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AN ELECTRO-THERMAL NONDESTRUCTIVE TESTING METHOD

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By

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ABSTRACT

A nondestructive testing technique capable of detecting flaws in metals has been developed. This technique uses electrical heating in conjunction with infrared mapping of surface temperatures. It has been demonstrated on steel bars having 1/16 in. diameter holes drilled at a depth of approximately 0.146 in. under the surface.

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SUMMARY

The purpose of this report is to provide an early announcement of a newly developed thermal technique for nondestructively testing metal parts. Welds and metal parts that have rough and uneven surfaces are often difficult to test using customary nondestructive testing methods. We have developed an electro-thermal technique which images defects such as welding flaws, cracks and voids in metal. An electrical current is used to produce heat in a test object and thermal imaging is used for readout of the resulting surface temperatures. This electro-thermal technique has been experimentally demonstrated by detecting small drill holes under the surface of carbon steel and stainless steel specimens. The technique is faster than most nondestructive testing methods since only a fraction of a second is required to image flaws in test specimens. Specimens of complex shape can be tested with this method; however, the depth at which defects can be detected is limited. A high electrical current is required for testing massive parts. This technique should be useful for testing welds in heavy pressure vessels and pipes, and testing complex parts such as valves.

DISCUSSION

EXPERIMENTAL DEMONSTRATION

A test bar configuration which demonstrates the electro-thermal technique is shown in Figure 1. One surface of the bar is painted black to equalize the emittance. Bars of this configuration, containing 1/4, 1/8, and 1/16 in. holes drilled parallel to the surface, were made from 1020 carbon steel and 304L stainless steel. During a typical test, the density of electrical heating in the bars is about 400 watts per surface square inch. A 60 Hz alternating current was used which restricted the heating within a depth of about 0.040 in. from the surface in the 1020 carbon steel, and would allow a penetration depth of 2 in. from the surface in nonmagnetic stainless steel.

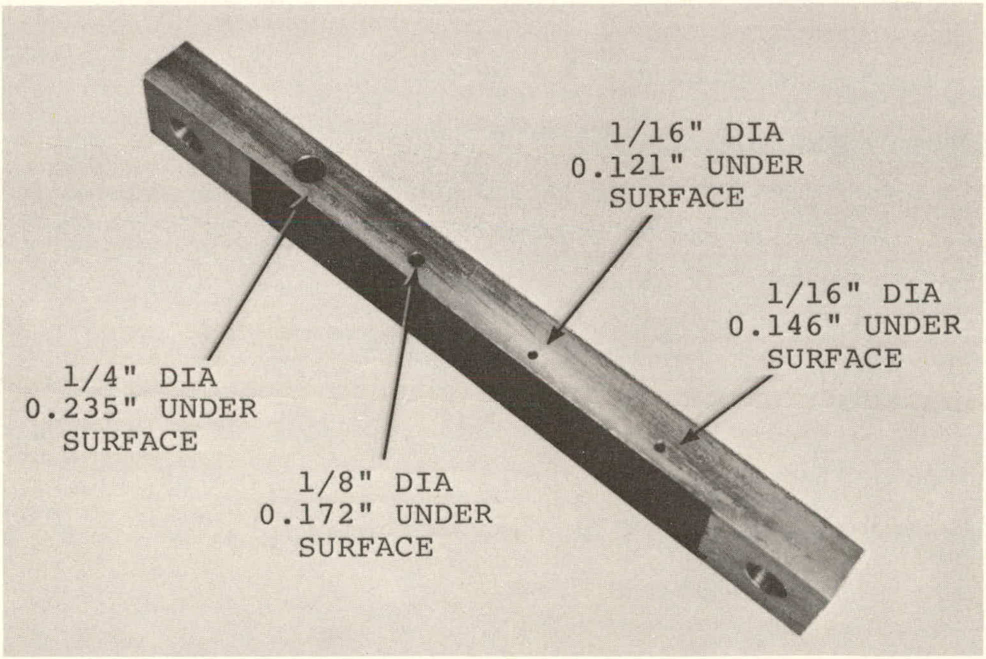

FIGURE 1. Test Bar Configuration Used to Demonstrate the Electro-Thermal Technique

Figure 2 shows the results of electro-thermal tests performed on the two test bars. The greater sensitivity of the test in the 304L steel bar was the result of its lower thermal diffusivity and a greater depth of electrical current penetration. Thermal images of the defects were obtained with an AGA Thermovision infrared scanning camera.

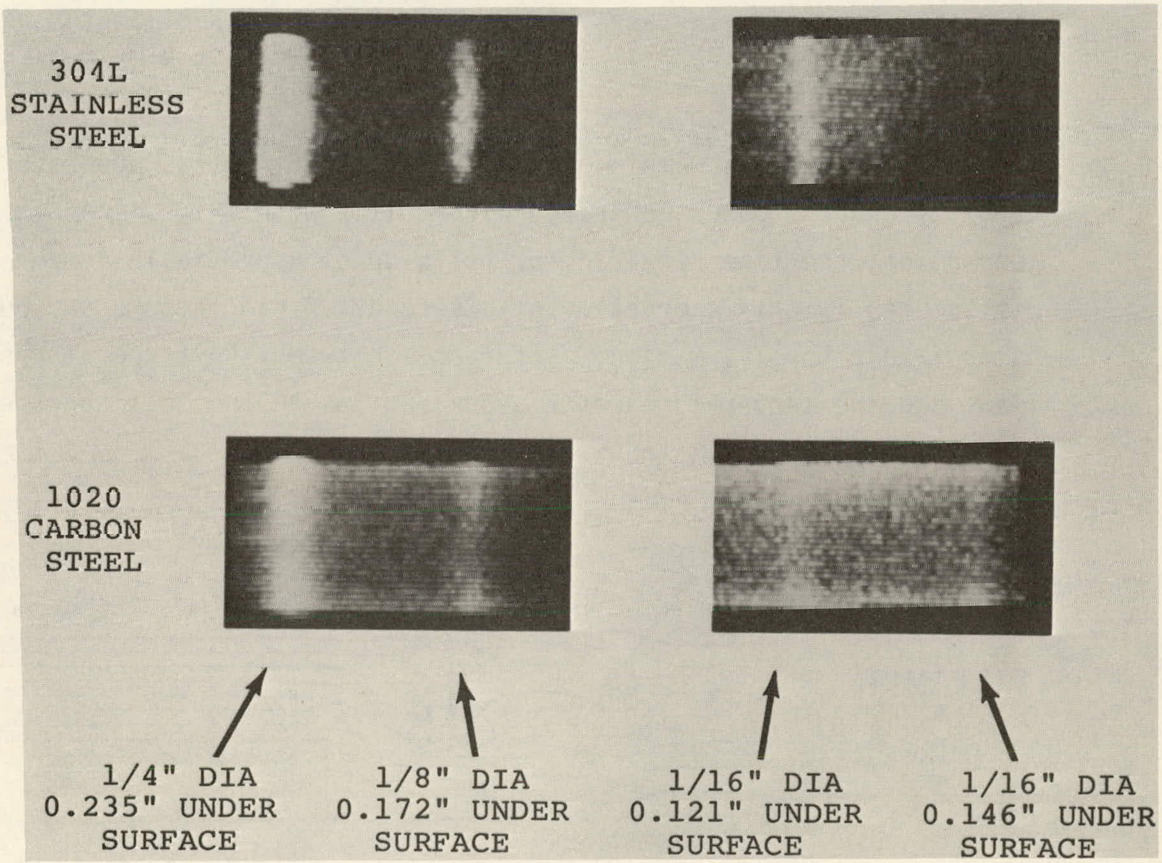

FIGURE 2. Electro-Thermal Test Results for Steel Bars of 1020 Carbon Steel and 304L Stainless Steel Having Holes Drilled Under Surface as Shown in Figure 1.

BASIC PRINCIPLE

The basic principle of the electro-thermal test can best be understood by inspecting Figure 3 which illustrates the electrical current flow through the test specimen.

An electrical current, passed through the specimen in a direction parallel to the top surface, must flow around nonconducting defects such as voids and cracks. This causes an increase in the electrical current density at the surface as indicated by crowding of the current stream lines shown in Figure 3. In each volume element of the specimen through which the current passes, heat is generated in an amount that depends upon the resistivity and the square of the current density. The initial rate of temperature increase within each volume element depends upon its heat capacity and the power generated within it. With a large enough power generation, the time required for build-up of appreciable temperature differences is only a fraction of a second. Rapid temperature build-up is desirable to give maximum differences between the temperatures over flaws and the temperatures over other regions in the test specimen.

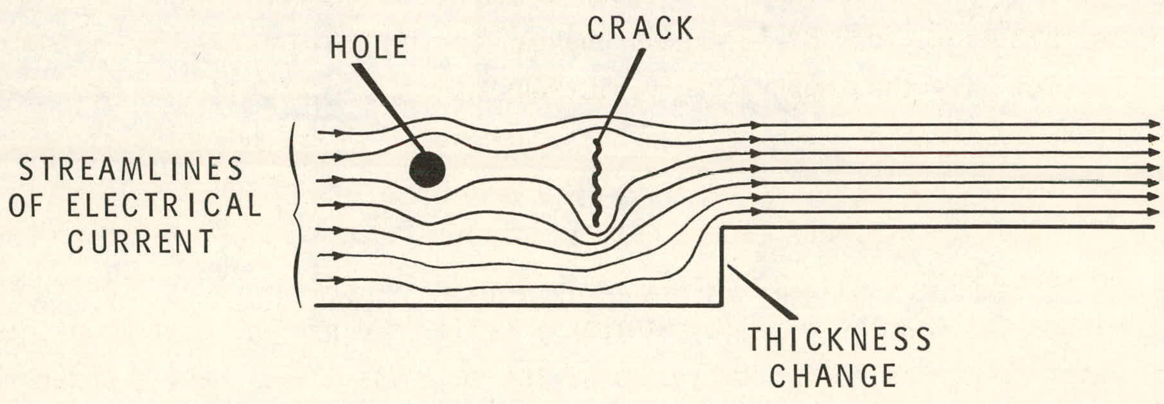

FIGURE 3. Electrical Current Flow Through a Metal Test Specimen During Electro-Thermal Testing

Although the stream lines shown in Figure 3 are for a direct current (as indicated by their uniformity throughout a uniform section of the specimen) the concept of stream line crowding in the surface of a specimen near a discontinuity is also applicable to alternating current (where current density drops off rapidly with depth). This assumes, of course, that the discontinuity is near enough to the surface that it interferes appreciably with the current flow. A lower frequency than 60 Hz would probably have given increased sensitivity in the 1020 steel sample, but was too expensive to obtain for the initial demonstration.

In addition to the effect on electrical current flow, discontinuities can interfere with the flow of heat into the specimen. This is why the defects can be seen in the 1020 steel bar even though the current is primarily concentrated in the material above the defects.

Limited electrical penetration depth would be advantageous when testing massive parts for near-surface defects, since not as much metal must be heated when the heat is restricted to a thin layer near the surface during the test. Hence, less power is required to produce the heat flux needed to generate detectable temperature gradients along the surface in the vicinity of defects. (This heat flux must, of course, be parallel to the surface.) Another advantage of limited penetration depth is that the effect of thickness changes in the part can be eliminated, leaving only the temperature variations caused by defects. On the other hand, penetration great enough that current flows around defects gives greater sensitivity, as seen in the stainless bar in Figure 2.

Another property of the electro-thermal technique allows it to be used on specimens having moderately wavy or bumpy surfaces. A low frequency electrical current will quite closely follow the surface contour without penetrating the entire thickness of the test specimen. Hence, under this condition heating is dependent only upon the sub-surface condition of the specimen, and not upon the moderate irregularity of the surface.

CONCLUSIONS

The electro-thermal technique appears to be a useful tool for imaging defects in metal parts. It is capable of higher speed than most other nondestructive testing techniques. It can be augmented with the emittance-independent infrared method to eliminate the necessity for an emittance equalizing coating. This technique promises to be applicable to detection of welding flaws, cracks in large valve seats, and flaws in other complex test specimens not adequately tested by existing nondestructive testing methods.

ACKNOWLEDGEMENTS

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