

Stress Corrosion Can Be Controlled

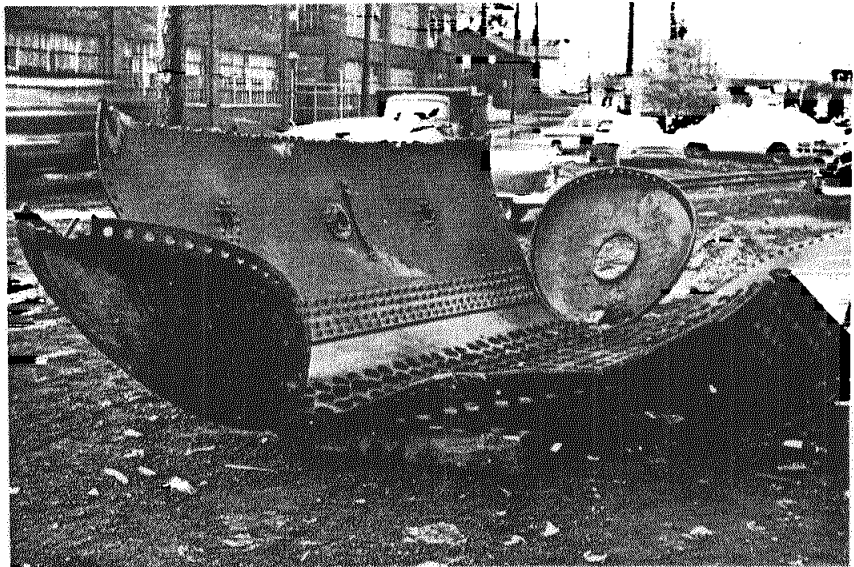
Performance requirements for materials continue to increase with no end in sight. But, at these higher levels, susceptibility to stress corrosion cracking rears its head. Can research meet the challenge?

By N. B. Schwartz and B. D. Wakefield

■ "No form of corrosion has caused more hysteria than stress corrosion cracking." Roger Covert, The International Nickel Co. Inc.'s corrosion specialist spoke straight from the shoulder when Iron Age asked him, "What's behind the sudden interest in this type of failure?"

"Engineers have been living with this type of attack for more than 50 years," says Dr. Covert. "The recent surge in interest in stress corrosion cracking seems to be caused by its emergence in previously untroubled areas. This, of course, has to be coupled with the use of new higher strength alloys in critical applications."

Catastrophic failures resulting from stress corrosion cracking cost industry and government millions of dollars annually. D. E. Carroll, chief metallurgical engineer, Factory Mutual System, Norwood, Mass., a company



A 1957 boiler explosion was attributed to caustic embrittlement in the shell at a riveted longitudinal seam. Proper water treatment has greatly minimized this hazard. In fact, failures of this kind are now rare.

which insures structures against failures, put a dollar sign on some stress corrosion related failures.

Under his classification of stress corrosion failures, he includes anodic dissolution, hydrogen embrittlement and caustic embrittlement. Each of these failures is the result of the interaction of a corrosive environment and tensile stress.

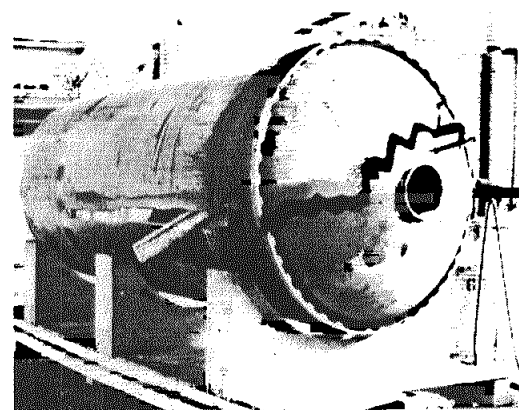
Who's Affected? One documented case of stress corrosion cracking refers to an expansion

joint which failed as part of an underground, high-pressure steam line. The joint, made of type 321 stainless steel, had a 10-in. diam and 0.049-in. wall thickness. It failed after 22 months of service, resulting in repair costs of \$200,000.

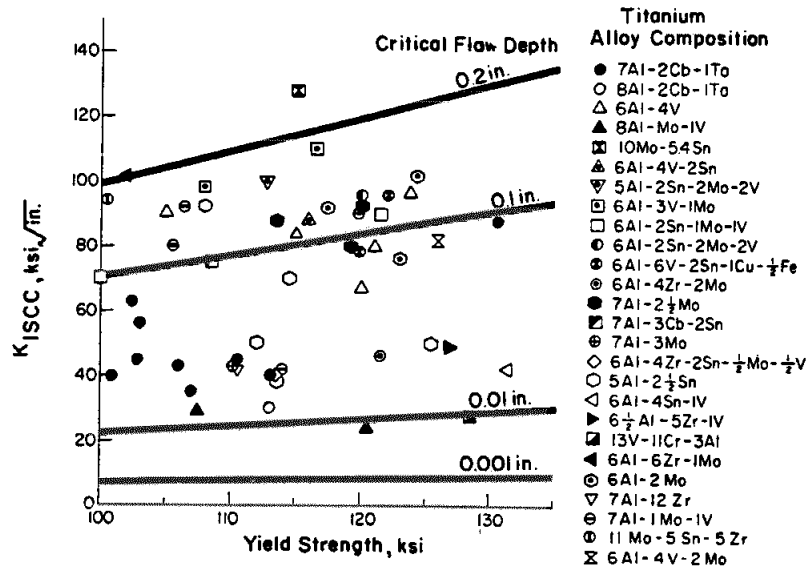
Failure of an 8-in. diam carbon steel pipe attached to the outlet of an ammonia processing unit resulted in seven days of lost production. Downtime here cost a company \$10,000 per day. Replacement of the pipe cost \$7000. The final bill of \$77,000 was attributed to a failure caused by hydrogen embrittlement.

Another claim concerned a

Tap water proved to be a dangerous medium for pressure testing rocket motor cases. Failures, four in all, cost \$160,000 before it was solved.



Avoid Titanium Alloy Susceptibility



Source: B.F. Brown, NRL

Utilization of available design information permits use of susceptible alloys. But, attention must be paid to tensile stresses for failures to be avoided.

180 psi steam boiler built in 1921. It exploded in 1957, killing one person and leveling a plant. Replacement of the boiler, which failed because of caustic embrittlement, cost \$600,000. No price tag can be put on the loss of life, lost production or plant reconstruction.

As one of International Nickel Co.'s Development and Research Department's corrosion specialists, Dr. Covert is exposed to queries on stress corrosion daily. His acquaintance with the problem crosses all industry boundaries and engineering disciplines.

He feels, "in many cases the solution to a stress corrosion problem is an economic rather than a materials problem. Engineers can provide suitable alloys for most applications."

Pinning down who's most affected by stress corrosion failures is another area of controversy. Inco believes the chemical and petroleum industries top the list, followed, perhaps, by aircraft manufacturers. Marine builders, on the other hand, seem to have the problem under control, based

on their requirements.

What's Being Done? But, the fact remains that industry interest in stress corrosion cracking is mushrooming. On one side are companies faced with producing reliable products today. They're forced to take an empirical approach to stress corrosion cracking, and seek immediate solutions to their problems.

On the other side are companies which have the time and funds available to take a theoretical look at the question. This type work often results in development of new techniques, alloy compositions and protective coatings.

The overriding fact about stress corrosion cracking is a lack of awareness of existing data. Failures are caused by the complex interaction of corrosive (environmental) attack and sustained tensile stress at the surface of a metal.

Virtually all materials are "susceptible" under specific conditions, according to the last count. Included are high-strength, quenched and tempered steels,

maraging steels, high-strength aluminum alloys, austenitic and hardenable grades of stainless, titanium alloys, copper base alloys and structural steels.

Fracture Mechanics. One of the more comprehensive approaches to stress corrosion cracking is a program funded with \$3.9 million by the Advanced Research Project Agency (ARPA) of the Department of Defense. Investigations are being carried out at the Naval Research Laboratories, Washington, D.C., under the direction of B. F. Brown, NRL's head of physical metallurgy.

Dr. Brown's work is keyed to the application of fracture mechanics in stress corrosion studies," states Dr. Brown, "allows the engineer to deal with stresses in the presence of flaws."

By using specially prepared specimens, Dr. Brown has been able to reproduce stress corrosion cracks in small pieces of metal in a relatively short time. The evidence obtained from these samples permits him to better predict failures in alloys like precipitation hardening stainless steels, martensitic quenched and tempered steels, aluminum, maraging steels and titanium alloys.

But, current findings could be of little significance in the future. For, as Dr. Brown states, "Stress corrosion problems will become more acute as future applications requiring high strength materials evolve."

Undersea Problem. The use of HY-80 steel in submarines, for instance, has generated no stress corrosion problem for the past 10 years. But, when yield strengths over 150 ksi are called for, stress corrosion cracking will be a definite threat.

Metallurgical developments will have to keep pace with applications. One development, which is not yet commercially

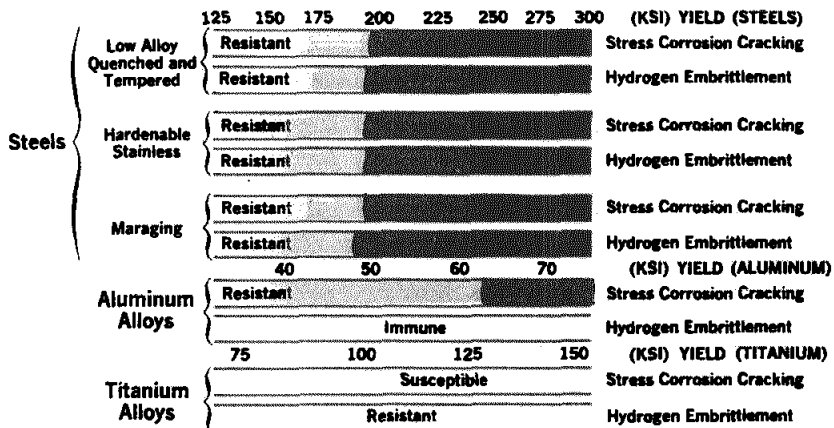
available, could provide some relief. It's a new two phase alloy system for providing immunity to stress corrosion hazards.

But this is only the first step, says Dr. Brown. Before a complete understanding of the stress-corrosion-related failures can be developed, experts in many fields are needed to conduct research. The mechanism is governed by mechanics, chemistry and physical metallurgy.

Aerospace's Answer. Because of its catastrophic implications, stress corrosion cracking is the most dangerous form of corrosion in aircraft design. But, the necessity for producing reliable planes demands work continue within the confines of existing knowledge.

As a result, aircraft builders like Lockheed-Georgia Co., Marietta, Ga., have shifted design emphasis to materials selection. "This," according to W. A. Boggs, Lockheed-Georgia's man

Is Everything Subject To Failure?



Estimated strength ranges for susceptibility to cracking in seawater, fresh water, or humid atmospheres

Recent test data indicates little hope of finding immune metals in our current crop. Metallurgists are pressing to find them. Will they succeed?

responsible for corrosion activities, "is the aircraft designer's most effective tool for preventing corrosion failures."

Close attention is also given to proper orientation of grain structure in components, special machining and heat-treat sequencing, stress relieving, appli-

cation of compressive stress, and coating materials.

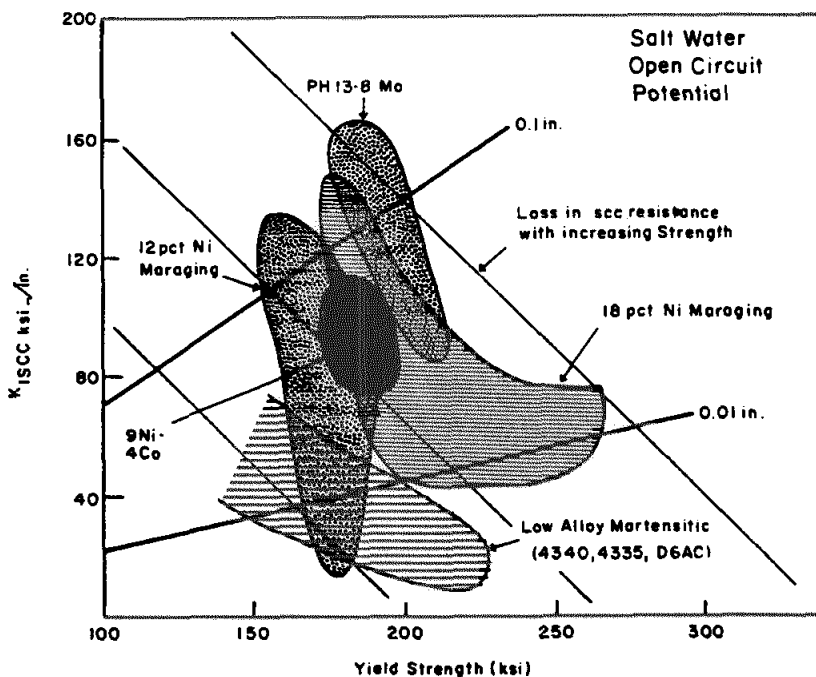
Designing Out Problem. Lockheed-Georgia goes to great lengths to design around stress corrosion problems. They have adopted a policy of designing stress corrosion susceptible parts to a stress level below the stress corrosion threshold.

"This technique," says Mr. Boggs, "is becoming one of the most widely used methods of avoiding stress corrosion cracking." It's also a technique which reflects some of the current work going on in corrosion research.

Aircraft manufacturers have developed a number of methods for working around the stress corrosion barriers. Many relate to steps taken in the fabricating process.

Tensile stress can, for example, be greatly relieved, and in many instances, eliminated, by cold working the surface of a metal. Shot peening is the most widely used mechanical method of introducing compressive stresses and is generally highly effective, according to Lockheed-Georgia. However, shot peening must be used to augment good design practices, not supplant them.

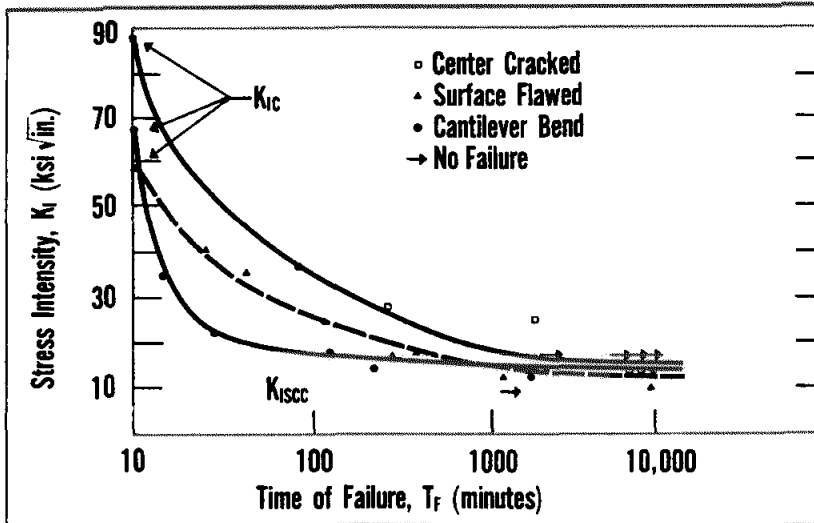
How Do Ferrous Metals Shape Up?



Source: B.F. Brown, NRL

Development of metals to withstand high stress intensity levels goes on. Over the past 10 years, the level has been raised by a factor of four.

Determination of Critical Stress



Design data uses a series of K_{ISCC} determinations at various yield levels. This is for AISI 4340 heat treated to a yield of 225 ksi. Knowledge of stress intensity variation with yield strength level is vital to safe fabrication.

Plate, bar and extrusions with constant cross sections may be stretched after heat treatment to minimize residual stress in the material. This stress relieving process reduces warpage during machining, as well as reducing the tensile stresses within the material.

Shapes with nonuniform cross-sections may not have the tensile stresses completely relieved, or they may be shifted to different directions, thereby presenting a possible stress-corrosion problem if exposed by machining.

Novel Fasteners. A promising way of controlling the magnitude and direction of stress imposed by interference, tapered fasteners has also been experimented with by Lockheed-Georgia. This technique utilizes an elliptical, tapered fastener instead of the conventional round shank taper.

By using an elliptical fastener it is possible to prestress the material in a plane parallel to the load direction for fatigue enhancement, and induce minimum tensile prestress across the short transverse material to avoid stress corrosion cracking in the plane. Titanium fasteners are also con-

sidered a major breakthrough in corrosion control of fasteners and aluminum structures joined with these fasteners, due to the remarkable galvanic compatibility of titanium with most other metals, including aluminum.

Coatings and Sealants. Significant advances have also been made in sealing materials. The Georgia manufacturer realizes, however, that some sealed areas will possibly fail in service leaving a joint vulnerable to corrosive attack.

So, they have supplemented the barrier action of the sealing compound with a soluble chromate inhibitor. The environmental sealing compounds now in use contain 5% magnesium chromate. The inhibitor is incorporated into the uncured sealant, and becomes available to protect the structure if the seal ever breaks down.

It's the inability to equate initial cost, and the aircraft business is extremely competitive, with the lifetime cost of the air vehicle. A case involving use of titanium in wing panels brings the problem into focus.

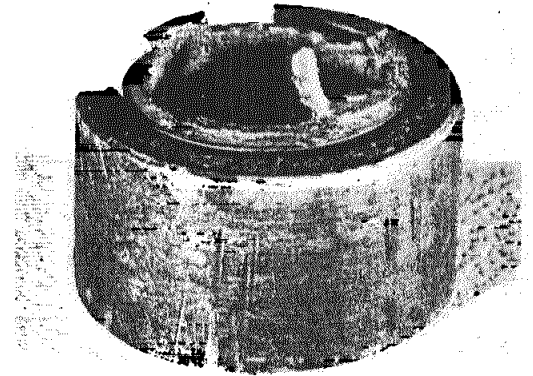
Titanium could virtually elimi-

nate any stress corrosion cracking likely to occur in an aircraft wing panel. But, utilization of this metal in place of aluminum has been delayed due to cost. But, the door is still open.

Titanium wing panels will probably outlive the aircraft on which they are used. When this life expectancy factor is considered, the cost difference takes on a new light.

Engineers in favor of titanium haven't had the time to document the performance of this material. Until they do, they will continue to have difficulty convincing management of its economic and performance advantages.

Mathematical Approach. One attempt to tie down this question



AISI type 316, 3/4-in. diam pipe, failed in 21 to 54 days. Environment cycled between molten sulfur and chloride containing water.

of time has been undertaken by Ted Renshaw of Fairchild Hiller Corp.'s Republic Aviation Div. in Farmington, L.I., N.Y.

His approach is a mathematical one, directed toward establishing an inspection schedule for keeping track of, and measuring stress corrosion crack propagation.

Mr. Renshaw became interested in the subject because of a serious stress corrosion problem

that arose on a large machined forging of 7075-T6 aluminum alloy. The forging was a primary structure for transmitting loads from the wing to the fuselage in fighter aircraft.

"Since a large number of these forgings were installed, it was necessary to establish some procedure with respect to identifying those which are susceptible, inspecting for those that have begun to crack and developing fixes for those which are so detected," says Mr. Renshaw.

In this instance, it was important to prevent cracks from growing large enough to become critical sized under flight loads and break catastrophically. Catastrophic failures did not cause aircraft failure, but the replacement of parts was extremely expensive.

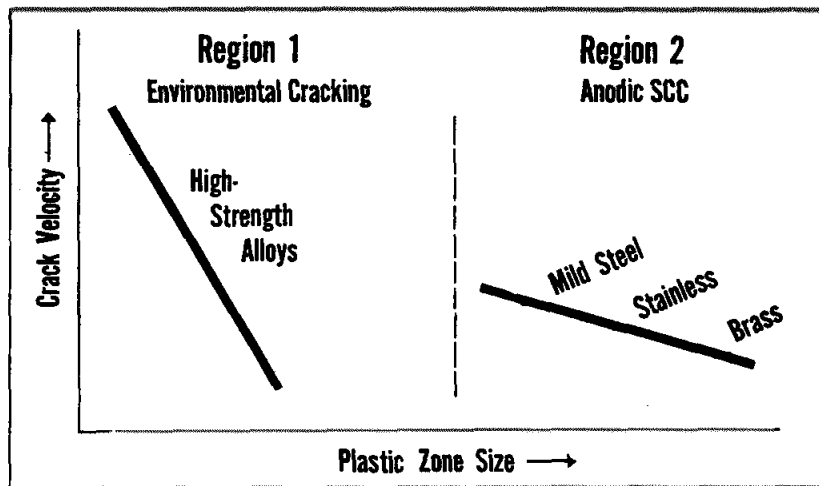
What to Look For. Ultrasonic inspection was proposed since the surface on which the cracks initiated was not exposed to direct view. The question was, "What size cracks should be looked for?" For practical reasons, it was decided to set a target for detecting cracks that were 0.01 in. deep, or deeper.

The next question was, "How often must one inspect, since there must be some discrete time period in which a crack less than 0.01 in. deep can grow to a failing size." To answer this question, Mr. Renshaw developed his mathematical theory which has generated considerable discussion in engineering circles.

But like most stress corrosion data, Mr. Renshaw's work does not provide a clear cut answer to current engineering needs. In fact, his theories exemplify one of the basic underlying questions concerning stress corrosion information.

Work is being done, but not being correlated with the findings of other researchers. According to many stress corrosion specialists,

Metals Are Divided By Two Failure Theories



Environmental Cracking

1. Crack needed to start cycle
2. High cracking velocity (material property)
3. Plane strain (triaxial stress) cause cracking
4. No specific environment for failure (wet air, wet argon H₂, chart paper ink, distilled water, etc.)

■ One group of materials follows the classical anodic dissolution model for stress corrosion cracking (SCC). The other class is not dependent on metal dissolution for crack propagation and ultimate failure. Service requirements of the future demand region 1 materials.

Anodic SCC begins with a pit on the metal surface. The pit acts as a stress raiser to locally exceed the yield strength. If the metal's ductility is high (as with HY-80 steel) the crack tip will tend to blunt, thus preventing propagation and failure. In order to have further propagation,

Anodic SCC

1. Pit forms first
2. Independent of plastic zone size; material
3. Axial tensile stress sufficient for cracking
4. Environment can be predicted to some degree

the tip has to be sharpened (chemically). Failure is the result of intermittent chemical and mechanical action.

Modern, high-strength alloys are faced with failure by "environmental cracking." Hydrogen embrittlement has been found to be responsible in steels with yield strengths over 200 ksi. Precipitation hardening stainless steels, aluminum alloys and titanium alloys may fail by the action of hydrogen or from anodic attack: there is evidence for both mechanisms. Present research is trying to find out. ■

the poor interchange of stress corrosion information between companies and societies is one of the major barriers they face.

It would be an understatement to say stress corrosion cracking is one of the greatest hazards facing metal fabricators in the coming years. But, two factors must be remembered in any discussion on the subject.

Avoidable Problem. Stress corrosion cracking can, in most in-

stances, be avoided. Proper materials selection and machining technique can almost always meet immediate problems.

And, two, a great deal of stress corrosion data is available if manufacturers take the time to look for it and use it. ■