the double walled and triple walled chimney sections tested in the Streicher test both showed severe evidence of sensitization (etching at the grain boundaries after the oxalic acid etch) after the materials had been heat treated for 100 hours at 1000° F. Specimens of sensitized materials tested by the Huey test method showed corrosion rates varying from 162 mpy for the materials from triple walled chimney sections to 420 mpy for materials from the double walled chimney. These much higher corrosion rates, compared with rates of 26 to 29 mpy in the "as received" material, indicate that severe and rapid intergranular corrosion took place in the sensitized material when tested in the sulfuric acid environment.

Evaluation of Material After Exposure to Wood Burning Stove Environmemts: Test coupons were tested in wood burning stove chimneys for periods of 3 months and 6 months according to the temperature and firing cycle previously described. The test coupons were examined metallographically and tensile tests and corrosion tests were conducted on the materials after the 3 months exposure period. All material was sensitized prior to exposure to the wood burning environment.

Metallographic Examination: Specimens of type 304 stainless steel material from double walled chimney sections showed no change in microstructure or in the degree of sensitization after exposure to the wood burning stove environment for 3 months. Several specimens from each of six coupons placed in different positions in the chimney were examined. The only evidence of any change in the material is the very slight surface roughening and grain boundary attack that can be seen at high magnification (1250x) as shown for example in Figure 11. The maximum extent of this attack is to a depth of one grain (approximately 0.0006 in). After six months exposure, the same materials show no additional microstructural change from the condition of the starting (as sensitized) material. As shown in FIgure 12, the attack at the surface of the specimen is still limited to a maximum of one grain diameter in depth. No severe attack or degradation was observed at the grain boundary which indicates that the presence of carbides in the grain boundaries due to sensitization does not significantly affect the degradation of the type 304 stainless steel in the flue gas environment.

Specimens of materials taken from triple walled chimney sections showed no significant change in microstructure or in the degree of sensitization after 3 months or 6 months exposure to the wood burning stove environments. After 3 months exposure, the maximum extent of attack was limited to the depth of one grain diameter and could only be observed at high magnification as shown in Figure 13. After 6 months exposure, the extent of attack in the surface of the specimens was not significantly greater than after 3 months exposure. As shown in Figures 14 and 15, the surface attack was limited to a depth of approximately one grain diameter (0.0009 in). This indicates that the rate of surface degration and attack is not accelerating as the exposure times are extended.

The type 321 (stabilized) stainless steel test coupons were exposed to the wood burning stove environment for a period up to 4 months after first being heat treated through the cycle that was used to sensitize the 304 stainless steel. As shown in Figure 16, no microstructural changes were observed in the type 321 stainless steel as a result of the exposure cycle. The only evidence of surface degradation or attack was limited to a depth of less than one grain diameter (0.0006 in.), as shown in Figure 16.

The results of the metallographic examination show that the wood burning stove heating cycle used in these tests does not cause any microstructural changes and does not cause significant degradation or attack of the surface of type 304 stainless steel even when the stainless steel is heavily sensitized prior to exposure to the heating cycle. Type 321 stainless steel, which is not subject to sensitization, does not show any difference from the type 304 stainless steel when exposed to the wood burning stove envrionment.

Mechanical Properties Tests: Tensile tests were conducted on samples of materials from double walled and triple walled chimney sections that had been exposed to wood burning stove environments for a total time of 3 months. The results of these tests, given in Table II, show that no significant change occurred in the yield strength, tensile strength, or percent elongation to fracture as a result of the exposure to the wood burning stove environments. The mechanical properties of the 304 stainless steel were within the normally expected range of property valves for annealed type 304 stainless steel.

Corrosion Tests: Specimens from both double walled and triple walled chimney sections were tested using the Streicher test after 3 months exposure to wood burning stove environments. This test, which evaluates the susceptibility of austenitic stainless steel to intergranular cracking, showed that both the double walled and triple walled chimney sections were susceptible to intergranular corrosion. However, these tests showed that the susceptibility to this type of corrosion was not increased by the exposure to the wood burning stove environmemt because the corrosion specimens gave the same results after exposure as they had in the sensitized condition prior to the 3 month exposure.

Specimens from both double walled and triple walled chimney sections were tested further using the Huey test to determine the corrosion rate in a ferric sulfate-sulphuric acid solution. The corrosion rate ranged from 369 to 420 mpy for the double walled specimens and from 55 to 162 mpy for the triple walled specimens. These results were the same as for these materials after sensitization but prior to exposure for 3 months in the wood burning stove environments. Therefore, it is concluded that the sensitization heat treatment increases the susceptibility to intergranular corrosion but that exposure to the wood burning stove environment after sensitization does not further increase the susceptibility of these materials to intergranular corrosion.

Evaluation of Type 304 Chimneys Removed From Service: Two entire chimneys were removed from service after an unspecified period of use. These two chimneys were not reported to have experienced any chimney fires. These chimneys, identified by CPSC sample numbers as F-815-3688 and F-815-3689, were both double walled chimneys manufactured by Selkirk Metalbestos Inc. and designated as model 7-SS-30. Five sections of each chimney were obtained. These sections were identified by their location in the chimney, with section one being at the stove end of the chimney and section five being the section above the roof of the house.

Only the inner liner of each chimney section was examined metallographically. Samples from sections nearest the stove and nearest the roof from each chimney were examined to determine the presence of sensitization. Figure 17 shows a representative microstructure after etching with oxalic acid to detect sensitization. No evidence of sensitization was found in the sections of these chimneys which were examined. This indicates that the temperature did not remain for sufficient time in the appropriate temperature range for sensitization to occur (800° F to 1200° F) during normal operation of these chimneys.

Additional samples were taken from each of the five sections from each chimney and examined by optical metallography to determine the extent of any microstructural changes and any corrosive attack during normal operation of the chimneys. Figure 18 shows the typical microstructure from the chimney sections. These chimney sections show a microstructure typical of annealed type 304 consisting of equiaxed grains of austenite containing annealing twins. No significant corrosive attack was found on the surface of the specimens. This examination did not show any significant microstructural changes as a result of the operation of the chimneys.

The two chimneys, one double walled design and one triple walled design, which were used in the CPSC laboratory for exposure of test coupons for 3 and 6 month tests were examined metallographically. The two sections of each chimney nearest the wood burning stove were obtained for evaluation. Specimens from the inner liner of the chimney sections were examined for evidence of sensitization due to the temperature cycle used in the exposure tests. As shown in Figure 19, no evidence of sensitization was found. This indicates that normal wood stove operating cycles will not cause sensitization of the type 304 stainless steel used to fabricate the chimney. Specimens of both double walled and triple walled chimney sections were also examined to assess the extent of any other microstructural changes or corrosive attack that occurred to the inner liner of the chimneys during the six month exposure tests. Figure 20 is representative of both the doubled walled and triple walled chimney section specimens and shows that the microstructure consists of equiaxed grains of austenite, typical of annealed type 304 stainless steel. No significant corrosive attack is noted at the edge of these specimens as a result of the exposure for 6 months to the wood burning stove environment.

Discussion:

Test coupons of type 304 and stabilized type 321 stainless steel were exposed to wood burning stove environments in a typical temperature cycle experienced for normal stove operation for up to six months. All of the type 304 material was heavily sensitized prior to exposure in contrast to the type 321 alloy which is not subject to sensitization. The as-received material for all test coupons and for all chimneys evaluated was typical of annealed, austenitic stainless steel. The mechanical properties, strength and ductility, of the type 304 were not significantly affected by the sensitization or by the exposure to the wood burning stove environments. The material from the particular triple walled chimney sections evaluated had a slightly higher ductility and lower strength than the material from double walled chimney sections. This effect may be attributed to the smaller grain size in the material from double chimney sections than in the material from triple walled chimney sections. No change was observed in the microstructure of any of the materials as a result of the exposure to the wood burning stove environments and to the temperature cycles used in this test program. A minimal amount of surface attack, limited to less than one grain diameter in depth, was the only observed change during the exposure tests or in chimney sections removed from normal service. Sensitized material did not perform significantly differently in these tests than the nonsensitized (stablized) type 321 stainless steel.

Under conditions which may occur in a wood burning stove chimney, the most likely changes in microstructure or mechanical properties in type 304 stainless steel are due to sensitization and oxidation. Sensitization will occur if the stainless steel is heated or slowly cooled within the temperature range of approximately 800° F to 1500° F. This will cause the precipitation of carbides at the grain boundaries which is known to increase the rate of corrosion in an aqueous environment. However, as shown in the tests reported here, sensitization does not result in increased attack in the dry, flue gas environments from the wood burning stove. The effect of sensitization on the high temperature oxidation rate was not investigated here.

The type 304 stainless steel may be subject to degradation by high temperature oxidation in the event of a severe fire in the chimney or due to sustained operation at temperatures in excess of 1500° F. No evidence of significant oxidation nor other attack was found in the present tests in which the temperature cycle was controlled within the normally expected range for a well operated wood burning stove.

Conclusions

From an evaluation of the mechanical properties and microstructure of austenitic stainless steel chimney liners, the following conclusions are reached:

1. The austenitic, type 304, stainless steel test coupons did not show significant degradation and did not show any change in microstructure as a result of exposure for up to 6 months to wood burning stove environments and temperatures used in these tests.

2. No significant change in mechanical properties, such as embrittlement, was found in the type 304 stainless steel as a result of sensitization or exposure to particular controlled wood burning stove environments used in these tests.

3. Sensitization prior to exposure did not increase the amount of degradation of type 304 stainless steel in the particular controlled wood burning stove environments used in these tests.

4. Stabilized stainless steel, type 321, did not perform significantly differently than sensitized type 304 in the exposure tests.

Suggested Future Work:

1. Evaluate the presently used test procedures to determine if they adequately assess the design integrity of the chimneys under normal operating conditions and reasonably expected temperature cycles.

2. Evaluate the design and materials degradation of chimney parts other than the inner liners, for example, the spacer brackets.

TABLE I

Chemical Composition (percent)

Material	C	Mn	P	S	Si	Cr	Ni	Other
304 Double Walled	0.06	1.80	0.033	<.005	0.61	19.03	8.43	
304 Triple Walled	0.06	1.53	0.024	0.007	0.54	18.75	8.17	
304 Specification*	0.08 max.	2.00 max.	0.045 max.	0.030 max.	1.00 max.	18.00 / 20.00	8.00 / 10.50	
321 Test Coupons	0.05	1.64	0.022	<.005	0.74	17.00	10.61	Ti=0.38
321 Specification*	0.08 max.	2.00 max.	0.045 max.	0.030 max.	1.00 max.	17.00 / 19.00	9.00 / 12.00	Ti=5xC min.

* From American Iron and Steel Institute Steel Products Manual

TABLE II

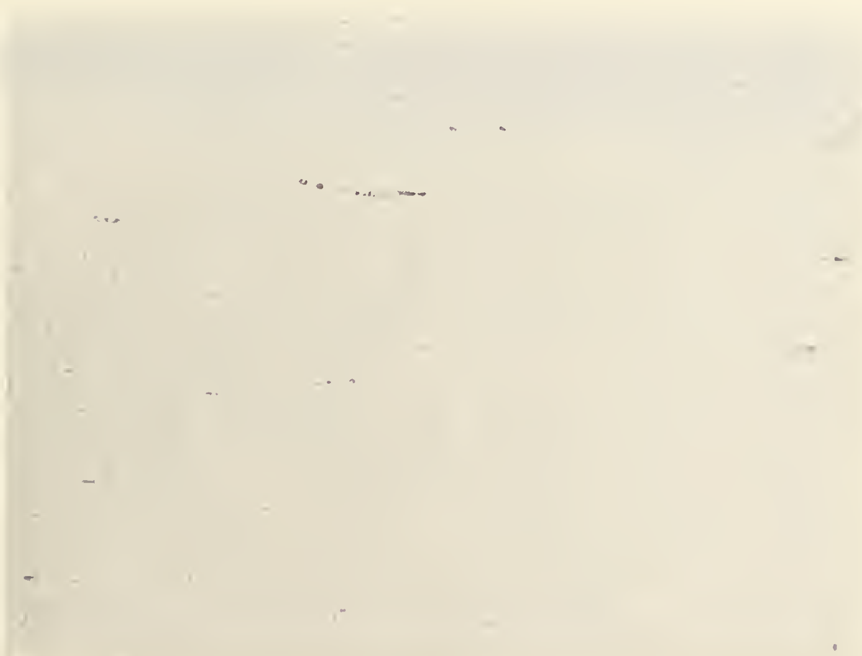
304 Stainless Steel
Tensile Test Results (1)

Material	0.2% Offset Yield Strength (KSI)	Tensile Strength (KSI)	% Elongation
Type 304 Double Walled:			
As Rec'd.	46.8	102.0	44.1
Sens.*	44.8	101.9	37.7
Exposed**	45.8	102.2	47.2
Type 304 Triple Walled:			
As Rec'd.	39.9	92.8	52.4
Sens.*	38.4	93.2	50.1
Exposed**	40.8	96.1	56.4
Typical Annealed Type 304:	35-50	80-105	40-60

*Sensitized at 1000°F for 100 hours
**3-month exposure in CPSC lab tests
(1) Each value represents average of four tensile tests

As-Received Double Walled Material 500X

Fig. 1



As-Received Triple Walled Material 500X

Fig. 2

As-Received Type 321 Stainless Steel 500X

Fig. 3

Double Walled Material After Sensitization 500X

Fig. 4

Edge of Double Walled Material 500X
After Sensitization

Fig. 5

Triple Walled Material After Sensization 500X

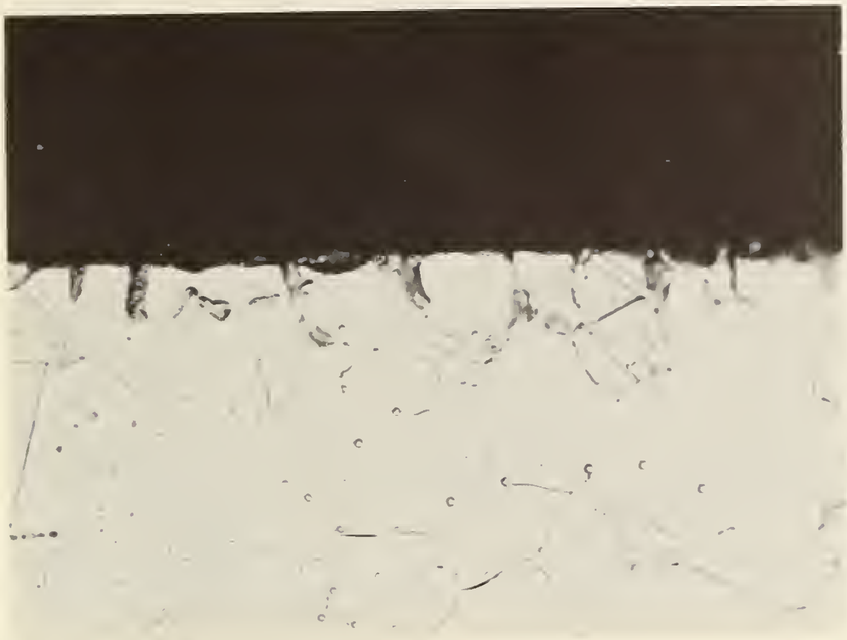
Fig. 6

Through Thickness Section of Triple Walled 200X
Material After Sensitization

Fig. 7

Triple Walled Material - Chimney Sensitized 500X

Fig. 8



Edge of Triple Walled Material 500X
After Sensitization
Fig. 9

Type 321 Stainless Steel After Sensitization Heat Treatment

Fig. 10

Double Walled Material After Exposure 1250X

Fig. 11

Edge of Double Walled Material After Exposure 500X

Fig. 12

Triple Walled Material After Exposure 1250X
(As Polished)

Fig. 13

Edge of Triple Walled Material After Exposure 500X

Fig. 14

Edge of Triple Walled Material After Exposure 500X

Fig. 15

Type 321 Stainless Steel After Exposure 500X

Fig. 16

Type 304 Chimney Section from Field Showing Carbides 500X

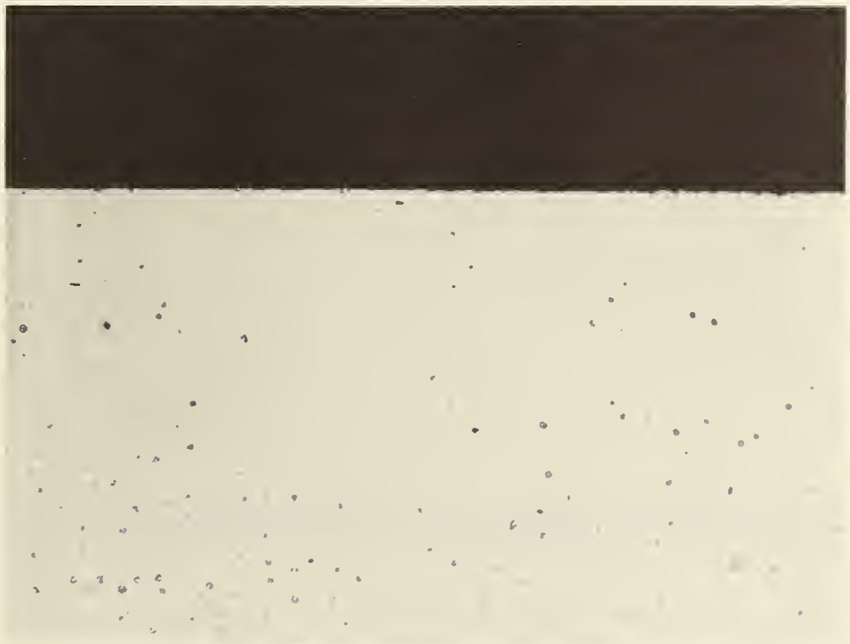
Fig. 17

Edge of Type 304 Chimney Section from Field 500X

Fig. 18

Type 304 Chimney from Lab Tests 500X
Showing Carbides

Fig. 19



Edge of Type 304 Chimney Section 500X from Lab Tests

Fig. 20

NBS-114A (REV. 2-8C)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 85-3103	2. Performing Organ. Report No.	3. Publication Date April 1985

4. TITLE AND SUBTITLE

METALLURGICAL EVALUATION OF TYPE 304 STAINLESS STEEL EXPOSED TO WOODBURNING STOVE FLUE GASES

5. AUTHOR(S)

John H. Smith

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

Engineering Laboratory
Directorate for Engineering Sciences
Consumer Product Safety Commission
5401 Westbard Avenue, Washington, DC 20207

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A metallurgical evaluation was conducted to evaluate the susceptibility of Type 304 Stainless Steel to degradation in woodburning stove flue gas environments. The Type 304 Stainless Steel did not show significant degradation when exposed to flue gas environments for up to six months. No significant change in the degree of degradation was found when the 304 stainless steel was sensitized.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Austenitic stainless steel; corrosion; flue gas; metallic chimney; stainless steel; woodburning stove chimney

13. AVAILABILITY

☐ Unlimited
☒ For Official Distribution. Do Not Release to NTIS
☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
☐ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

15. Price