EDDY CURRENT EVALUATION OF POROUS MAGNESIUM ALLOY CASTING

Gabor Blaho, Alain Quirion & Laszlo Adler
Department of Welding Engineering
The Ohio State University
Columbus, Ohio, 43210

INTRODUCTION

Metal matrix composites (MMCs) have increasingly found a home in high technology industries. Even though much research and money have been invested in their conception, manufacturing and incorporation into load bearing structures, the development of suitable nondestructive evaluation technique to test their integrity has lagged behind. Eddy current testing may provide a suitable method of inspection the internal structure of MMCs through differences in electrical conductivity and/or magnetic permeability between fibers and matrix.

In the first part of this paper, the effect of porosity in a magnesium alloy casting ingot on eddy current testing will be studied. An eddy current and reflectivity measurement system, having C-scan and raster scan capability was used to compare electrical conductivity versus porosity content on a number of specimens. In the second part of this work the same eddy current system was used to study the fiber distribution in a magnesium alloy reinforced with unidirectional graphite fibers.

THEORY

Using the conductivity tensor calculated for various fiber distributions in a unidirectional MMC, Beissner [1] found that, in spite of the anisotropy, the probe response for composites can be compared to that of a conductor with the same effective isotropic conductivity. Eddy current results can then be directly related to the volume fraction of fibers through the rule of mixture [2]. In the fiber direction the conductivity can be expressed as

$$\sigma_c = \sigma_f V_f + \sigma_m V_m \qquad (1)$$

and in the transverse direction

$$\sigma_t = \frac{1}{\left(\frac{V_f}{\sigma_f} + \frac{V_m}{\sigma_m}\right)}, \qquad (2)$$

where the subscripts "f" and "m" represent the fiber and matrix respectively, and V is the volume fraction.

Taking the conclusions of Beissner work one step further, the percentage content of evenly distributed particles (or porosity) in a matrix component could be determined through eddy current testing.

SAMPLES

The MMC that was used during the experimental testing is a magnesium alloy (AZ-91D) with an electrical conductivity of 11.5% IACS reinforced with graphite fibers (type P-55S 2K) of 10 microns diameter and 0.20% IACS conductivity. The MMC is unidirectional with a 35% fiber percentage and dimension of 2.0 inch x 4.0 inch x 0.08 inch.

Upon microscopic inspection of the surface of the MMC specimen, it was discovered that the matrix component was subject to the presence of porosity, the effect of which had to be studied before advancing to the eddy current testing of MMC.

A slice of the magnesium alloy casting ingot from which the MMC was constructed was obtained and specimens cut out. Preliminary microscopic inspection revealed that a number of specimens had porosity present. It can be postulated that the difference in shape and size of the porosity as well as their presence can be attributed to gradients in the cooling rate at different locations in the ingot that can produce solidification shrinkage at the grain interface during solidification [3].

EXPERIMENTAL SETUP

Figure 1 provides a simplified schema of the experimental setup used. The personal computer (an IBM PS/2 model 30) controls all the other components of the system and is used to gather, process and store the appropriate experimental parameters and data. Even though the eddy current and the reflectivity measurement systems are shown in parallel, only one can be used at a time.

The core of the eddy current system is a Nortec/Metrotek NDT-19 Portable Eddyscope and the probe used is a commercially available shielded ferrite core probe (NEC-2006) with a nominal frequency of 0.1 MHz and an outside diameter of 2.8 mm. The probe sits in a fixed holder within a hole slightly bigger than the probe diameter thus allowing the probe to move freely up and down but not sideways. This configuration prevents lift-off variation while keeping the probe perpendicular, with its tip in contact with the test specimen that is moved below the probe.

The reflectivity measurement system was conceived as a method of estimating the percentage area of porosity at the surface of the magnesium alloy. The reflectivity probe consists of a high output infrared LED that shines light at an angle onto the specimen surface and is then

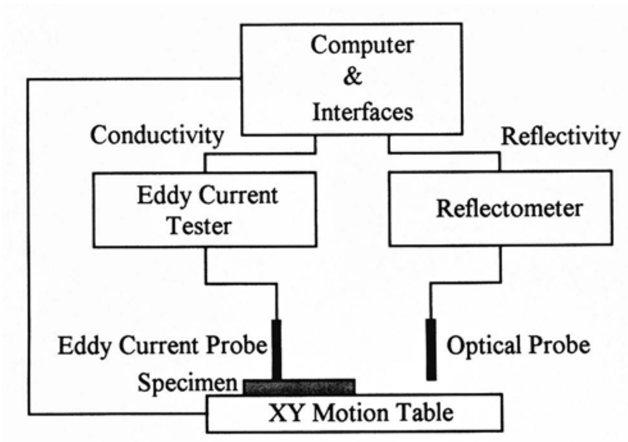

Figure 1. Experimental setup.

reflected to an infrared phototransistor. A plastic spacer at the bottom of the probe keeps the probe at a suitable distance from the specimen while preventing scratching and marring of the surface.

A magnesium alloy sample is used as reference by nulling the instrument to this specific specimen before each eddy current measurement. Once the testing parameters were chosen, they remained unchanged for all eddy current testing. The phase angle of the instrument was chosen so that change in conductivity would correspond exclusively to a change in the vertical output.

Eddy current and reflectivity measurement data can take the form of either a C-scan picture (200x200 pixels) or a raster scan where the position is recorded as well as the appropriate measurement.

EXPERIMENTAL RESULTS AND DISCUSSION

Figures 2 and 3 are microscopic pictures of a representative area of porosity in specimens #1 and #2 respectively. Figures 4 and 5 are reflectivity measurement C-scan pictures, eddy current C-scan pictures of the same area (0.5 inch wide x 1.5 inch long) are presented as Figures 6 and 7.

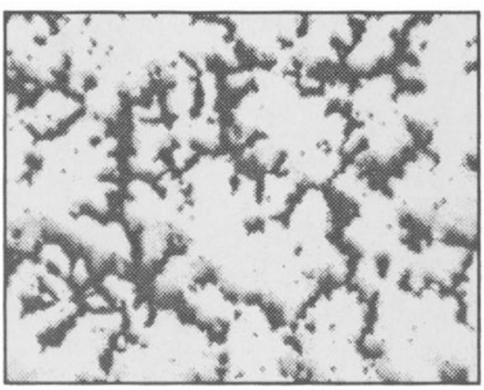

Figure 2. Microscopic picture of specimen #1.

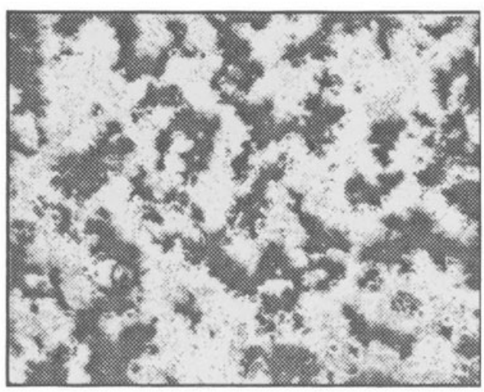

Figure 3. Microscopic picture of specimen #2.

Figure 4. Reflectivity picture of specimen #1.

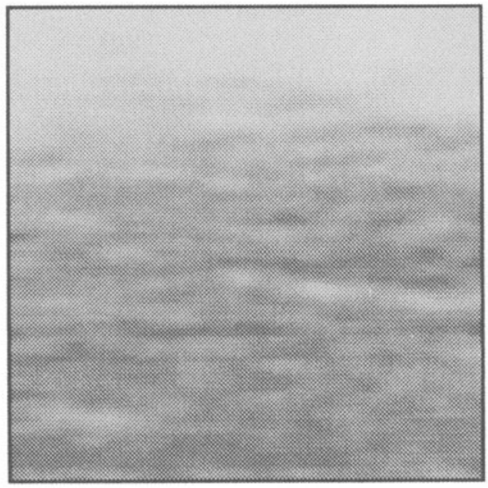

Figure 5. Reflectivity picture of specimen #2.

Figure 6. Eddy current picture of specimen #1.

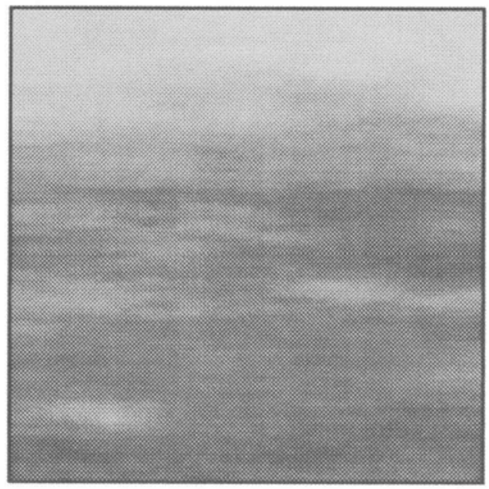

Figure 7. Eddy current picture of specimen #2.

A comparison of the microscopic features reveals that specimen #1 has pores that are elongated while the pores in specimen #2 tend to be much larger and more globular in appearance.

In both reflectivity measurement and eddy current C-scan pictures it can be observed that regions of high reflectivity correspond to regions of high conductivity (whiter areas) while regions of low conductivity correspond to region of low reflectivity (presence of porosity). While the top portion of each scan is of the same shade (unflawed magnesium alloy = high conductivity = high reflectivity), the bottom portion that correspond to areas of porosity is of a darkest shade in specimen #2 than in specimen #1. This is in agreement with the microscopic pictures (Figures 2 and 3).

Raster scans (both eddy current and reflectivity) of specimens #1 and #2 were also obtained. The eddy current data was transformed into conductivity measurement using a calibration curve constructed from specimen of known conductivity (tin, lead, solder). The reflectivity data was transformed into porosity content through a conversion factor calculated from an image processor and using specimen #2 (greatest porosity content = lowest reflectivity = 56%). Figures 8 and 9 provide graphs of the porosity content vs. the conductivity.

The rule of mixture indicates that if the porosity defects are evenly distributed in the matrix component, the slope of the curve should be -0.115 %IACS/%porosity content. The slope of specimen #2 agrees with the theoretical slope, but specimen #1 diverges from the expected results. Three options are available (singly or in combination) to explain this deviation:

a. The pores are not evenly distributed;
b. The shape of the porosity influences the eddy current results; or
c. Eddy current is a layer (skin depth) inspection technique while the optical scan is a surface measurement only.

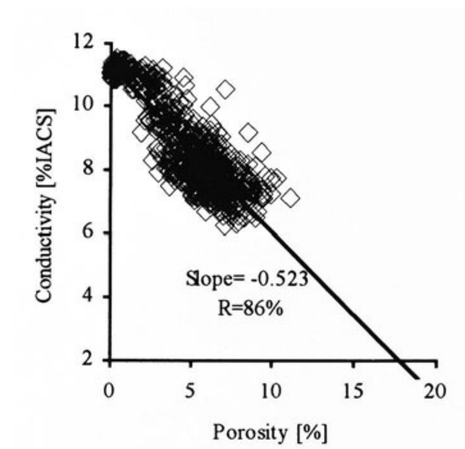

Figure 8. Porosity content vs. conductivity. of specimen #1.

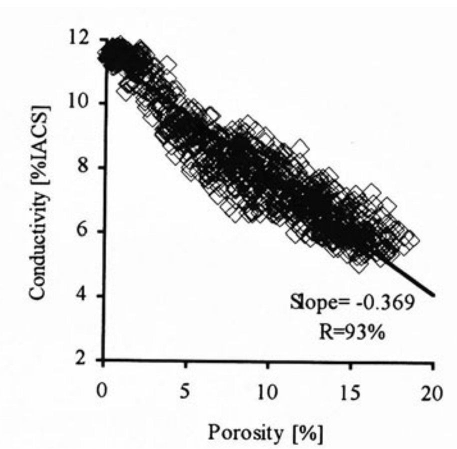

Figure 9. Porosity content vs. conductivity. of specimen #2.

METAL MATRIX COMPOSITES

Using the same experimental setup and inspection parameters, two eddy current C-scans of one specimen of MMC-35% fiber volume content were taken and are presented as Figures 10 and 11. In both figures the direction of the fibers can be detected, but Figure 11 offers a much sharper contrast.

Microscopic pictures of the MMC normal to the scanning plane have revealed that the surface layer of the matrix element is not constant throughout the specimen. The thicker surface layer also contains porosity which can be seen in Figure 10.

Eddy current raster scans along a single line in two different areas of the MMC were done and the sample cut along these same lines. Graphs of the eddy current data gathered (transformed to conductivity value) and thickness measurement of the surface layer of the matrix (from microscope observation) for the same position are provided as Figures 12 and 13.

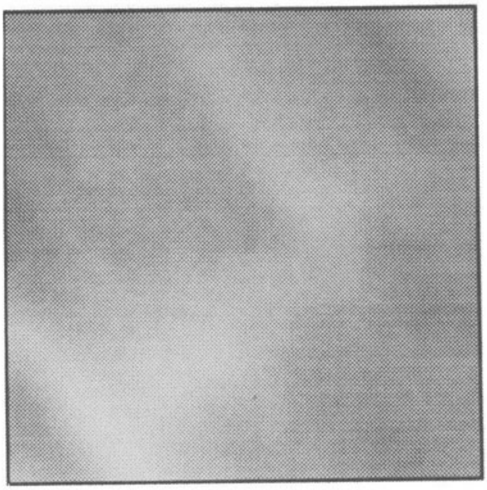

Figure 10. Porosity content vs. conductivity. of specimen #1.

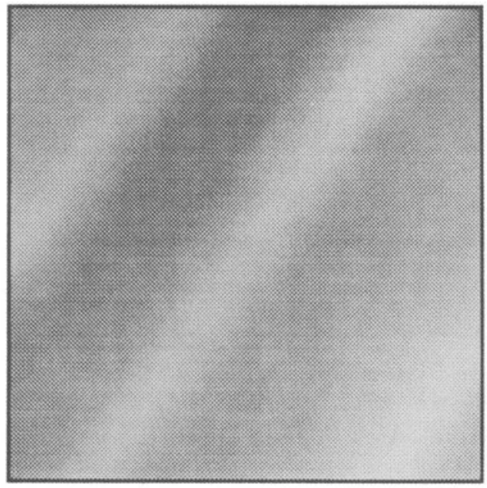

Figure 11. Porosity content vs. conductivity. of specimen #2.

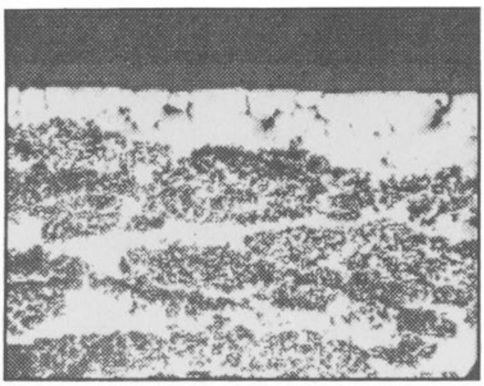

Figure 12. Porosity content vs. conductivity. of specimen #1.

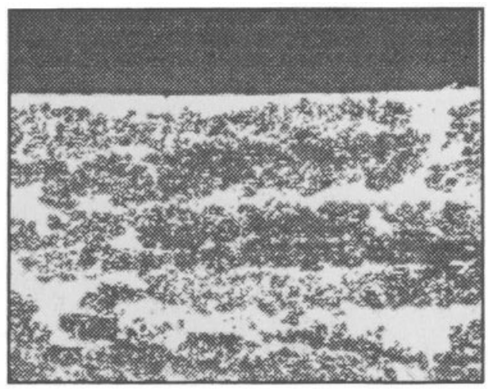

Figure 13. Porosity content vs. conductivity. of specimen #2

In general the peaks in conductivity correspond to peaks in the thickness of the surface layer. The lack of contrast in Figure 10 can either be attributed to the presence of porosity or to the thickness of the matrix layer which prevents the layers of fibers from having a greater effect on the eddy current results. The fact that the surface layer of the matrix component is not uniformed does no allow the differentiation between fiber distribution and/or the presence of porosity. The conductivity calculated by the eddy current method is lower than the nominal conductivity of the magnesium alloy thus proof that more than the top surface of the matrix component was being scanned (the skin depth is 0.6 mm).

CONCLUSIONS

It was determined that the rule of mixture can be applied under certain conditions to determine the porosity content in magnesium alloy samples. C-scan images were obtained from metal matrix composites using eddy current which indicated the general fiber direction. We were

MMC due in part to the non-uniform thickness of the surface layer of the matrix component. Much remains to be done in the field of electromagnetic testing of metal matrix composites.

REFERENCES

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