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DIGITAL IMAGE PUBLICATION FOR BACKSCATTER SEM MICROGRAPHS

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ABSTRACT

A number of limitations impede visualization and interpretation of backscatter SEM images reproduced photographically in technical journals and proceedings. The size of the image presented is often too small to visualize all of the details discussed by the author. Often the loss of contrast and of detail in the half tone reproduction processes used severely limits the information actually conveyed to the reader. In contrast, digital images can be readily reproduced in any desired size without loss of detail. Such images can be readily obtained, stored and manipulated (if necessary) in computer files, and printed out by standard laser printers. The writer is of the opinion that the publication of such digital images instead of conventional photographic reproductions vastly increases the clarity and effectiveness of the visual information actually transmitted to the reader. Several examples of backscatter SEM images of concrete are provided to illustrate the potentials of this method.

Introduction

In recent years microstructural research in cement systems has concentrated heavily on backscatter SEM imaging of plane polished surfaces, usually of epoxy-impregnated specimens. A number of recent examples can be cited (1-8).

Such images are frequently rich in detail and important information can readily be detected and described by the investigator. However, it often appears to the present writer that some of the details perceived and described by the investigator working with the original image are not, in fact, able to be verified from the published reproduction of the micrograph in the journal.

Partly, this is due to the usual reduction in size undergone by the image in publication, especially in publications like *Cement and Concrete Research* that publish camera-ready copy. Typically micrographs are obtained on Polaroid™ film with an image size of 90 mm × 115 mm (3.5 in. × 4.5 in.). Even if the image is not cropped, it is usually reduced about 20% in each dimension in the final publication. In itself this reduction has a significant effect on clarity of visual information. Details that are readily perceived in the original size are often much more difficult to appreciate in the reduced size of figure in the final publication.

Added to this is the inevitable reduction in image quality attendant on publication. This may be of greater or lesser severity, depending on the details of the photo reproduction process used and on the quality of the paper used, but it is always significant.

The combination of the two factors frequently renders important aspects of the observations made by the investigator impossible to confirm or verify independently from the published micrograph.

The problem exists to some extent with secondary electron images of fracture surfaces, as well as backscatter micrographs. However, secondary SEM images are often of high contrast and are less rich in detail than many backscatter SEM micrographs and the problem is not so severe. Backscatter micrographs are often secured for image analysis purposes, which require consistent gray scale settings that are not adjusted to optimize the contrast or the appearance of individual micrographs.

There are now opportunities to avoid these difficulties by the publication of digital images rather than analog photographic images.

Many SEMs are currently being produced with or are being retrofitted with systems that permit the direct recording of digital images on computers screens that serve either as the primary output of the SEM or as auxiliary output. Such systems may use popular microcomputer platforms (such as Windows 3.1™, or more recently, Windows 95™. The images themselves can usually be saved in standard file formats such as TIFF or JPEG, and can be printed out on normal laser printers.

Such digitally encoded micrographs can be submitted for publication on disc, assuming that the printer used in final publication is optimized for gray scale printing, or they can be submitted for publication as pre-printed copy in the usual manner.

FIG. 1.
Backscatter SEM of area of concrete.

FIG. 2.
Backscatter SEM of area of mortar.

A major advantage of this mode of reproduction is the flexibility in size of final image that can be reproduced without loss of information. The writer is of the opinion that large, even full-page publication of properly printed digital micrographs can convey much more information to the reader than the customary reproduction of analog photographs.

Examples of Digital Micrographs

There is considerable current concern with the degree to which the now commonly accepted concepts of the interfacial transition zone (ITZ) actually reflect the reality of the microstructures actually present in properly mixed concrete.

Figure 1 is a digital backscatter image published in full page size representing an area of approximately 1150 μm × 750 μm on a flat polished specimen of concrete. Aggregate grains and the bright residual ground cement (clinker) grains are obvious; the spatial relationships between them can readily be perceived and independently judged by the reader.

Figure 2 is a digital backscatter image representing a field of approximately 400 μm × 270 μm taken from a mortar at higher magnification than Figure 1. The bright areas are again residual unhydrated clinker grains. Rims of hydration product ("hydrated phenograins" in thenomenclature of Diamond and Bonen (5)), multi- micron sized pores, and highly variable gray scale "groundmass" hydration products are all easily perceived. The large uniformly gray grains in the upper portion of the micrograph and the large dark grain touching the scale marker are all sand grains.

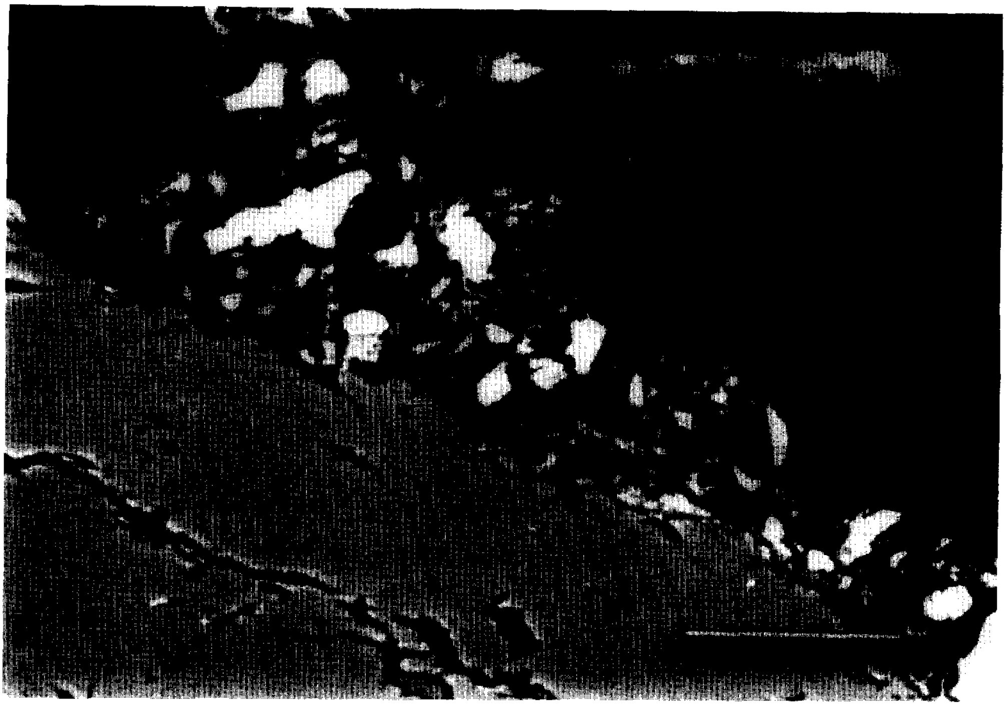

FIG. 3.
Backscatter SEM of area of a different mortar.

Figure 3 is a digital backscatter image at higher magnification representing a narrow zone of cement paste (about 50 μm in width) between two adjacent sand grains.

The writer believes that these figures convey the microstructural information needed for independent judgment by the reader concerning the question at issue far better than would small-scale reproduction of analog photographs that might be obtained of the same areas.

Other Advantages of Digital Recording of Micrographs

Digital images have been discussed in terms of perceived advantages for journal publication. However, digital recording of SEM micrographs offers a variety of other advantages as well.

One of these is inherent in the fact that each micrograph is in fact a normal computer file. Such files can be stored on hard drives, transmitted over networks, and easily archived and recovered. The files can be opened and manipulated by commonly used graphics programs such as Photoshop™, and by desktop personal computer based image analysis programs.

In the equipment and computer package used by the writer, the analog signal normally sent to the CRT of the SEM, is digitized "on the fly" and presented in real time as a raster display on a computer equipped with a large screen. Manipulations to optimize brightness and black level can be done almost instantly and effortlessly by mouse manipulation on the computer itself, rather than by using the SEM controls. The writer finds that the ease associated with this mode of operation permits him to concentrate almost exclusively on the microscopic structure being displayed rather than on the manipulation of the SEM instrument. This provides for much more efficient use of SEM time and much more immediate focus on interpretation than has heretofore been possible.

Operational Details

The micrographs reproduced here were obtained using a Hitachi S-2300 SEM equipped with a GW backscatter detector and the Quartz PCI™ Version 2 digital imaging system developed by the Quartz Imaging Corporation, West Vancouver, B.C., Canada. Output was printed on a Laser Jet 4P printer set to 120 screen.

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