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Patron: Steven Vitto

Journal Title: ASTM bulletin /

Volume: **Issue:**
Month/Year: October 1957 **Pages:** 46-52

Article Author: A.W. Dana

Article Title: Stress-Corrosion Cracking of Insulated Austenitic Stainless Steel

Imprint: Philadelphia, Pa. ; The Society, 1940 19

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Stress-Corrosion Cracking of Insulated Austenitic Stainless Steel*

By A. W. DANA, JR.

The phenomenon of stress-corrosion cracking which may occur when austenitic stainless steels are exposed to moist thermal insulating materials is believed to result from the action of water-soluble chlorides leached from the insulations. Chemical analyses showed that water-soluble chlorides are present in 85 per cent magnesia, calcium silicate, and glass fiber insulating materials, with little difference in chloride level between them. Simulated service tests indicated that 85 per cent magnesia insulation had the greatest tendency to produce cracking at 100 C. After 200 days of exposure, no statistically significant difference in cracking tendency was present between calcium silicate and glass fiber insulations.

AUSTENITIC stainless steels may be defined as those chromium-iron alloys to which sufficient nickel has been added to retain the austenite phase[1] at ambient temperatures. These steels are used throughout the chemical industry because of their excellent resistance to chemical attack. However, failures of austenitic stainless steels by stress-corrosion cracking can occur when certain conditions of stress and environment are present.

Stress-corrosion cracking of austenitic stainless steels is often associated with chloride-bearing environments and the presence of stress, residual or applied. The corrosive environment by itself usually produces only mild general corrosion. However, under the influence of stress, the corrosion concentrates along relatively few paths, and penetration of the steel becomes rapid. Thus, stress-corrosion cracking causes equipment to fail much sooner than by corrosion alone, and at stresses that, by themselves, would not be damaging.

A number of investigators (**1, 2, 3, 4, 7**)[2] have described failures of austenitic stainless steel equipment by stress-corrosion cracking. The exposure conditions under which these failures occurred vary widely, from city water to industrial process media. In all cases, the failed part had been subjected to stress. This discussion is concerned with the specific case (**2**) where thermal insulation was used over austenitic stainless steel piping or tubing operating at temperatures from 50 to 110 C, and the insulation became wetted. This cracking has been attributed to the action of water-soluble chlorides leached from the insulation (**2**).

The leaching process can be visualized by reference to Fig. 1. The water for the leaching action can originate as rain

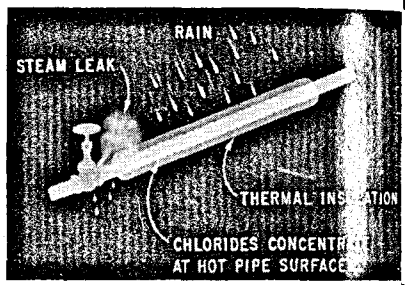


Fig. 1.—Illustration of factors involved in stress-corrosion cracking under thermal insulation.

ARTHUR W. DANA, JR., research project engineer at the E. I. du Pont de Nemours & Co. Engineering Department's Engineering Research Laboratory, has engaged in research on the phenomenon of stress-corrosion cracking of austenitic stainless steel since 1954. He is active on the stress-corrosion task force of subcommittee IV of ASTM Committee A-10 on Iron, Chromium-Nickel, and Related Alloys.

* Presented at the Symposium on Thermal Insulating Materials, Philadelphia, Feb. 6, 1957.

[1] Solid solution of alloying elements in gamma or face-centered cubic iron.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper.

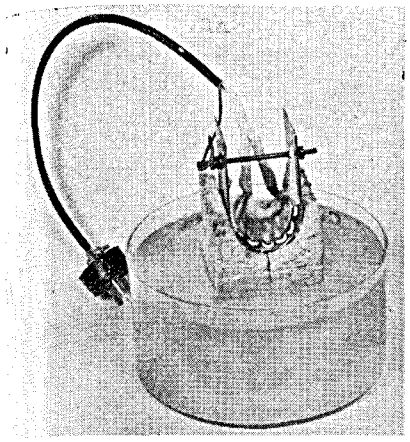


Fig. 2.—Experimental method for determining tendency of insulation materials to stress corrosion crack austenitic stainless steels (× 0.5).

water or as a steam leak. The water, on passing through the insulation, leaches out the water-soluble chlorides. At the hot surface of the equipment, the water-soluble chlorides are concentrated by evaporation of the water. In this manner, environmental conditions for stress-corrosion cracking of austenitic stainless steels are established.

At least 40 failures of austenitic stainless steel process equipment within the du Pont Co. have been traced to the thermal insulation. In each case, failure of the piping or vessel was initiated at the surface covered with the insulation. Where chemical analyses of the deposits on the metal surfaces were available, chloride contents as high as 3 to 5 per cent have been found. This is in contrast to less than 0.5 per cent chlorides present in the insulation on a bulk basis. In one instance, an austenitic stainless tower failed after two years' service at 100 C. Stress-corrosion cracking started on the outside of the column about 3 to 6 ft from the top. The tower had been lagged with 85 per cent magnesia insulation and was exposed to rain water.

In the above cases, austenitic stainless steels were specified as the materials of construction because of the corrosive requirements of the process streams. Therefore, substituting an alternate material not susceptible to stress-corrosion cracking in chloride environments was not an acceptable solution to prevent the occurrence of failures unless the corrosion resistance and cost were comparable to stainless steel.

Three types of thermal insulating material are normally used where service temperatures range from 50 to 110 C: 85 per cent magnesia, calcium silicate, and glass fiber. The 85 per cent magnesia insulation material consists of a minimum of 85 per cent by weight of hydrated, basic magnesium carbonate reinforced with mineral fiber. Calcium silicate insulation contains 55 per cent or more by weight of hydrous calcium silicate reinforced with mineral fiber. Glass fiber insulations usually are silica glass fibers reinforced with a resin binder. These three materials were studied in the present investigation.

The primary objective of the experimental program was that of determining whether moist samples of 85 per cent magnesia, calcium silicate, and glass fiber insulating materials would cause stress-corrosion cracking of austenitic stainless steels. As a necessary adjunct to this program, the chloride contents of samples of the three insulating materials were determined.

Material and Procedure

Chloride analyses were performed by an independent testing laboratory employing standard gravimetric techniques. Unused insulation samples were obtained in box lot quantities from as many sources as possible. Both the edge and center of the block and pipe insulation samples were analyzed for total and water-soluble chlorides.

After completion of a test, samples of the surface residues were scraped from the stainless steel specimens and analyzed for their chloride contents.

In the test method, Fig. 2, the block of insulation acts as a wick, drawing the deionized water up from the dish to the specimen surface. Water-soluble chlorides are leached from the insulation as the water travels from the dish to the specimen. At the specimen surface, the chloride concentration of the water solution is increased by evaporation, in many cases to dryness. Specimen temperatures are controlled to within ±3 C by varying the current flow through the resistance heater which is taped to the curved portion of the specimen. Power input is controlled by a transformer. The U-bend specimen is stressed by tightening the bolt assembly.

Annealed 16-gage ($\frac{1}{16}$-in. thick) type 304 stainless steel (0.06 carbon, 0.54 silicon, 0.59 manganese, 18.32 chromium, 8.97 nickel) sheet stock was used for the U-bend specimens. Specimens 2 in. wide by 7 in. long were sheared from the sheet with the 7-in. dimension taken parallel to the rolling direction. The sheared edges and one flat surface were ground wet on a 80 grit belt (the ground surface was exposed to the insulation). A 1-in. radius bend was placed in the center of the specimen utilizing a precision bender. The head of the bending machine was modified so that a roller did the bending rather than a friction arrangement which is normally used. In this manner, scratching and scoring were minimized. A jig was used for drilling the holes and to check that specimens had been uniformly bent.

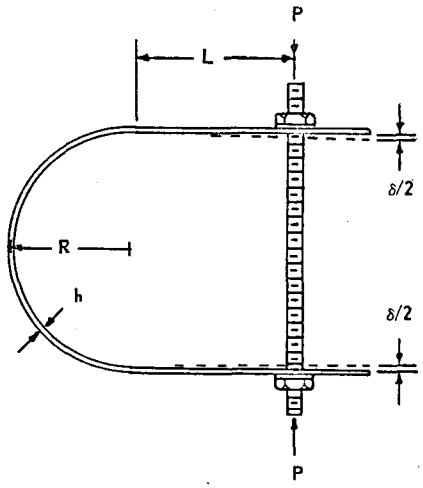


Fig. 3.—Measurements required for deflection calculations.

$$\delta = \left[\frac{12S(2R+h)}{(L+R)(8R+h)(h)(E)}\right] \cdot \left[\frac{L^3}{3} + R\left(\frac{\pi}{2}L^2\frac{\pi}{4}R^2 + 2LR\right)\right]$$

δ = Deflection, in.
S = Applied stress, psi
E = Modulus of elasticity, psi
R = Radius of bend, in.
h = Thickness, in.
L = Length straight section, in.

A maximum stress of 30,000 psi at the apex of the bend was chosen for the entire experimental program. This stress is approximately 95 per cent of the yield strength of the annealed type 304 stainless steel. The necessary deflection to induce this stress at the bend was calculated by means of a formula derived from the theory of elasticity. Deflections were measured from the rest position of the U-bend specimen. The formula is given below and the measurements needed in Fig. 3.

$$\delta = \left[\frac{12S(2R+h)}{(L+R)(8R+h)(h)(E)}\right] \left[\frac{L^3}{3} + R\left(\frac{\pi L^2}{2} + \frac{\pi R^2}{4} + 2LR\right)\right]$$

where:

δ = deflection, in.,
S = applied stress, psi,
E = modulus of elasticity, psi,
h = thickness, in.,
R = radius of bend, in., and
L = length of straight portion, in.

Calculations of the deflections are obviously long and tedious. By using fixtures and employing careful bending procedures, it was possible to bend specimens to close tolerances. As a result, it

TABLE I.—CHLORIDE ANALYSES[a] OF INSULATIONS.

Manufacturer	*Total Chlorides*		*Water Soluble Chlorides*	
	Edge	Center	Edge	Center
85 PER CENT MAGNESIA				
A	0.17 to 0.23	0.10 to 0.25	0.13 to 0.22	0.05 to 0.22
B	0.15 to 0.22	0.10 to 0.24	0.12 to 0.20	0.05 to 0.21
C	0.22 to 0.26	0.21 to 0.25	0.19 to 0.25	0.20 to 0.24
D	0.44 to 0.55	0.45 to 0.54	0.35 to 0.46	0.33 to 0.51
E	0.27 to 0.33	0.09 to 0.33	0.27 to 0.32	0.05 to 0.32
F	...	0.05 to 0.10	...	0.03 to 0.09
CALCIUM SILICATE				
G	0.42 to 0.47	0.43 to 0.48	0.38 to 0.44	0.40 to 0.45
H	0.21 to 0.29	0.04 to 0.25	0.20 to 0.22	0.04 to 0.22
I	0.16 to 0.33	0.15 to 0.33	0.15 to 0.32	0.15 to 0.32
J	0.18 to 0.19	0.06 to 0.20	0.16 to 0.18	0.02 to 0.17
K	...	0.08 to 0.19	...	0.04 to 0.18
L	...	0.05 to 0.13	...	0.02 to 0.11
GLASS FIBER				
M	0.29 to 0.33	0.27 to 0.32	0.03 to 0.06	0.03 to 0.10
N	0.33 to 0.42	0.30 to 0.40	0.26 to 0.33	0.24 to 0.29
O	0.12 to 0.14	0.11 to 0.15	0.09 to 0.10	0.08 to 0.10
P	...	0.05 to 0.55	...	0.01 to 0.50
Q	...	0.10 to 0.13	...	0.06 to 0.10
R	...	0.10 to 0.19	...	0.09 to 0.15

[a] Per cent by weight, dry basis, as chlorides.

was necessary only to recheck these measurements every 5 specimens to insure uniformity.

The use of a U-bend specimen places limitations, which have been described by other investigators (6), on the test method. However, its application here is to screen environments, the thermal insulation materials, for tendency to promote stress-corrosion cracking. For this purpose, the test is believed adequate and has the advantage of low cost and permits running many tests simultaneously.

Specimens have been exposed at 100, 80, 60, and 40 C. The results at 100 C have been nearly completed and, therefore, comprise the major portion of the data presented. However, preliminary results at the other temperatures are included.

During each test, the incidence of cracking was observed as a function of exposure time. Specimens were checked each day during the first few weeks of exposure and then at longer time intervals. Specimens were examined using a binocular microscope at magnifications up to 50 diam. Cracking was predominately associated with black or reddish black deposits (corrosion products) along the cracks.

Deionized water which contained no measurable amounts (<0.05 ppm) of chlorides was added to the dishes twice daily. The average daily consumption of water was 1500 ml for the 85 per cent magnesia and calcium silicate and 2000 ml for the glass fiber samples.

Results and Discussion

Chloride Analyses

Chloride analyses of the three types of insulation studied are listed in Table I. In each case, ranges of chloride contents are given since samples were obtained from more than one source for a given type and supplier. No significant difference was noted in the chlorides present in the edge and center of the block or pipe samples. On the other hand, considerable variations were present for different samples from a given manufacturer and between manufactures of each type of insulation material.

The results of the chloride analyses are summarized in Table II. Comparing the three insulation types, two points are evident: (1) all of the thermal insulations analyzed contained water-soluble chlorides, and (2) for practical purposes, there was very little difference in the ranges of chloride contents for the three types. These data emphasize the necessity of defining the relative susceptibility of austenitic stainless steel to stress-corrosion cracking as a function of exposure to the various insulating materials.

TABLE II.—SUMMARY OF CHLORIDE ANALYSES[a]

Insulation Type	Range in Water-Soluble Chloride	Average Water-Soluble Chloride Content
85 per cent magnesia	0.05 to 0.51	0.16
Calcium silicate	0.02 to 0.45	0.17
Glass fiber	0.01 to 0.50	0.17

[a] Per cent by weight, dry basis, as chlorides.

Preliminary Cracking Tests

Preliminary tests were conducted at 100 C specimen temperatures to evaluate the tendency of the various insulating materials to cause stress-corrosion cracking of type 304 austenitic stainless steel (standard material for this investigation). For these tests, the apparatus shown in Fig. 2 and previously described was used. The data from these tests are summarized in Table III.

In Table III note that of the six 85 per cent magnesia insulations tested, five produced cracking. In contrast, only two of the five calcium silicate insulations tested caused stress-corrosion cracking of the type 304 stainless steel specimens. Both specimens exposed to

TABLE III—PRELIMINARY STRESS-CORROSION CRACKING TESTS AT 100 C.

Insulation Type	Manufacturer	Exposure[a] Time, Days	Results	Chloride Content New Insulation, per cent by Weight	Chloride Content Deposits Scraped from Specimens, per cent by Weight
85 per cent Magnesia	A	266	Cracked	0.05 to 0.22	0.41 (8.1)
85 per cent Magnesia	B	7	Cracked	0.05 to 0.21	0.33
85 per cent Magnesia	C	44	Cracked	0.20 to 0.24	1.83
85 per cent Magnesia	D	160	No cracks, Pitting	0.33 to 0.51	0.43
85 per cent Magnesia	D	218	Cracked	0.33 to 0.51	...
85 per cent Magnesia	E	160	No cracks, Pitting	0.05 to 0.32	0.85
85 per cent Magnesia	F	39	Cracked	0 03 to 0 09	0 34
Calcium silicate	G	204	Cracked	0.40 to 0.45	1.22
Calcium silicate	H	160	No cracks	0.04 to 0.22	0.25
Calcium silicate	I	162	No cracks	0.15 to 0.32	0.34
Calcium silicate	J	162	No cracks	0.02 to 0.17	0.20
Calcium silicate	L	96	Cracked	0.02 to 0.11	0.51
Glass fiber	P	9	Cracked	0.01 to 0.50	...
Glass fiber	P	348	Cracked	0.01 to 0.50	...

[a] If specimen cracked, days for cracking to occur listed. Where no cracking was observed, test terminated at indicated exposure time.

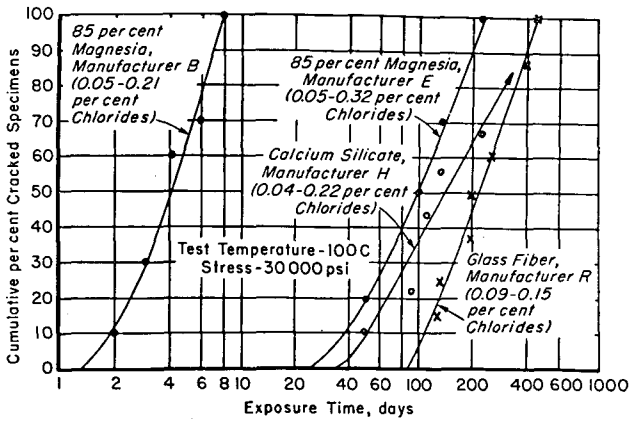


Fig. 4.—Multiple cracking tests on type 304 stainless steel specimens exposed to samples of three types of insulation.

the one manufacturer's glass fiber insulation were cracked. The fact that for both the 85 per cent magnesia and calcium silicate insulations some manufacturers' insulation caused cracking, while others did not, suggested that differences in cracking tendency exist between sources of a given insulation type. This difference cannot be rationalized by comparing the chloride analyses of the insulations. The 85 per cent magnesia insulations that did not cause cracking within 160 days exposure time contained the highest chloride contents, up to 0.51 per cent. On the other hand, one manufacturer's insulation that did crack the stainless specimen within 39 days contained the lowest amount of chlorides—0.03 to 0.09 per cent. Similar results were obtained on the calcium silicate insulation.

Considering now the variations in cracking times observed among samples of the three insulation types, the time for cracking for the 85 per cent magnesia insulations varied from 7 to 266 days, while that for the calcium silicate ranged from 96 to 204 days where stress-corrosion cracking occurred. The one glass fiber insulation caused cracking in 8 to 348 days. While not conclusive, these results indicated that differences in cracking behavior may exist between the three types of thermal insulation.

No correlation was apparent between the chloride contents of the deposits scraped from the specimens after termination of the tests and the incidence of cracking. The relatively low chloride concentrations found in the deposits probably reflected dilution effects caused by particles of the insulation sticking to the specimen. In one case (85 per cent magnesia from manufacturer A), it was possible to obtain a sample adjacent to the cracked area free from appreciable amounts of insulation. This sample contained 8.1 per cent chlorides *versus* a bulk average for the deposit of 0.41 per cent. The data for the chloride contents of the surface deposits given in Table III indicated that chlorides were concentrated at the specimen surface to a level higher than that present in the insulations. However, the actual chloride analyses were not directly comparable with each other as a result of errors involved in sampling.

While these preliminary results indicated that differences in cracking behavior may exist between the three types of thermal insulation and between sources of a given type, the question was posed whether these differences were real or due to scatter inherent in the test procedure.

Multiple Cracking Tests

To statistically check the differences in cracking behavior noted in the preliminary tests, 10 duplicate tests were run at 100 C specimen temperatures with selected samples of each insulation type. The results are summarized in Fig. 4. The 85 per cent magnesia insulation from manufacturer B was chosen because this insulation produced cracking of the type 304 stainless steel specimens within the shortest period in the preliminary tests. The other three insulations were selected for two reasons: (1) their chloride contents were comparable, and (2) neither the 85 per cent magnesia insulation from manufacturer E nor the calcium silicate insulation from manufacturer H caused cracking in the preliminary tests.

The curves in Fig. 4 were obtained by plotting the number of cracked specimens in cumulative per cent as a function of test time measured in days. Consider the curve for the 85 per cent magnesia insulation from manufacturer B. After 3 days exposure time, 3 of the 10 specimens had cracked. After 6 days, 5 more specimens had cracked or a total of 8 specimens. All 10 specimens were cracked in 8 days.

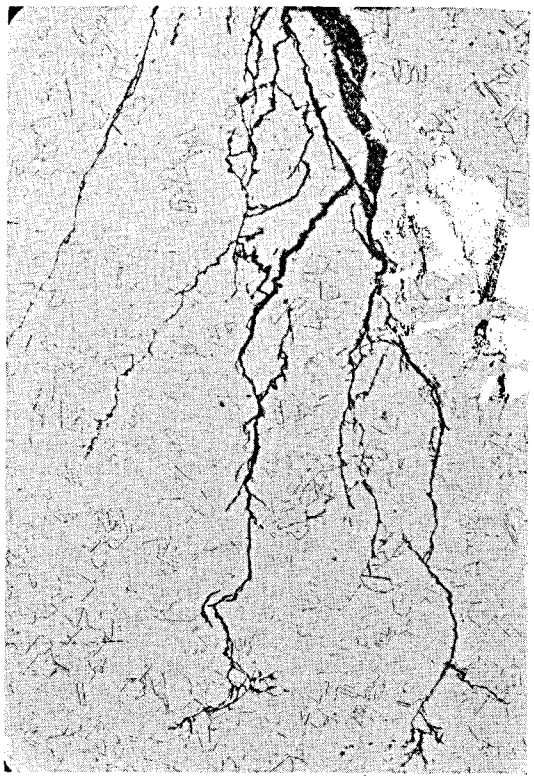
The positions of the four curves from left to right show the relative cracking tendency of the four insulation materials. For example, the 85 per cent magnesia insulation from manufacturer B obviously has the strongest cracking tendency. Comparing now the two 85 per cent magnesia insulations from different manufacturers, a significant difference in cracking behavior is noted. This behavior is not related to the chemical contents of the two materials, for chemical analyses did not show any significant differences in chemical content. In fact, the chloride content of the 85 per cent magnesia insulation from manufacturer B on the average was lower than that from manufacturer E. On the other hand, the chloride contents of deposits scraped from four of the ten U-bend specimens tested were consistently higher for the insulation from manufacturer B which caused cracking in the shortest exposure time. The analyses were 4.20, 3.00, 20.00 and 1.60 per cent by weight *versus* 1.07, 0.86, 0.51, and 1.20 per cent for insulation E. These analyses suggest that chlorides are more readily leached from the 85 per cent magnesia exhibiting the shortest cracking time. Why this is the case is not clear.

Turning now to the curves for the calcium silicate and glass fiber insulations, a statistically significant difference in cracking tendency is noted up to 100 days exposure time. At longer times, this difference becomes less pronounced.

The data shown in Fig. 4 indicate that all three types of thermal insulation, 85 per cent magnesia, calcium silicate, and glass fiber, will cause cracking of austenitic stainless steels if the insulation becomes wetted and the exposure time is sufficiently long. No correlation is apparent between the time for cracking and the chloride content of the three insulation types. The presence of water-soluble chlorides appears to be a sufficient condition for cracking.

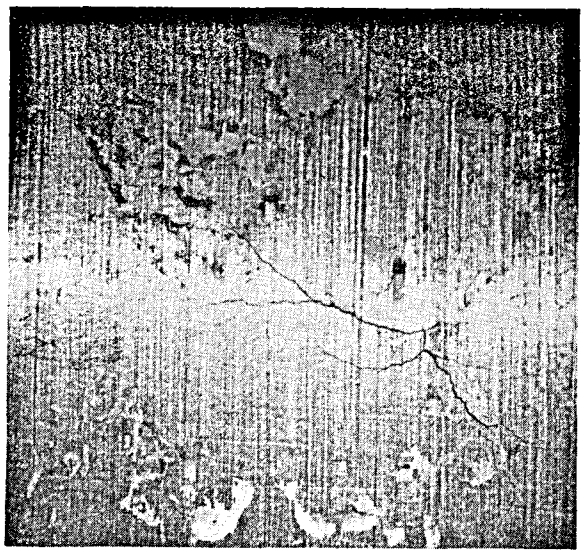
To evaluate further whether the presence of chlorides in the insulation is necessary for cracking to occur, a block of the 85 per cent magnesia insulation from manufacturer B was soaked in a solution of silver nitrate. Silver chloride is only slightly soluble in water ($<1\times10^{-6}$g per ml). After treating with silver nitrate, no cracking has been observed after 264 days exposure. The untreated blocks caused cracking in 8 days or less under the same conditions. Thus, the presence of water-soluble chlorides must be considered a major factor contributing to the stress-corrosion cracking of austenitic stainless steel by moist thermal insulation.

(*a*) Appearance of cracks on surface of specimen (×6).

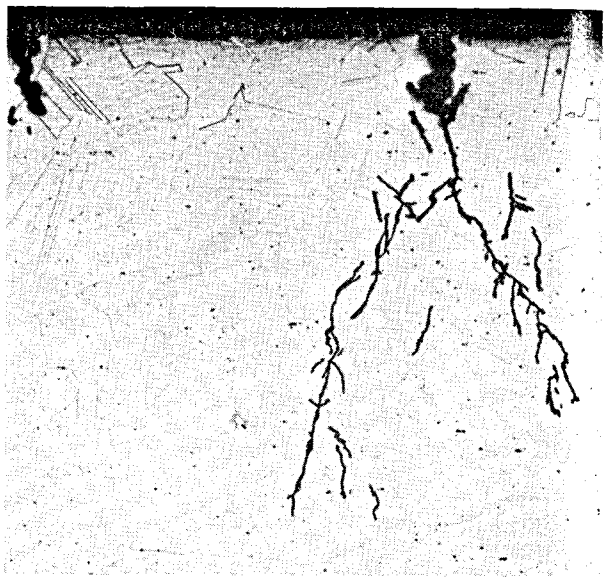


(*b*) Aqua regia etch (×100). Cross-section of specimen showing penetration of cracking.

Fig. 5.—Stress-corrosion cracking of type 304 stainless steel specimen exposed to 85 per cent magnesia insulation at 100 C.



(*a*) Surface cracks (×6).



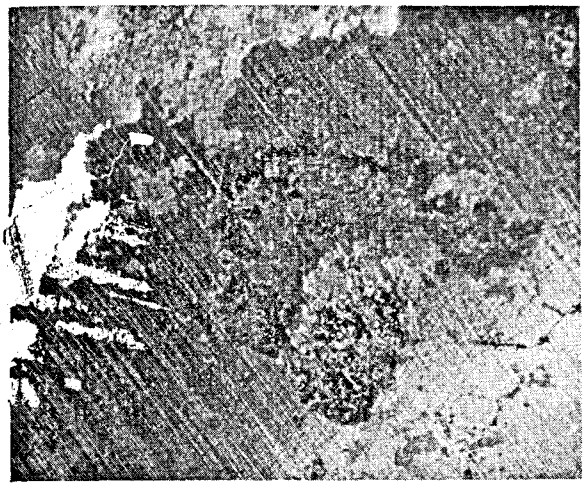
(*b*) Aqua regia etch. Cross-section of specimen. Note branching cracks (×250).

Fig. 6.—Stress-corrosion cracking of type 304 stainless steel specimen exposed to calcium silicate insulation at 100 C.

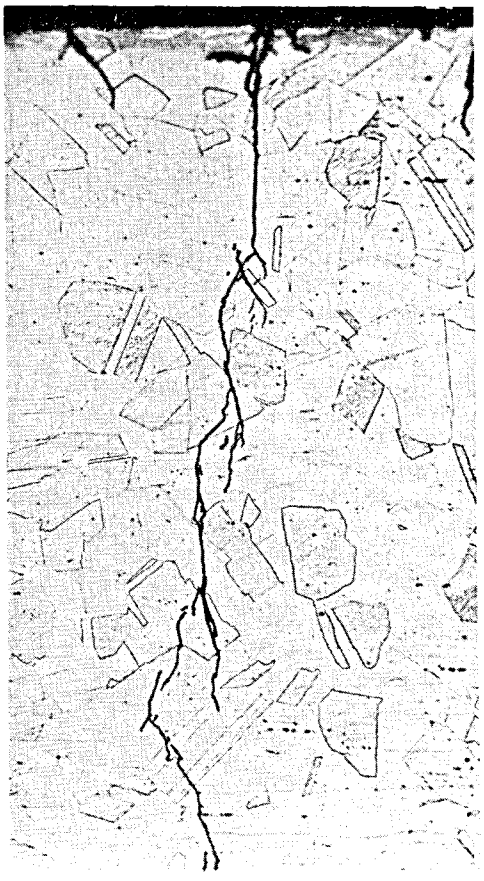
Effect of Specimen Temperature

Temperature has two effects in the present investigation. Temperature has a direct influence on the stress-corrosion cracking process. Hoar and Hines (5) have reported that changes in temperature on the order of 10 C can result in a twofold increase in time to failure of austenitic stainless steels exposed to concentrated $MgCl_2$ solutions. Specimen temperature also will directly influence the rate of evaporation of the water in the experimental method used in this investigation. The rate of evaporation not only controls the concentration of chlorides at the specimen surface but also the amount of water drawn through the block of insulation. This latter factor depends on the continual removal of water at the top of the block to provide the driving force for the wicking action.

Experiments are in progress at 80, 60, and 40 C specimen temperatures with the same four insulation materials studied in the multiple cracking tests. Only the 85 per cent magnesia insulation from manufacturer B has caused cracking of the type 304 stainless steel specimens to date. This cracking occurred at an 80 C specimen temperature after 183 days exposure. At 100 C specimen temperature, consistent cracking was



(*a*) Surface cracking. Note pitting associated with cracking (×6).



(*b*) Aqua regia etch. Cross-section of specimen. Note small surface cracks (×250).

Fig. 7.—Stress-corrosion cracking of type 304 stainless steel specimen exposed to glass fiber insulation at 100 C.

observed in 8 days or less on exposure to this insulation material. All of the specimens have been in test for at least 293 days. These preliminary data indicate that temperature has a pronounced influence on the incidence of stress-corrosion cracking of insulated austenitic stainless steel equipment.

Metallographic Examination

The stress-corrosion cracks noted on the surface of the specimens were usually very fine (Figs. 5(*a*), 6(*a*), and 7(*a*)) and often associated with black corroded areas and pitting attack. The cracks are branched and can occur at many sites. On propagating through the cross-section of the specimens (Figs. 5(*b*), 6(*b*), and 7(*b*)), the cracks take a "lightning-like" pattern that is transgranular.

Examination of the surface layers of the specimens after polishing showed that the main cracks often started from areas where preferential corrosion attack had occurred (Fig. 8). These areas of preferential corrosion attack appeared to be slip lines or deformation bands formed in the distorted surface layer of the specimens. After the corrosion had proceeded sufficiently far, a pit-like depression formed from which larger cracks propagated. These data may provide a clue to the mechanism of crack initiation. The relation of the observed preferential corrosion attack

Fig. 8.—Surface of specimen exposed to 85 per cent magnesia insulation. Note main crack starting from corroded deformation lines. Unetched (×1000).

in the surface layers and the crack initiation process will be studied in another program.

Summary and Conclusions

The phenomenon of stress-corrosion cracking which may occur when austenitic stainless steels are exposed to moist thermal insulating materials is believed to result from the action of water-soluble chlorides leached from the insulations. Therefore, the leaching reaction and the mechanism by which chlorides are concentrated at the surface of the specimen or equipment are of primary importance in determining the exposure time required for cracking. Translation of cracking times observed in laboratory tests into service cracking times remains to be done.

The data obtained from chemical analyses and exposing stressed type 304 stainless steel U-bend specimens to samples of 85 per cent magnesia, calcium silicate, and glass fiber insulating materials in a simulated service test indicated the following:

1. Water-soluble chlorides are present in all three types of thermal insulation, with little difference in chloride level between them.
2. No correlation exists between chloride content of the insulating materials and time for cracking of type 304 stainless steel.
3. The 85 per cent magnesia insulation had the greatest tendency to produce cracking at 100 C specimen temperature. After 200 days exposure, no statistically significant difference in cracking tendency is present between the calcium silicate and glass fiber insulations tested.
4. Exposure temperature has a pronounced influence on the incidence of stress-corrosion cracking of specimens in contact with moist insulation materials.

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DISCUSSION

MR. F. N. ALQUIST.[1]—What effect on chloride content would heating in steam for one week have?

MR. A. W. DANA, JR. (*author*).—Steam is an excellent leaching agent. In fact, as I mentioned in the introduction, a considerable number of failures have been experienced in the vicinity of steam leaks. Application of a "steam cleaning" treatment to remove chlorides from insulation materials, however involves the requirement that the chloride be carried out of the insulation with the steam. Whether this could be practically carried out to make chloride-free insulation, I am not prepared to answer.

MR. W. J. SAUBER.[2]—My interest has been primarily in the plastics field. In discussing the variables of stress cracking in stainless steel, we noted they were the same as those we encounter in the environmental stress cracking of plastic materials such as polyethylene or polystyrene. This is in the line of a question and yet somewhat of an offering of some of our experience with environmental stress cracking of polystyrene.

We have tried to develop a test which would account for these same variables which you have encountered also. What we do is vary the stress under controlled conditions until we have reached that point or critical stress above which the material will crack and below which it will not.

I noticed that you stressed a part by bending it in a U-shaped form. We bend the plastic over an elliptical section which, by having a variable radius, produces a variable stress. This varying radius produces a high stress on one end of our so-called bending form and a low stress on the other end, varying proportionately in between. We can then determine the so-called critical stress of the plastic stressed in this manner. We wonder if you have investigated this approach and, if not, am offering this for your use.

MR. DANA.—To date, the question of whether a critical stress exists for the stress-corrosion cracking of austenitic stainless steels remains in doubt. In our work, we were primarily interested in the environment, the thermal insulation, and for that reason have not studied the effect of applied stress.

MR. WILLIAM S. ELLIOTT.[3]—Three commonly used insulating materials of the premolded type have been mentioned as being unsuited for the protection of stainless steel pipe at elevated temperatures. There are many insulating materials which could be molded and which do not contain calcium chloride. Would there be a good market for such products if developed for high-temperature pipe insulation?

MR. DANA.—We have not ruled out product development of new materials as a solution to the problem. However, chlorides are common in nature and we have analyzed materials other than calcium silicate and glass fiber and have yet to find one that did not contain chlorides. One must realize that we are dealing with a situation where a minor constituent of the environment becomes the major constituent contributing to the cracking process. Chloride contents measured in the ppm range can cause the stress-corrosion cracking of austenitic stainless steels. At the same time I am sure that if a chloride-free insulation were produced there would be a market for it.

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