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Failure Analysis of Brass Bolt from Mausoleum

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Brass is usually considered to be a good candidate material for use in a nonaggressive corrosion environment. Brass 260 was used in a rural environment (at a mausoleum) as fixturing hardware that holds etched marble slabs that cover the interment region. After 12 years of service, the bolts began breaking, and the marble slabs crashed to the ground. Failure analysis investigation showed that "seasonal cracking" occurred due to interaction of the bolt with moisture and fertilizer. The company that designed the mausoleum hardware believed that the bolt manufacturer was at fault. However, the only specification given to the bolt manufacturer indicated alloy and dimensions. The bolts were replaced at considerable cost, proving once again that even a seemingly simple component can prove to be costly if not designed by the proper engineer.

Keywords: brass, corrosion, corrosion failure analysis, failure analysis, residual stress, stress-corrosion cracking

Introduction

A company reported that brass bolts used in two mausoleums were failing. Failure of these bolts resulted in crypt-front marble slabs crashing to the ground. Fortunately, no one was present when the slabs fell; thus, no injuries were associated with the failures. However, the probability existed that eventually someone could be injured.

The bolts were manufactured from cartridge brass (C26000) and were beginning to fail after 8 to 12 years of service. Several failed bolts along with several unused bolts were examined. Figure 1 shows an unused bolt with cold-forged nut. Figure 2 shows the assembly drawing.

Results and Discussion

The metallurgical examinations of the bolts included chemical analysis, macroscopic and microscopic examination using optical and scanning electron microscopy, and both tensile and hardness testing.

Chemistry results are presented in Table 1. The bolts P-14 and P-15 were pulled from service, and chemistry results showed that they were Copper Development Association (CDA) 260, except that high iron content was present as compared to the specification for cartridge brass. It has been shown that high iron promotes grain refinement and increases resistance to dezincification.[1]

Fig. 1 *Unused bolt, ⅜ 16 threads per inch by 2¼ in. (9.5 by 57.2 mm) long, with cold-worked nut integral with bolt*

Several fractured bolts were provided from the mausoleums that had been in service for 8 to 12 years. They all exhibited the same fracture appearance, and typical bolts are shown in Fig. 3 and 4. In all instances, the short, threaded end of the bolt fractured at the top of the nut. Table 2 lists the hardness of each bolt. These values were obtained on one end of each bolt. The minimum and maximum values were 82 and 97 R_B, respectively. A sample of blank material was obtained from the bolt manufacturer. The hardness of the blank material prior to final forging was softer, as was expected.

Three unused bolts were tensile tested, and the ultimate tensile strengths were 385, 393, and 394 MPa (55,800, 57,000, and 57,100 psi). These tensile strengths were considerably lower than the

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equivalent tensile strength for 92 R_B hardness (average hardness). Tensile failures occurred in the threaded portion of the bolt; the tensile failure locations were not similar to the failure sites of the used bolts. The low tensile values were related to the fact that the bolt had threads that acted as regions of stress concentration, which lowered the performance of the material.

Table 1 Chemistry Results

Material	Composition, wt.% Cu	Pb	Sn	Fe	Zn
P-14	70.10	0.06	<0.01	0.13	bal
P-15	70.30	0.04	<0.01	0.09	bal
Specification of CDA 260 (cartridge brass)	68.5-71.5	<0.07	...	<0.05	bal

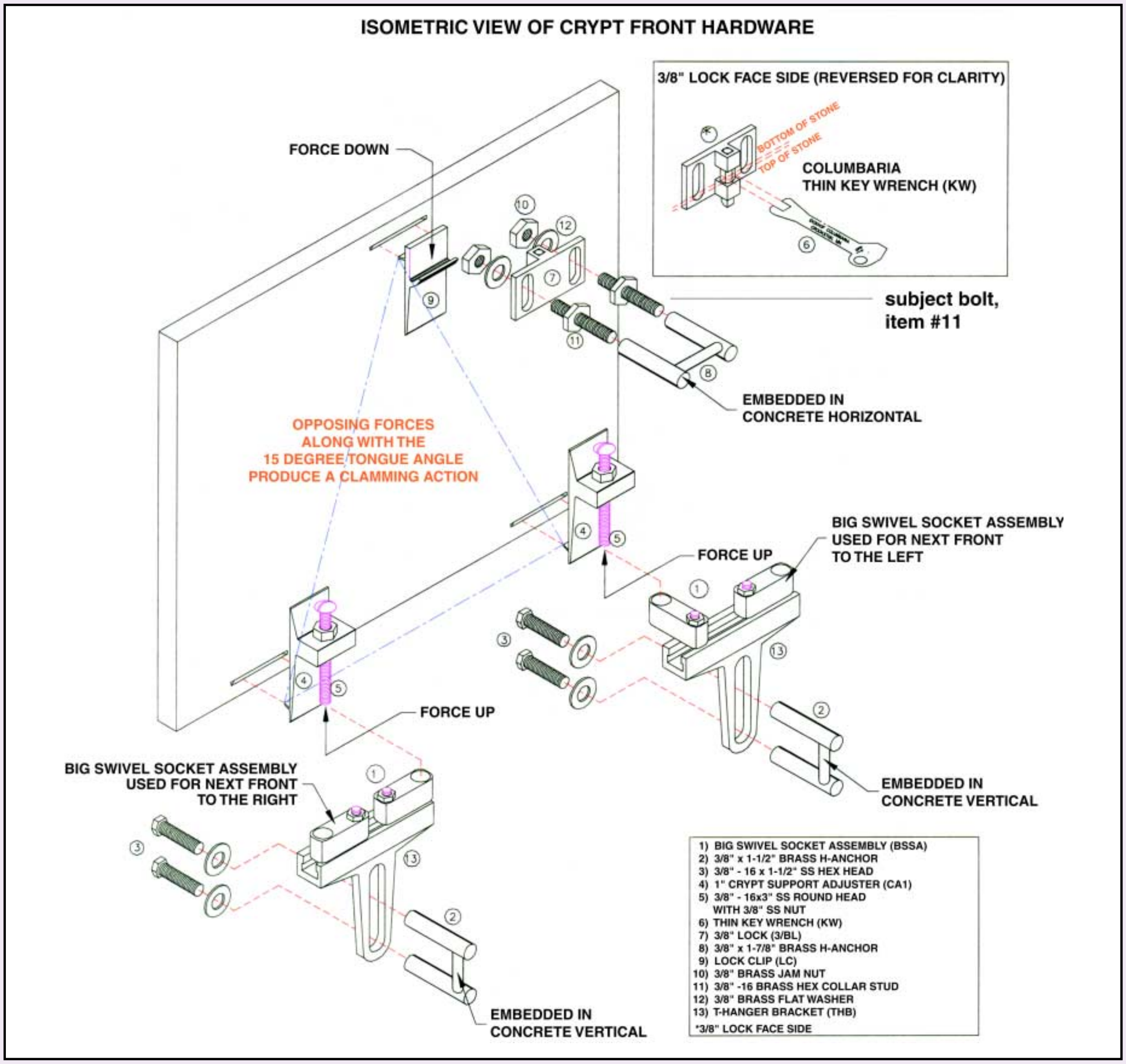

Fig. 2 Assembly drawing

Fig. 3 *As-received fractured bolt (M-1; M, mausoleum located in Michigan)*

Fig. 4 *As-received fractured bolt (P-3; P, mausoleum located in Pennsylvania)*

Table 2 Rockwell Hardness Values

Bolt(a)	Hardness, R_B	Bolt(a)	Hardness, R_B	Bolt(a)	Hardness, R_B
Prior to final forge	59, 65	P-5	95	P-13	90
M-1	88	P-6	93	P-14	83
M-2	97	P-7	94	P-15	88
M-3	95	P-8	92	P-16	93
P-1	96	P-9	91	P-17	97
P-2	97	P-10	94	P-18	94
P-3	96	P-11	93	P-19	92
P-4	96	P-12	82		

(a) M, mausoleum located in Michigan; P, mausoleum located in Pennsylvania

Several bolts were sectioned through the forged nut and evaluated metallographically. Figure 5 shows a typical macroscopic view of the sectioned bolts. There appeared to be a difference in grain structure related to the manufacturing process; heavier cold work and a corresponding higher strength appeared in the forged nut region.

Figures 6 and 7 show the macroscopic cross sections of two used bolts that were retrieved from the mausoleum prior to fracture. (Several bolts were retrieved at random. Two bolts were severely cracked, while the remaining bolts were free of cracks or defects.) These cracks followed the same path as the bolts that failed in service (Fig. 8). The cracks

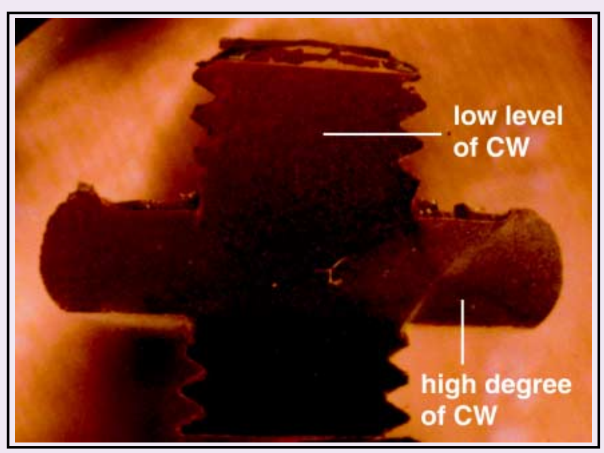

Fig. 5 *Macroscopic view of forged bolt showing various levels of cold work*

in Fig. 6 and 7 followed the interface between the duplex grain structures. This interface between large grains and small grains causes the grain boundaries at the interface to line up, which facilitates crack propagation.

The grain structure in the threaded region of the bolt, which received less cold work than the forged nut region, possessed larger grain size and lower microhardness. The microhardness for two bolts is tabulated in Table 3.

Intergranular cracking was readily apparent, as shown in Fig. 9(a) and (b). The main crack is intergranular, and secondary intergranular cracking is present in numerous locations. Stress-corrosion

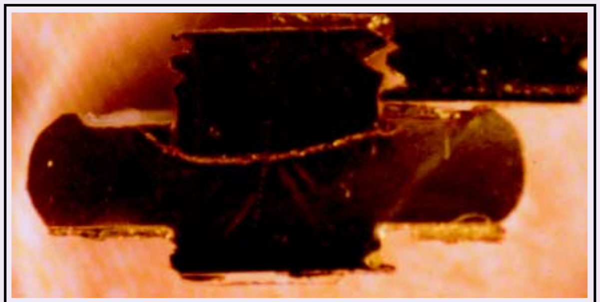

Fig. 6 *Cracked bolt (P-12)*

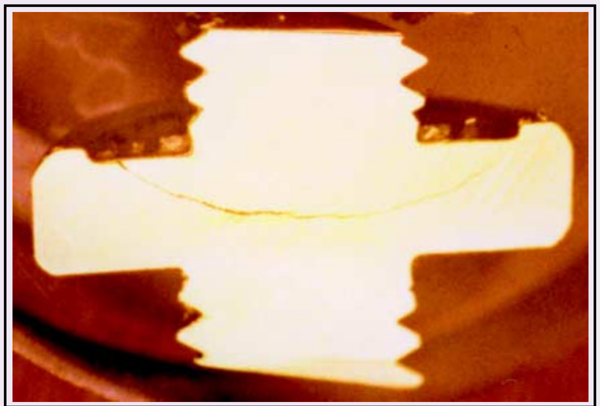

Fig. 7 *Cracked bolt (P-8)*

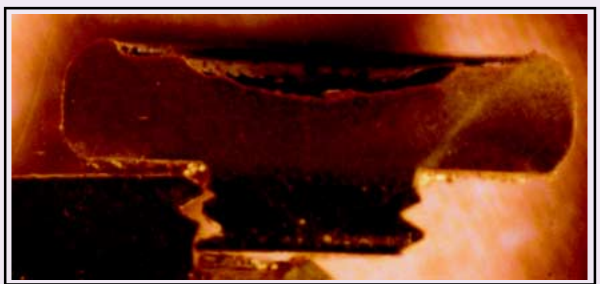

Fig. 8 *Bolt that failed in service*

Table 3 Microhardness (Equivalent R_B) of Two Retrieved, Cracked Bolts

Bolt P-12	Bolt P-4
61	(a)
61	...
60	...
73	...
73	Fracture
Crack	67
76	89
82	80
79	82
87	85
89	87
90	84
85	71
79	58

(a) Broken end missing

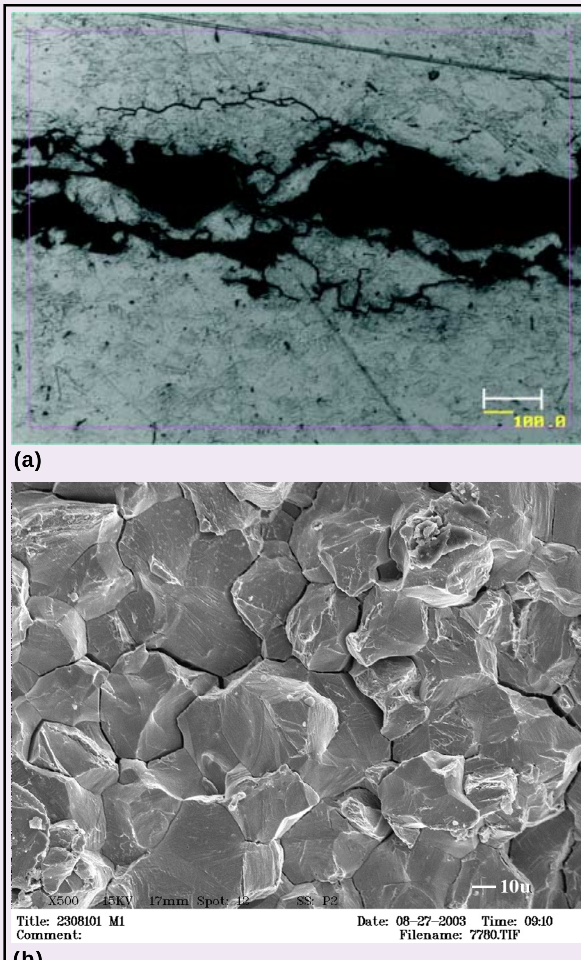

Fig. 9 *(a) Intergranular cracking via optical microscopy. Scale marker is 100 μm. (b) Intergranular cracking via scanning electron microscopy. Scale marker is 10 μm.*

cracking (SCC), also known as seasonal cracking, occurred on the failed bolts.[2] Seasonal cracking was first observed in brass cartridge cases in India that were adjacent to a horse stall during the monsoon season. This was the first evidence that ammonia caused SCC in brass. Three criteria are necessary for SCC to occur: the presence of stress, a corrosive environment, and a material susceptible to SCC. Brass is known to be susceptible to SCC when ammonia is present. Ammonia can be present in the atmosphere in minute quantities that are difficult to measure. Bacteria as well as fertilizer can be sources of ammonia. Another environmental concern is an alkaline atmosphere (lithium, sodium, potassium, rubidium, cesium) that may leach from the concrete during rainy weather. The stress is present due to residual stress from cold forging and/or overtorquing of the jam nut during assembly.[3] Witnessing the retrieval process revealed that a strong groundskeeper worked hard to loosen the bolts. This observation is consistent with overtorquing during installation. All of the failed bolts came from areas of the mausoleum that were exposed to the environment: for example, wind, rain, and birds. Overtorquing of the bolts is completely unnecessary. It may not be obvious from the assembly drawing (Fig. 2), but the weight of the marble slab is carried by the brackets underneath. The bolts in question (item 11 in Fig. 2) do not carry any load; they merely keep the marble slab in a vertical position.

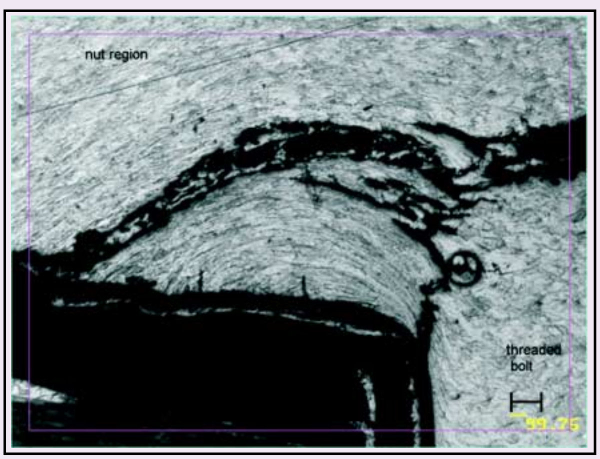

Fig. 10 Heavily cold-worked grains. Scale marker is approximately 100 μm.

The assembly page is the extent of the specification for the bolt. Basically, only dimensional information is specified; strength and environment are not noted. The bolt manufacturer supplied a dimensionally correct bolt.

Stress-corrosion cracking initiated at the heavily cold-worked transition region between the forged nut and the outside diameter of the threaded bolt, as shown in Fig. 10. This region possesses high residual stress. The cracking continued along the interface between the high-cold-worked and low-cold-worked regions. The amount of ammonia in the atmosphere to cause seasonal cracking is not known.[4] The amount may be very small, and cracking may occur after prolonged exposure. Intergranular cracking is prevalent.[5]

Conclusions/Recommendations

Conclusions/recommendations from this failure analysis are:

- Stress-corrosion cracking occurred in the subject bolts. Three criteria are required for SCC: corrosive environment, stress, and susceptible material. Removing any one of these three criteria will prevent SCC from occurring.
- Minimize residual stress: Reduce torque values used in assembly at the mausoleum; perform stress-relief annealing after cold forming of the bolt.
- Minimize the presence of a corrosive environment (rainwater leaching concrete chemicals and carrying fertilizer residue and bird droppings).
- Change the bolt material: Consider low-zinc brass, tough-pitch copper, or oxygen-free high-conductivity copper.
- Some of the remaining bolts in service will continue to fail due to SCC, especially those that are exposed to rain.
- The bolts were manufactured without any specifications and without the bolt supplier knowing the end use (true for most of the hardware). In this particular case, hindsight is once again perfect. The company should have provided a detailed specification for critical components, but

this component was not considered critical until unexplained failures occurred.

Final Note

The company has had to replace most of the retaining bolts at these two sites, at great expense. A review of the drawings prior to ordering these components may have prevented these failures and the replacement expense, but it would have taken a very experienced metallurgist to have predicted this outcome. Nevertheless, obtaining the services of mechanical engineers for loading evaluations and metallurgists for materials property knowledge can minimize cost down the road.

References

1. U. Borggren and M. Selleby: "A Thermodynamic Database for Special Brass," *J. Phase Equilibria,* 2003, *24*(2), pp.110-21.
2. G. Pantazopoulos: "A Review of Defects and Failure in Brass Rods and Related Components," *Prac. Fail. Anal.,* 2003, *3*(4), pp. 1-22.
3. R.G. Baggerly: "Evaluating the Effects of Overtorque in Bolts," *Prac. Fail. Anal.,* 2001, *1*(1), pp. 41-46.
4. T. Rakich: Copper Development Association, private communication, Sep 11, 2003.
5. J.M. Popplewell and T.V. Gearing: "Stress Corrosion Resistance of Some Copper Based Alloys in Natural Atmospheres," *Corrosion,* 1975, *31*(8), pp. 279-86.