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Proposal

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Characterization of the Delhi Pillar

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CHARACTERIZATION OF THE DELHI PILLAR

by

H. J. Fullbright, L. A. Schwalbe, and W. P. Ellis

ABSTRACT

We are proposing a detailed study of the internal and surface properties of the Delhi Pillar. These studies will be done on the site in collaboration with Indian scientists and engineers. All results obtained from this work either will be published in the open literature or will be otherwise made available to the general scientific community.

I. BACKGROUND

In the Qutab Minar section of Delhi stands an ancient iron pillar. Although built around 300 A.D. (Ref. 1), apparently by welding together sections of wrought iron, it is still standing relatively free of rust after 16 centuries of exposure to weather. This is a truly remarkable example of corrosion resistance. The "Delhi Pillar," or "Iron Pillar" as it is also called, has been of more than passing interest to westerners for over a century.[2] The earliest reports contain only sketchy historical details, along with translations of inscriptions and rough estimates of outer dimensions and densities.[3] Quantitative analysis of pieces of the pillar's composition some 70 years ago indicated 99.75% iron, but apparently, detailed studies of internal structure and surface characteristics are still lacking. A thorough investigation of these properties would be of value not only to archeologists and metallurgists but also to those primarily interested in surface science and particularly in solutions to the corrosion problem.

The purpose of this proposed study is to provide scientific answers to several intriguing questions, such as, "Why indeed has this metallic object resisted corrosion over a period of 16 centuries?" The potential practical value of characterizing the surface layer could be significant. The pillar has apparently withstood corrosive attack in a seasonally humid subtropical climate for countless years.[4] If the reason for such resistance to rust can be found, and it probably can with the techniques described below, then the application to corrosion prevention would be direct.

From the materials resources point of view, iron is a high-energy product derived from dwindling ore reserves. Corrosion is not only wasteful, amounting to a loss of billions of dollars per year in the U.S.A. alone,[5] but also it depletes a valuable mineral reserve and squanders the energy required to produce replacement metal. Thus, any process that reduces corrosion by even a very small amount would be worth investigating.

From the viewpoints of the archeologist and the metallurgist, the Delhi Pillar is a very creditable accomplishment in itself. Greater appreciation for the construction techniques could well be expected from the weld penetration studies, along with the general information gained concerning elemental composition, homogeneity, void inclusions, and crack structures.

II. APPROACHES

We have outlined a number of nondestructive evaluation techniques, all of which could be performed on the structure at the site. Our Indian collaborators are invited to comment on these and to suggest additional tests that may be performed. A second pillar, twice as tall but fallen, is found at Dhār (ancient capital of Malava, 33 mi. west of Indor). If permitted by the Indian authorities, we will take a small chunk and scrapings of the protective film of the Dhār pillar for later, thorough metallurgical analysis at Los Alamos Scientific Laboratory. For correlation, other relevant metallic artifacts would also be examined as available.

A. Sputter/Auger (Ellis)

A surface-sensitive probe, Sputter/Auger, will be used to obtain elemental compositions of the Delhi Pillar. The low-energy Auger technique detects all elements with $Z \geq 3$ and is sensitive only to the outermost 2 to 3 atomic layers; i.e., those of prime importance in corrosion. By sputtering away atomic layers successively with 500-eV Ar^+ ions, elemental depth distribution profiles will be obtained and compared with the scientific literature on corrosion. Except for sputtering away a very thin layer in selected spots approximately 5 mm by 5 mm, the technique is nondestructive and the pillar will not be harmed in any way.

We propose to examine several positions on the structure at the site with a miniaturized portable Sputter/Auger system we conceived several years ago specifically for such in-field applications.

B. Radiography (Bryant and Morris)

Using a portable isotope gamma-ray source, radiographic images could be obtained from top to bottom, or on a sample basis of the pillar. Views at right angles (0° and 90°) would be recommended.

The type of information probably obtainable from such radiographic coverage is as follows.

1. Confirmation of disk-type construction and details such as thickness of individual disks, spacing between disks, and the nature of the joint between disks.
2. Quality of pillar material such as radiographic visualization of voids, general porosity, and possible segregation if any impurities or alloy constituents are included. Also, possible detection of any internal cracks that could be open and fortuitously oriented.
3. Any other internal, unexpected abnormalities that would result in a pronounced change in atomic number, thickness, or density.

In general, this radiography would be performed by a source that would be locked and safely shielded when not in use and that could remain at ground level for all exposures. A scaffold or elevator-type arrangement would be required for positioning of source hose and film holders. By varying film and screen type and exposure time, a variety of image types could be obtained to optimize acquisition of whatever types of data began to be revealed in the initial exposures.

Technique development on suitable billets would be performed before arrival at the site to minimize the time and radiation at the pillar. Film processing could be performed by several arrangements such as with a portable, on-site, small trailer, or using local industrial, government, and/or medical facilities. The clearly identified radiographs and even photographic copies of the negative can be made available to all parties. No damage or modification would occur to the pillar as a result of the radiographic inspection.

C. Penetrant Inspection (Bryant)

Using liquid penetrant, solvent cleaner, and powder, a penetrant inspection could be performed on the surface of the pillar to reveal any previously undetected cracks or, perhaps, a greater extent than realized for any visually detected cracks.

The penetrant test could be applied using the scaffolding referred to in Sec. B. Again, no damage or modification would occur to the pillar as a result of the penetrant inspection.

D. X-Ray Fluorescence (Fullbright and Schwalbe)

X-ray spectrometry is a well-established nondestructive evaluation procedure used to quantitatively determine elemental concentrations of solid, liquid, and gaseous samples. With this rapid technique, analysis of the material along the length and perhaps around the circumference of the pillar at various points would yield compositional information for individual disk components as well as the weld regions.

We propose to use the following radioisotopes for the respective fluorescence energy ranges.

1. Iron-55 (1 to 5 keV) is useful for analyzing low-Z material compositions; these include elements between and including magnesium and titanium.
2. Cadmium-109 (2 to 20 keV) is the most commonly used source in this laboratory because both the K-lines for materials below silver and the L-lines for higher-Z elements lie in this energy range.
3. Samarium-145 (less than 40 keV) is often used, in addition to Cd-109, when the broader energy range is desired.

Our apparatus would also include a lithium-drifted silicon (solid state semiconductor) detector and multichannel analyzer system for collecting and displaying the data. These energy spectra would then be read onto either magnetic tape or floppy disk for later, more intensive processing. Typically elemental concentrations on the order of parts per million can be measured with this technique. Again, the scaffolding referred to in Sec. B of this proposal could be used to support the relatively portable apparatus needed for this test.

E. Mössbauer Spectroscopy (Fullbright and Schwalbe)

Mössbauer spectroscopy has become a valuable tool in physical metallurgy. The feasibility of fielding an experimental system for use at the pillar is being considered. The expected data would supplement that from the Auger investigation, Sec. A. Information on the combining state of the iron may be determined. Other information may be obtained on the phase identification, internal oxidation, magnetic properties, and possible precipitation properties in the iron. Again, this procedure is completely nondestructive and nonintrusive.

F. Ultrasonic and Eddy Current (Strong and Morris)

Ultrasonic and eddy current tests are routinely used at this laboratory for inspection of weld penetrations, grain-size effects, microscopic cracks, and voids in assembly components. Again, these techniques are nondestructive in nature and can be applied to the present problem in a straightforward manner. The apparatus involved is compact and portable and could therefore be supplied by us if it is not found to be readily available to our Indian collaborators.

REFERENCES

1. The *Encyclopedia Britannica* **7**, 198 (1978) describes the pillar as having been built in the fourth century A.D. Inscriptions relate the conquests of King Chandra Gupta II Vikramaditya (A.D. 375-413) and mention the name of Raja Anangapala (1052-1109). Some archeologists have dated the pillar's construction as late as the ninth century (Prof. Nag Chaudhuri, private communication).

2. The Committee of the Iron and Steel Institute **2**, 156 (1872), quoted in Ref. 3.

3. J. Iron Steel Inst., London **85**, 153 ff (1912).

4. *The New Encyclopedia Britannica Macropedia* **5**, 570 (1973) describes the climate of Delhi as being extremely dry for most of the year with hot (77° to 110°F) summers and cool (45° to 70°F) winters. Higher humidities occur during the months of July and August, and the monsoon season, which continues until the end of September, yields an average rainfall of about 25 inches.

5. Michael Baum, "The Economic Effects of Corrosion," Dimensions/NBS **62**, 12 (June 1978). There is an annual loss of 70 billion dollars in the U.S.