Steel; Failure Analysis

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Weak Link

High-Strength Steel Is Implicated as Villain In Scores of Accidents

Brittleness Is Called a Factor In Car and Plane Crashes, Bridge and Reactor Flaws

Becoming Hip to Titanium

By BILL PAUL
Staff Reporter of THE WALL STREET JOURNAL

On Oct. 26, 1981, pilot Charles Madison Hairston took off from the Mineral Wells, Texas, airport in his Beech Aircraft E-90. He climbed to about 500 feet when, without warning, the plane's left wing fell off. The aircraft plummeted to the ground, killing Mr. Hairston in a fiery crash.

On March 27, 1980, many of the more than 200 oil workers living aboard the Alexander L. Kielland hotel platform in the North Sea were assembled in the movie room waiting for the evening's entertainment when they heard a loud cracking noise. Minutes later, the platform plunged into the sea. That night 123 men perished, the greatest loss of life ever in an offshore drilling-platform accident.

One day in November 1981, a 56-year-old forklift operator in Chester, Pa., began feeling pain in his hip. A few weeks later, while he was on the job, the pain became excruciating. Co-workers helped him off his rig, and he was rushed to a Philadelphia hospital, where surgeons replaced an artificial hip implant that had cracked.

Structural Underpinning

All three of these accidents were caused by the failure of high-strength steel, a key structural underpinning of modern life. Cars and buses, ships and airplanes, pipelines and tanks, oil-drilling equipment, bridges, buildings, nuclear reactors, dams, missiles and even surgical implants contain and rely on high-strength steel. It is called upon to prop up, bolt together, reinforce and otherwise guard against disaster in a multitude of safety-critical applications.

To an alarming degree, it is falling down on the job. Cracked or corroded high-strength steel has grounded jet fighter planes and municipal buses, weakened bridges and caused roofs to collapse. It is a chief suspect in the recent Texas railroad accident that killed four, and in two unexplained crashes of F-111 jets over Vietnam. The steel's flaws caused a rash of automobile accidents and injuries so numerous that General Motors Corp. was forced to recall 5.9 million vehicles in 1981.

Possibly most ominous of all, walls of the steel that shield many of the nation's nuclear reactors are turning brittle; some express worry that a dangerous accident could result. In failure after failure, a pattern has emerged: High-strength steel is far more fragile and temperamental than its name would imply.

"The problem of high-strength steel is pervasive in a wide range of industries," says Geoffrey Egan, the president of Aptech Engineering Services Inc., a Palo Alto, Calif., firm specializing in steel-accident analysis. "There are probably hundreds of high-strength steel failures or costly incidents every year."

Alloys and Heat

For around 30 years, steelmakers have produced high-strength steel by doctoring ordinary steel with certain alloys or treating it with heat. High-strength steel grew out of research during World War II aimed at lessening the cracking of steel used in ships. It was sold as a technological breakthrough, and it caught on quickly because designers saw a way to cut costs by using less steel, while at the same time giving their structures less weight and added strength and durability.

In one early U.S. Steel Corp. ad, a col- [redacted] of high-strength steel was shown beside [redacted]mns of classic Greek design. The cap- [redacted] read: "Greatest column since 426 B.C." [redacted]oday, virtually all sophisticated steelmakers make high-strength steel, and most prominent designers and fabricators work with it frequently.

But high-strength steel's great resistance to weight and stress was achieved by sacrificing much of the ductility, or pliability, found in ordinary steel. The difference between ordinary steel and high-strength steel can be visualized as the difference between a rubber band and a paper clip. Because it is so unyielding, high-strength steel is highly susceptible to cracking, corrosion and brittleness.

Its flaws are all the more pernicious because designers specify its use in precisely those applications where the margin for error is the slimmest. Too often, experts say, manufacturers and users of high-strength steel have misunderstood or ignored its limitations with calamitous results.

Storage-Tank Blast

In Carson, Calif., for example, a 20,000-gallon hydrogen storage tank made of high-strength steel exploded one Sunday morning in 1975. Two people at the Air Products & Chemicals Inc. facility were injured in the blast, which was felt several miles away, and nearly 60% of the plant was destroyed. Had the accident happened on a weekday rather than on a Sunday, many workers might have been killed, one expert says.

A lawsuit stemming from the Carson blast was settled out of court, but not before a Lehigh University metallurgist hired by Air Products co-wrote a report that blamed the accident on cracks in the high-strength-steel tank. The metallurgist, Richard Roberts, says that if any hydrogen is still being stored in tanks made of the same variety of steel, they are "ticking bombs." (Lukens Inc., which manufactured the SA517 grade F

Please Turn to Page 14, Column 1

Weak Link: High-Strength Steel Is Called the Villain In More and More Accidents and Flaws in Structures

Continued From First Page

steel used in the Carson tank, says it doesn't know of any.)

Steel-accident investigators say that mishaps involving the failure of high-strength steel have occurred for as long as it has been in use. Only in the last seven or eight years, however, has accident investigation become sophisticated enough to begin making specific connections between, say, a seemingly isolated plane crash and the collapse of a roof. Previously, many accidents were diagnosed simply as "metal fatigue."

"Twenty years from now, high-strength steel will be considered to have been a lot bigger problem than it is seen to be today," warns Roger McCarthy of Failure Analysis Inc., another Palo Alto accident-analysis firm.

But the alarm being sounded by some engineers, metallurgists and steel companies is being muffled by the litigation that typically follows such accidents. Engineers and other experts say the fear of being sued has made them increasingly closemouthed in discussing why a particular structure failed. Moreover, such suits tend to be settled out of court, with all parties agreeing to keep facts in the case confidential.

Nevertheless, enough accidents and near-accidents involving high-strength steel have come to light to call its reliability into question. Some accidents have resulted in loss of life or injury, as when corroded high-strength-steel wires supporting an auditorium roof in West Berlin failed in 1980, killing one person and injuring three others. At the very least, the incidents have necessitated users to make extensive and costly repairs.

Carolina Power & Light Co. plans to install a special shield around the high-strength-steel vessel walls of its nuclear reactor in Hartsville, S.C. The shield is designed to reinforce the walls, which have become prematurely brittle. Around 20 other nuclear reactors around the country are afflicted with similar brittleness problems, damage that the Nuclear Regulatory Commission says could cause a catastrophic accident if uncorrected. The underlying concern is that in the event of an emergency, cool-down procedures might crack the brittle walls and allow radiation to escape into the atmosphere. Carolina Power says the shield should keep its reactor safe.

Are other brittle reactors safe? "The scary thing is we really don't know," says George Sih, a metallurgist and head of Lehigh University's Fracture Mechanics Institute. Mr. Sih, who also consults for a congressional subcommittee, contends that current testing methods aren't sufficiently accurate to determine the extent of damage to a reactor wall. The public-utility industry strongly disputes his assessment.

Beech Aircraft in Omaha has been underwriting part of owners' costs to replace thousands of high-strength steel bolts on thousands of its planes as a result of the fatal crash in Texas and another near-fatal accident. "We were scared," says William Schultz, the manager of technical engineering. "We ride those planes ourselves, and we have friends who ride them." He adds that "all the testing in the world" failed to turn up the problem—namely, the bolts' tendency to corrode and crack after years of service wore down their protective cadmium coating.

Orthopedic surgeons estimate that in the past decade, perhaps 2,000 hip-implant failures were caused by cracks in high-strength-steel hip joints. The problem is improving, as surgeons join with engineers to design better-quality joints. One solution: Titanium has begun to supplant high-strength steel as the material of choice.

The University of Texas had to replace all 12,000 high-strength-steel bolts in its fieldhouse roof after a 1979 incident in which a two-pound bolt split in two and part of it fell 90 feet, driving a wicked dent into an unoccupied seat in the stands. Bethlehem Steel Corp., which had recently acquired the firm that made the bolts, did the replacement work. Ralph Kristoferson, of the university's office of facilities, planning and construction, swears he will never use high-strength steel again. "We weren't aware that we were taking such risks," he says.

That same year, faulty high-strength-steel bolts were discovered on the General Dynamics Corp. assembly line for the F-16 jet. As a result, the U.S.'s most sophisticated fighter plane was temporarily grounded while the company searched for other defective bolts. The check turned up 25 bad bolts, some of them already in planes. Had they gone undetected, the bolts could have caused planes to crash.

Defective high-strength-steel bolts also prompted General Motors in 1981 to undertake the second-largest car and truck recall in history. Nearly six million vehicles in the U.S. were called back to the factory; after 27 accidents and 22 injuries were attributed to the failure of bolts supporting the rear suspensions of various models made between 1978 and 1981. Of those defective vehicles, GM says 1.4 million hadn't been brought in for repairs two years after the recall notice was sent out.

'A Miracle'

Accident victims reported that their cars collapsed and fishtailed in traffic. David R. McKinney's case was fairly typical. The Upper Darby, Pa., fireman was driving with his wife, daughter and parents on Sept. 2, 1980, when a bolt on his Chevrolet Malibu cracked in two and the car spun out of control and crossed the white line of a two-lane road in southern New Jersey. "It was a miracle nobody got hurt," Mr. McKinney says, noting that the day before had been Labor Day and the same road was jammed with traffic. GM paid Mr. McKinney's repair bill, but not until his car was one of those recalled the following March.

Thomas J. Hughel, a GM metallurgist who investigated the auto maker's problems with steel bolts, frets that no standard test would have detected their susceptibility to corrosion and cracking. The Society of Automotive Engineers still lists this bolt for use, Mr. Hughel observes, adding: "It bothers me. I want to say, 'Don't use it in critical applications.'"

About five million tons of high-strength steel are produced in the U.S. annually. More of it is used in the automobile industry than in any other except construction. Ever since the early 1970s, auto makers have stepped up their use of lightweight high-strength steel in cars to promote fuel efficiency.

Even more would be in use by now were it not for auto makers' concern over poor-quality steel. Officials at Inland Steel Co., a Chicago-based supplier to the auto industry, say that the quality of high-strength steel used in cars needs improvement. In the mid-1970s, says Ian Hughes, an Inland Steel metallurgist, "we were fat, dumb and happy." He explains that as high-strength steel came to be used in increasingly sophisticated designs, the tolerance for even the smallest manufacturing error was shrinking. U.S. steelmakers were slow to recognize "that product quality was becoming absolutely essential," he says.

Losing to Competitors

By contrast, Japanese steelmakers were quick to sense the need for more stringency and improved their steel formulations accordingly. Nippon Steel recently licensed Inland Steel to use a Nippon Steel process that an Inland press release says "raises quality and consistency in high-strength steels to a level previously unattainable." Bethlehem is the only other U.S. steelmaker with this advanced process for automotive steel, Mr. Hughes says.

When it comes to steel quality, Japanese and German steelmakers have sprinted ahead of their American competition by installing state-of-the-art computerized testing equipment at their foundries. Noted British engineer Harry Cotton warns that U.S. steelmakers will be forced out of business if they don't soon narrow the quality gap. "Your accountants don't want to hear about it," he says, "but you've got to start spending more on research and development." U.S. steelmakers have already lost the oil-pipeline business, he adds, to foreign firms selling better-quality high-strength steel.

Quality concerns are being raised in other industries as well. Daniel H. Stone, manager of metallurgy for the Association of American Railroads, says that the German firm Krupp makes a better high-strength-steel rail than do the two U.S. rail manufacturers, Bethlehem and U.S. Steel. Mr. Stone blames the situation on both U.S. steelmakers and the railroads. Neither side, he says, is willing to pay the premium needed to produce and install a top-quality high-strength-steel rail. He maintains that Krupp sells in the U.S. at below cost, a charge that Krupp denies.

Between 20 to 30 rail accidents in the past decade were caused by problems with high-strength-steel rails, Mr. Stone says. They include some of the most severe accidents, because the steel is generally used on curves and in other critical applications.

How U.S. Steel Reassured Customers Even While It Reformulated T-1 Steel

By a WALL STREET JOURNAL Staff Reporter

When U.S. Steel Corp. discovered in the late 1950s that its patented, high-strength T-1 steel was likely to crack in certain safety-critical applications, the company put its engineers to work revising T-1's chemical composition.

While those engineers toiled in private, U.S. Steel took pains to reassure worried customers. Its sales department maintained that the company had proved that the problem was due entirely to steel users' faulty designs or fabrication methods. Never, company salesmen were instructed to say, was the T-1 steel itself at fault.

In 1980, a jury in Tennessee found U.S. Steel and its T-1 licensee, Lukens Inc. of Coatesville, Pa., guilty of "negligent misrepresentation" of T-1 steel. The following year—29 years after T-1 was patented—U.S. Steel added a "CAUTION" to its "How to Weld" T-1 booklet, in effect conceding that the steel was likely to crack in certain situations, no matter how good the design or fabrication methods.

The T-1 story has particular relevance today, given widespread concern over the durability of all types of high-strength steel. Though T-1's formulation eventually was changed and it is little used today, experts worry that some structures fashioned from the original material may still be in use, possibly containing dangerous undetected cracks.

Moreover, internal company documents made public at the Tennessee trial raise troubling questions about how steel-safety problems are resolved and how, in this environment, U.S. Steel chose to put profits ahead of public safety.

U.S. Steel declined to be interviewed for this story, a spokesman saying that T-1 is "an old story." A U.S. Steel attorney suggested to a Lukens attorney that Lukens cancel an interview with this newspaper, but Lukens officials agreed to be interviewed nonetheless.

The 1980 Trial

The 1980 trial involved a dispute over who was to blame for cracks that had developed in parts of a hydroelectric plant's turbine before it went into service. The plant's operator, the Tennessee Valley Authority, and its builder, Allis-Chalmers Corp., blamed the T-1 steel for the damage, known as "stress-relief" cracks. Such cracking can occur when steel is heated after welding to relieve potentially dangerous residual stresses. U.S. Steel and Lukens argued that the damage resulted from improper design and fabrication. The jury faulted both the steel companies for "negligent misrepresentation" of T-1 steel, and the TVA and Allis-Chalmers for negligence that contributed to the problem.

One key trial document is a report of a 1966 U.S. Steel sales meeting in Pittsburgh. By this time, the company's customers and competitors alike were expressing serious reservations about T-1. A salesman asked: "Why do we hear of welding problems with the T-1 steels? And how do we reply to our customers?"

An unidentified respondent answered: ". . . In every case where a fabricator has encountered difficulty in welding the T-1 steels, it has been conclusively proven that the fabricator didn't follow proper welding procedure or the design of the structure itself was faulty. In no case was the steel itself at fault."

The answer was extraordinary, considering U.S. Steel's then years-old research project aimed at eliminating the T-1 cracking problems. It was also important, because customers frequently rely on steel-industry salesmen for information about the proper use of the product.

Modification Sought

In the early 1960s, U.S. Steel researchers recommended that a modified T-1 be marketed for structures of the thicknesses where the cracking problem was worst. But J.R. England, a U.S. Steel metallurgical engineer in the early 1960s, testified at the trial that the new product was shelved in part because "the commercial department was adamantly against the introduction of a more expensive product."

Meanwhile, T-1 customers continued to encounter problems. In 1963, a Lukens official wrote to U.S. Steel, listing some of them. He cited accidents caused by cracks in truck tanks made from T-1 and extensive cracks in storage tanks at Atlas missile bases.

As early as the late 1950s, a respected steel fabricator had identified T-1's high boron content as a primary cause of stress-relief cracking. And in December 1965—a month before salesmen were assured there was nothing wrong with T-1 steel—the company's own engineers reported: "Preliminary results indicate that boron is responsible for cracking in the heat-affected zone after stress-relief."

At the trial, U.S. Steel officials defended their delay in reformulating T-1 until 1973 by stating that the evidence wasn't conclusive. But court documents suggest that the main consideration was U.S. Steel's unwillingness to jeopardize its patent.

A 1962 internal company memo stated that an improved high-strength steel could be made but added that by doing so, "the commercial advantage of having a proprietary steel which has been widely promoted and publicized would be largely lost."

In U.S. Steel's defense, T-1's susceptibility to cracking was noted in technical literature and product brochures read by many fabricators.

Finally, in 1973, U.S. Steel recommended changing T-1's formula. An internal memo from the company's engineering laboratory that year observed that in the original T-1 steel, the boron minimum was set "four times higher than needed," a policy that "was dictated by patentability considerations in 1952." The memo further explained: "Since a lower minimum will help the boron addition problem and since the patent has expired, we can permit our mills and licensees to use it if necessary."

Early this year, the National Transportation Safety Board is expected to issue its report on the cause of last November's Amtrak train wreck in Texas that killed four persons and injured dozens more, some seriously. Investigators have been focusing on a section of high-strength-steel rail that shattered. (Ironically, the rail in question was made by Krupp.)

If problems with high-strength steel often begin at the steel mill, they can be intensified by faulty design. Sometimes, accident investigators say, designers specify high-strength steel without fully considering its limitations.

That appears to have happened in the case of Grumman Corp.'s Flxible bus. The company had to repair hundreds of the buses in dozens of cities after cracks developed in the high-strength-steel underframe and engine cradle. Grumman, enticed by the federal government's offer to pay bonuses for the lightest vehicle possible, apparently placed undue emphasis on the steel's structural integrity without considering whether the steel would be thick or heavy enough to withstand the stress of city streets.

A Grumman spokesman concedes that the federal bidding arrangement provided an incentive to build as light a bus as possible. He says that Grumman has sued Rohr Industries Inc., the bus's designer, charging that Rohr was to blame for the cracks. The case is still pending in a U.S. district court in Uniondale, N.Y.

Designers also appear to be at fault for nuclear-reactor brittleness problems. Because a reactor is so costly to build, designers have tended to rely on computer models, rather than far more costly field testing, to ensure a structure's safety. As a result, the industry was caught off guard when, about 10 years ago, it was discovered that traces of copper found in the steel at weld joints hastened the rate of embrittlement.

While he argues that reactors are safe, William Pellini, formerly the U.S. Navy's chief metallurgist, says that perhaps half of the designers working with high-strength steel "don't know enough to stay out of trouble." He complains that they "haven't been trained to understand fabrication and metallurgy."

Nor have many welders and other fabricators acquired expertise with high-strength steel. Sometimes, experts say, their lack of training causes them to build cracks into the structures they erect.

Poor welding was the principal cause of the Kielland platform disaster in the North Sea, according to the official Norwegian government report. The accident occurred when a high-strength-steel tube connecting two of the platform's legs cracked. The report says the tube had been cracked when it was welded to the leg years before. The fissures had been left to grow, undetected, hundreds of feet below the ocean surface.

Serious welding cracks were built into several major high-strength-steel bridges, including one near New Orleans and one in Paducah, Ky. In 1981, cracks that had eluded detection for 20 years were found in the girders of the New Orleans bridge; an investigator says that eventually the bridge could have collapsed. The cracks in the Paducah bridge were found in 1979, less than a year before the bridge could easily have failed, officials say. The federal government started a mandatory bridge-inspection program several years ago. As a result, it is likely that all high-strength-steel bridges have been inspected by now.