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Nondestructive Examination of Glass-Reinforced-Plastic Rod End Fittings

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George F. Sushinsky and Leonard Mordfin

ABSTRACT

An exploratory study was performed on the feasibility of using nondestructive examination techniques to detect voids in two types of potted compression end fittings. Four methods of nondestructive examination were tried: conventional pulse-echo ultrasonics, ultrasonic holography, x-radiography, and neutron radiography. The ultrasonic and x-ray methods that were tried proved unsatisfactory as a nondestructive examination tool for the two types of end fittings, and the neutron radiographic procedures successfully displayed the internal structure of only one of the specimen types. The procedures and results from the different methods of examination are summarized. Additional comments are given regarding the application of the methods to aluminum-jacketed specimens, and regarding improved methods for the inspection of steel-jacketed specimens.

Key Words: End fitting; glass-reinforced-plastic rod end fitting; nondestructive examination; neutron radiography; ultrasonics; x-radiography.

1. INTRODUCTION

Glass fiber-reinforced-plastic (GRP) rods, manufactured by pultrusion and related processes, are widely used as tension members in large, modern antenna systems and arrays. In these applications the rods serve as structural guys and catenaries, or as insulators for guys and top-loading elements. The tensile loads are introduced into the rods with end fittings (terminations) mounted on the rod ends and the load-carrying capability of a given rod depends upon the efficiency of the end fittings used.

Various kinds of end fittings are used; several of these are described in References 1 and 2. Some are more efficient than others, but 100 percent efficiency is rarely achieved; tensile failures of GRP rods most commonly initiate in or adjacent to an end fitting due to the discontinuities and stress concentrations which are imposed by the fittings. Many of the end fittings which are used belong to a class which might be described as potted compression end fittings. These consist of a hollow, conical metal member, or basket, and related hardware such as yokes, bails and eyes. The end of the rod is potted into the basket, usually with an epoxy formulation;

frequently, a wedge is driven into the rod end prior to potting in order to give the end a roughly conical shape.

The potting compound is selected to provide good adhesion to the GRP to enable the rod to resist pulling out under load. The basket is oriented so that the cured, potted mass, or cone, is pulled more tightly into the basket as the tensile load is increased. Some users treat the inside surface of the basket with an epoxy-release agent, prior to potting. This treatment facilitates this seating process. The conical shape of the basket imposes radial compressive stresses upon the potted cone as load is applied and these compressive stresses effectively increase the strength of the bond between the potting compound and the rod.

If the potting process is not carried out properly, air bubbles or gas pockets may be created in the potted cone which reduce its strength and the efficiency of the connection. The result may be a premature tensile failure in service. Since the GRP rods are frequently used in regions of high electrical stress or electromagnetic radiation, voids in the end fittings may also contribute to failures of an electrical origin. Void discontinuities can conceivably foster increased corona activity and, if the voids accumulate moisture due to rain, ocean spray or condensation, an electrical path may be created leading to the development of arcing and carbon tracking. The result, in either case, may be the failure of the rod due to burning.

Failures due to voids inside end fittings are particularly insidious because of the difficulty in detecting their presence. The investigation described in this report was undertaken to explore the feasibility of detecting such voids by nondestructive examination (NDE) techniques. A variety of inspection techniques was tried. These were ultrasonics (including both contact and immersion pulse-echo techniques and holography), low energy x-radiography, and neutron radiography (using both thermal and fast neutron sources).

This investigation was carried out at the National Bureau of Standards under the sponsorship and with the financial assistance of the U. S. Coast Guard. The technical assistance and loan of x-ray equipment by Michael Kearney of Automation Industries are sincerely appreciated. The helpful contributions of time and technical expertise by Martin Ganoczy and Harold Berger of the NBS Reactor Division are gratefully acknowledged.

2. SPECIMENS

Several samples of two different kinds of rod-and-fitting assemblies were furnished by the sponsor, Figures 1 and 2. All had seen service as insulators in top-loading elements of Loran C towers. They had been removed from service following several incidents of burning in some of these samples as well as in other, nominally identical, units.

Figure 1 - Type 1 end fitting.

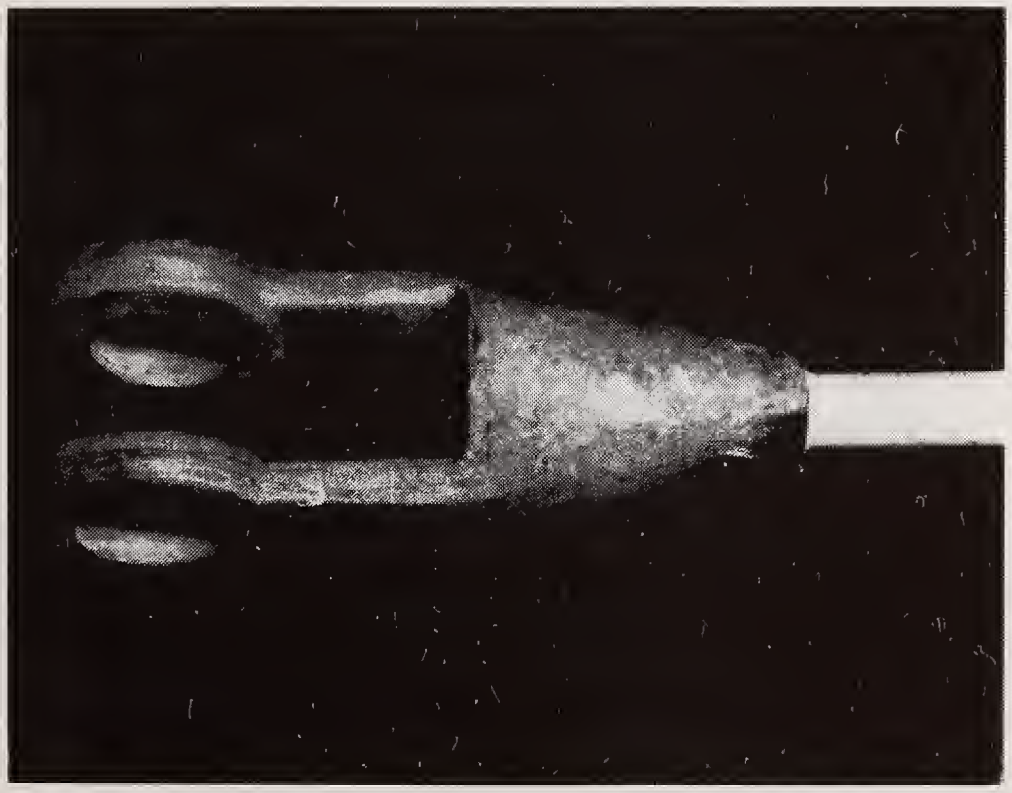

Figure 2 - Type 2 end fitting.

The Type 1 assembly, from the Loran station at Lampedusa, consisted of 17-mm (11/16-in) diameter, glass fiber-reinforced-polyester rod, terminated with potted compression end fittings. The Type 1 end fitting (Fig. 1) had a conical steel basket which is normally fitted with a metal yoke and bail (not shown in the figure) for attachment to thimble-and-eye hardware. A rubber boot covered the narrow end of the basket and the first few centimeters of rod where it emerged from the basket. Prior to potting, the end of the rod within the basket had been quartered and spread with a cruciform-shaped metal wedge similar to that shown in Figure 3. The basket was approximately 5 mm (3/16 in) thick at its thickest point.

The Type 2 assembly, from the Loran station at Angissoq, consisted of 20-mm (25/32-in) diameter, glass fiber-reinforced-epoxy rod, terminated with potted compression end fittings. The Type 2 end fitting (Fig. 2) is also of steel, and is fabricated with integral clevises as shown in the figure. Conical metal wedges were used to spread the quartered rod ends prior to potting in these fittings. The wall of the basket part of the fitting measures approximately 11 mm (7/16 in) at its thickest part and 10 mm (3/8 in) near the tip of the wedge, the suspected area of trouble. See Figure 4.

In the Type 2 end fitting the potting compound completely surrounds the rod end, separating it from the fitting. In the Type 1 end fitting part of the spread rod appeared to be in line contact with the inner surface of the fitting. The nondestructive penetration of a minimum of three interfaces, set at shallow angles to each other and to the entry surface, is required for the examination of these parts. Penetration of three materials (metal, epoxy and reinforced plastic) with vastly different attenuation characteristics and acoustic impedances is also required for the end-fitting inspection.

Due to the problems associated with the inspection of specimens with complex geometry, numerous interfaces, and material mismatches, two simpler but similar specimens (Fig. 5) were chosen for the initial feasibility study. The first was an aluminum end-fitting with a potted rod and no wedge. This end fitting was sectioned longitudinally and two short, transverse holes, 3.2 mm (1/8 in) in diameter, were drilled in the rod to serve as artificial defects. The second sample specimen consisted of a potted cone, containing a rod and wedge, removed from its metal end fitting.

3. ULTRASONIC EXAMINATION

Ultrasonic nondestructive examination techniques are commonly used to detect and locate concealed flaws in a wide variety of inspection problems. In ultrasonic NDE, high-frequency sound waves are emitted by a transducer which is mechanically coupled into the test object, and are reflected from material interfaces and other discontinuities (defects, voids, etc). In

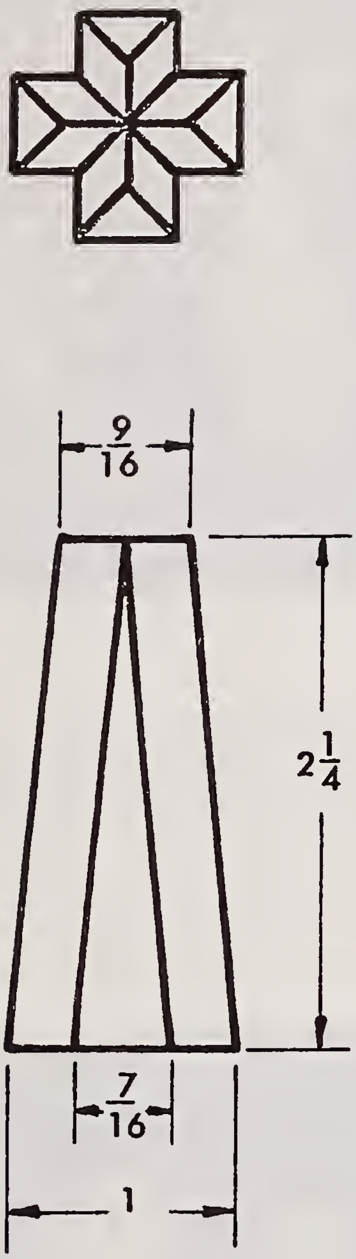

Figure 3 - Cruciform wedge similar to those used in conjunction with Type 1 end fittings. All dimensions in inches (1 in = 25.4 mm).

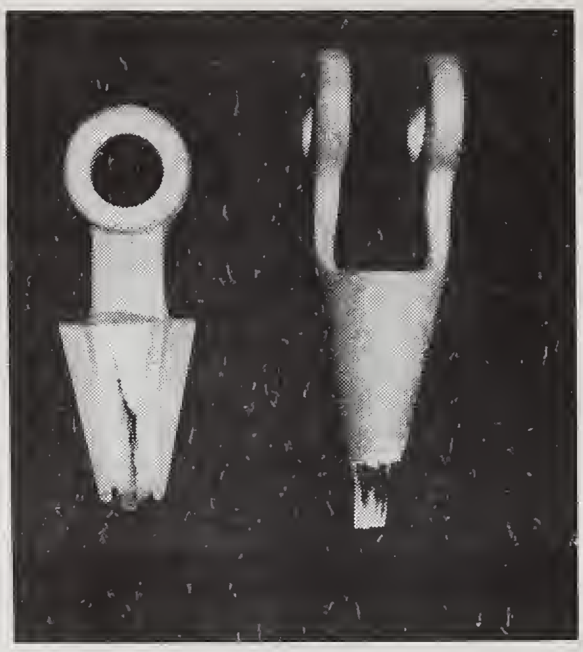

Figure 4 - Sectioned and unsectioned Type 2 end fittings from rods that had experienced electrical burning damage. Note the void in the rod at the tip of the conical wedge.

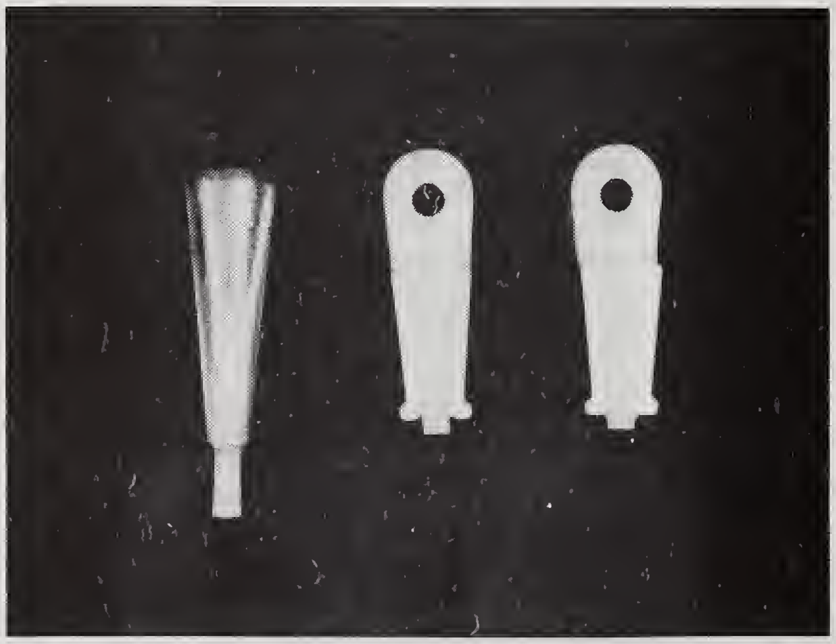

Figure 5 - Left: Potted cone containing a wedged rod, removed from a compression end fitting. Center and right: Sectioned aluminum end fitting. Note the two small holes drilled into the rod in the center view.

conventional pulse-echo ultrasonics, the reflected sound energy is received by the sending transducer; this energy is then electronically processed and displayed visually on a cathode-ray tube or by other means. The basic ultrasonic NDE techniques are relatively fast, inexpensive, and accurate.

The ultrasonic examination of end fittings for GRP rod was performed in the ultrasonic measurements laboratory of the Engineering Mechanics Section at NBS. The laboratory arrangement is shown in Figure 6. It consists of commercially available ultrasonic equipment and accessories suitable for both contact and immersion ultrasonic testing. Ultrasonic flaw detection equipment, with both tuned and untuned pulser-receiver combinations, an immersion tank with a motorized scanning bridge and precision manipulator, and accessory equipment are available for ultrasonic interrogation of test specimens. A detailed description of this measurement facility is given in Reference 3.

Problems were anticipated in the ultrasonic inspection of these specimens due to the complex geometry, the number of material interfaces, and the curved and rough nature of the sound-beam entry surfaces and interfaces. Technique development began with the ultrasonic interrogation of the simpler specimens (Fig. 5) using the broad-band pulser-receiver with 2.25 and 5.0 MHz (nominal center frequency) transducers. Using longitudinal waves in a conventional pulse-echo mode, both contact and immersion techniques were tried. Technique development related to the detection and identification of the various material interfaces and the known defects was the primary concern in the inspection of these "simpler" problems. Little success was achieved; only the return interface echo from the aluminum jacket could be identified by its location on the time axis of the oscilloscope screen. The penetration of deeper material layers was not evident.

Despite this, the two types of steel end fittings were inspected. One of the Type 2 fittings, which had been sectioned previously, contained a gross defect at the tip of the wedge (Fig. 4). This 40 by 6 mm (1 1/2 by 1/4 in) void could not be detected by the ultrasonic methods that were tried. The only echo that could be positively identified was the reflection from the inside wall of the steel jacket. Similar results were obtained with end fittings of Type 1.

Conventional ultrasonic methods do not appear to be a useful inspection tool for the solution of this problem due to specimen geometry and material impedance mismatch at the various interfaces.

An ultrasonic hologram was made of the half of the split aluminum end fitting that contained the artificial defects. The test conditions were not necessarily optimized in this experiment and the result, as shown in Figure 7, is not completely satisfactory. Part geometry, material impedance mismatch, and inadequate system resolution were factors that limited the quality of this hologram. It is believed that better results for this

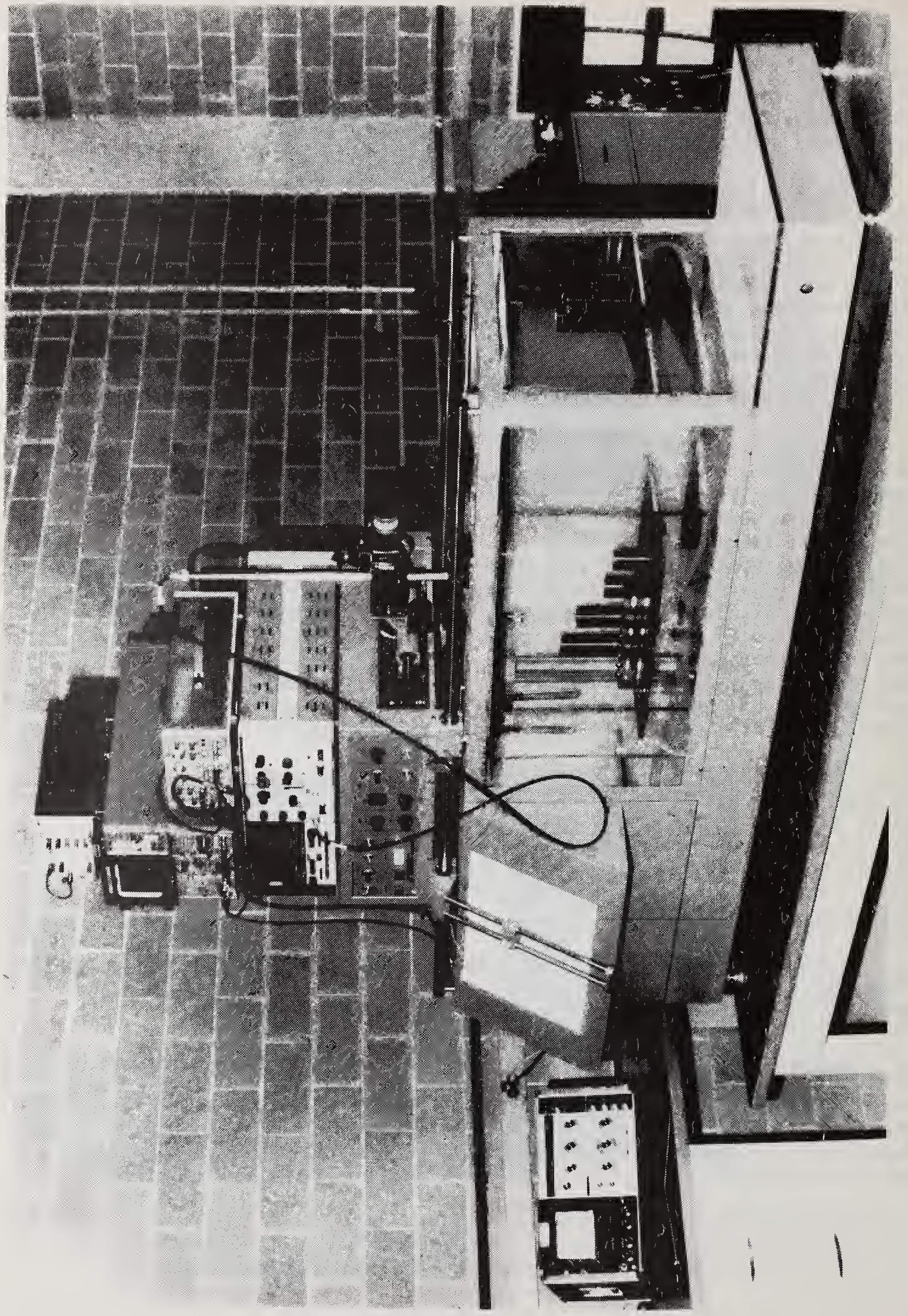

Figure 6 - Ultrasonic measurement facility.

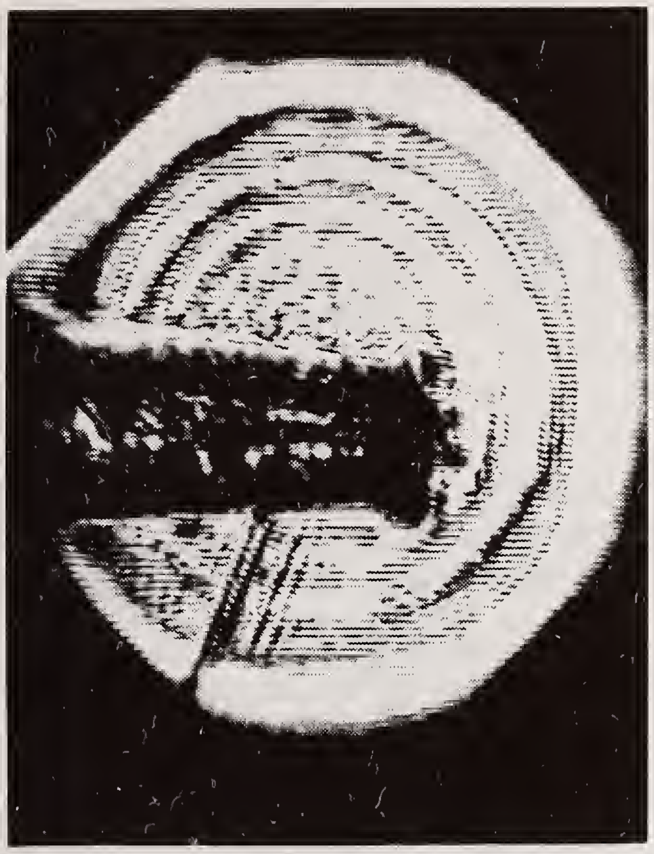

Figure 7 - Ultrasonic hologram of the sectioned aluminum end fitting. The end fitting is in the 9 o'clock position. The patterns in the light hexagonal background represent "noise".

specimen could possibly have been obtained under optimum conditions using the more advanced holographic and imaging systems that are currently available.

4. RADIOGRAPHIC EXAMINATION

With the inability of conventional ultrasonic methods to detect defects in the end-fitting samples, the feasibility of using radiographic methods of nondestructive examination was examined. Radiography, like ultrasonic methods, is relatively fast, inexpensive, and simple to perform. In radiography, radiant energy in the form of neutrons, x-rays or gamma rays is used to produce graphical film records of the relative soundness of opaque objects under test. Both x- and neutron radiography were considered to have advantages pertinent to the end-fitting problem.

4.1 X-Radiography

X-radiography is a widely used industrial technique for nondestructive examination. Background material suitable for a basic understanding of the experimental aspects of x-radiography is available in Reference 4.

A portable x-ray unit was used to produce the radiographs of the specimens. The two operating parameters of the x-ray unit were continuously variable from 35 to 160 kV and 2 to 5 ma.

Two types of industrial x-ray film (ASTM Class I and ASTM Class II) were used. Class I films are medium speed, extra fine grain, very high contrast films which are used primarily for the critical radiography of light metals and alloys. Class II films are high speed, fine grain, high contrast films which are used for the radiography of light metals at low voltages (less than 250 kV) and thin steel sections (less than 50 mm (2 in)) at voltages less than 1000 kV. Both of the film types were compatible with the specimen dimensions and the possible x-ray unit energy radiation levels. Commercially available film packets containing one of each film type were used. This packaging feature is useful in defining the exposure settings needed to produce good radiographs, relative to the x-ray current and voltage, for each particular specimen.

For this investigation, only elementary x-ray techniques were employed. The film packet was placed on a concrete floor* with the specimens placed

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*It has since been learned that the use of a concrete floor as a backstop may produce film and detail fogging due to backscatter and its use is, in general, not recommended.

directly on the packet. The x-ray beam port was located perpendicular to the floor, approximately 750 mm (30 in) from the film plane. Radiographs were made of the joined halves of the sectioned aluminum end fitting (Fig. 5), one half of the sectioned Type 2 fitting (Fig. 4), and Type 1 and Type 2 end fittings as received (Figs. 1 and 2).

As many specimens as possible were radiographed simultaneously. Reasonably good results were achieved on the assembled sections of the aluminum specimen as shown in Figure 8. Fair results on the half of the sectioned Type 2 fitting (Fig. 9) and poor results on the Type 1 end fittings (Fig. 10) were produced.* A complete Type 2 end fitting was not penetrated. These results are considered to be of limited usefulness since aluminum end fittings were outside the intended scope of this investigation and the results on the Type 1 and Type 2 end fittings were unsatisfactory.

A summary of quantitative results for the better radiographs produced, based on x-ray tube voltage, exposure time, and film class is presented in Table 1. This listing indicates the range of variables over which the radiographs were made and also provides subjective ratings of the quality of the radiographs within each end-fitting group.

It is evident from the results obtained to date that the simple experiments performed are inadequate for all but the aluminum end fitting. It is probable that more advanced x-ray techniques would lead to better results on aluminum end fittings or on thin-walled steel end fittings similar to Type 1. Obvious improvement would result from the use of specimen shielding to reduce radiation scatter and from the development of compensation techniques, related to part geometry and thickness, to provide uniform radiation penetration. The use of higher energy radiation, the optimization of x-ray film, specimen, and radiation parameters, and image enhancement techniques could also be beneficial. These variables are briefly discussed in Reference 4.

A 350-kV x-ray facility will soon be operational in the Applied Radiation Division of NBS. The higher energy radiation available at this facility plus the expertise of that division's personnel may be expected to provide the solution to some of these radiographic problems.

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*Figures 8, 9, 10 are prints or radiographs that were developed using normal photographic procedures. These figures do not present the detail that is evident in viewing the original radiographs using a diffused light source. Image enhancement methods, such as densitometry, may provide even greater detail of the original radiographic films.

Figure 8 - Print of an X-radiograph showing reasonably good detail of the artificial defect in the aluminum end-fitting assembly (right). The detail is poor for one half of the Type 2 end fitting (left) and for the Type 1 end fitting (center).

Figure 9 - Print of an X-radiograph showing fair detail of one half of a Type 2 end fitting (lower left). The detail is poor for complete Type 2 (upper left) and Type 1 (center) end fittings. The aluminum end fitting (right) is completely overexposed.

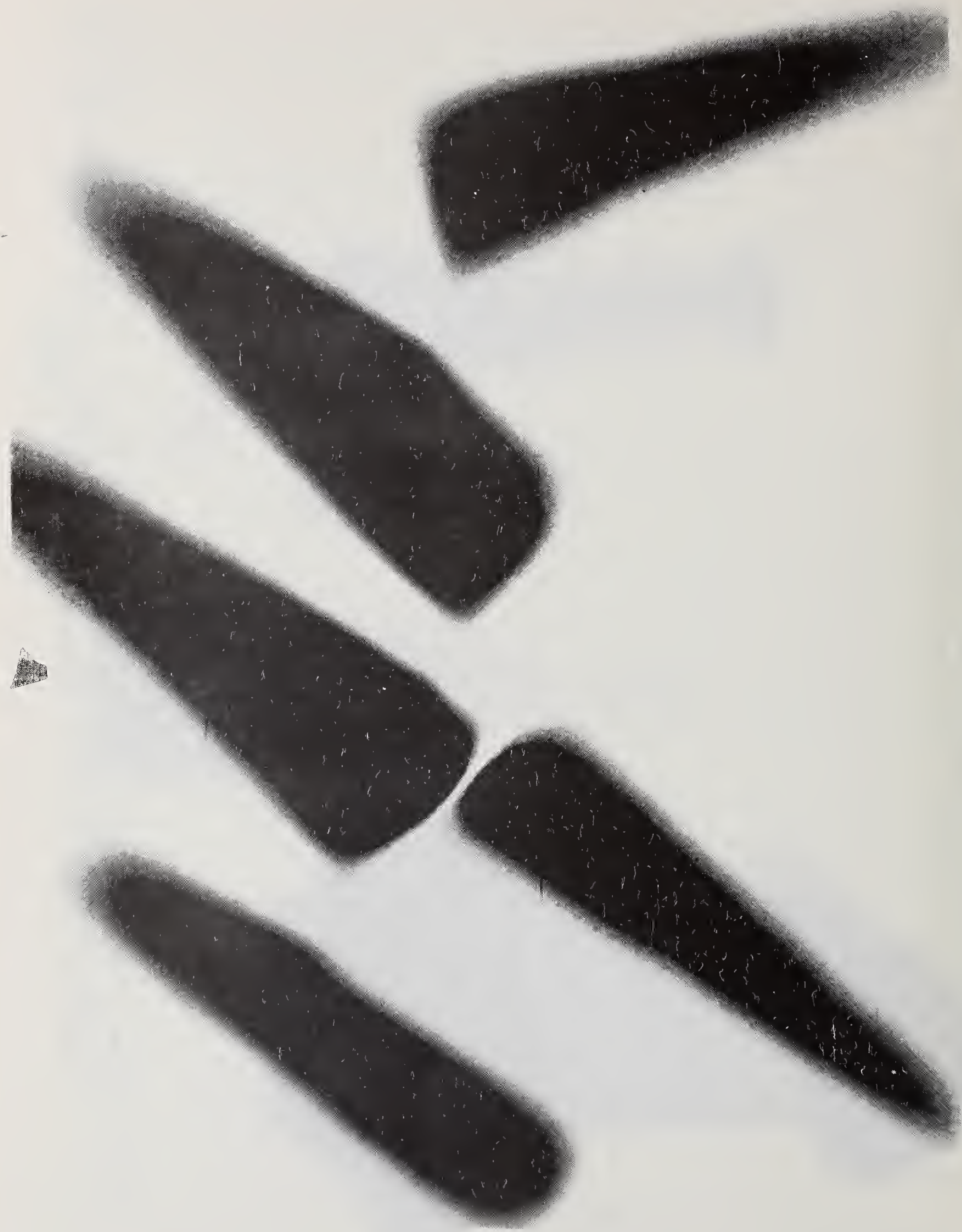

Figure 10 - Print of an X-radiograph showing faint traces of the cruciform wedges in Type 1 end fittings. The blank area (lower center) is a completely overexposed aluminum end fitting.

Table 1 - Subjective Evaluations of X-ray Radiograph Quality as a Function of X-ray Parameters(a).

ASTM film class	X-ray tube voltage kV	Exposure time s	Radiograph rating(b)	Group rating(b)
		Half of Type 2 fitting		
I	160	75	2	
II	160	20	1(Fig. 9)	
		Type 1 fitting Group A		1
I	160	60	4	
I	160	90	2	
I	160	120	1(Fig. 10)	
I	160	240	3	
		Group B		2
II	160	15	3	
II	160	30	2	
II	160	60	1	
		Aluminum fitting Group A		2
I	160	15	2	
I	160	20	1	
I	160	30	3	
		Group B		3
I	60	180	1	
I	60	300	2	
		Group C		1
II	60	120	2	
II	60	150	1(Fig. 8)	
II	60	300	3	

(a) All radiographs made with an x-ray tube current of 5 ma and a source-to-film distance of approximately 750 mm (30 in).

(b) Radiographs are numerically ranked according to quality within each group. Groups are numerically ranked within end-fitting type. Increasing numbers denote decreasing quality.

4.2 Neutron Radiography

Materials containing hydrogen (e.g., plastics) are somewhat opaque to neutrons while most metals are relatively transparent. Neutron radiographs were made of Type 1 and Type 2 end fittings with thermal neutrons (energy level of 0.25 eV) using the facilities of the 10-MW research reactor at NBS. Fast neutrons (energy level of 800 keV) were then used in an attempt to improve the radiograph quality for the thicker Type 2 end fitting. The fast neutrons were produced using the 3.0-MeV Van de Graaf generator at NBS through a proton-to-neutron collision reaction (Li(p,n)).

To produce the radiographs using the thermal neutron source, two neutron radiography film types were used: high-speed Type TLX film and high-resolution Type AA film. Two different neutron beam port apertures, 9.5 mm (3/8 in) and 25 mm (1 in), were used. A 2-m (80-in) source-to-film distance was maintained and the specimens were positioned as closely as possible to the film plane.

The use of the smaller aperture produced insufficient radiation levels for radiographs on the end fittings. Only radiographs using the 25-mm (1-in) aperture and Type AA film produced satisfactory results with a Type 1 end fitting. These results were significantly better than those obtained with x-ray techniques. For example, the tapered cruciform wedge of the Type 1 end fitting (Fig. 11) was well defined after a 10-minute exposure to thermal neutron radiation. But the conical wedge of the Type 2 end fitting (Fig. 12) was still not evident after a 15-minute exposure. At this exposure the Type 1 end fitting was slightly overexposed. Table 2 summarizes the conditions used to produce the thermal neutron radiographs.

Figure 13 shows the results of a fast neutron radiograph of one-half of the sectioned Type 2 end fitting using Blue Brand film and a TL-2 film screen. These results are better than those obtained using x-rays, but results on half of a specimen are of little practical use. Figure 14 is a fast neutron radiograph of a complete Type 2 end fitting using RP/R type film and a TL-2 film screen. Only a faint definition of the interface between the steel fitting and the potting compound is visible. The conditions used to produce these radiographs are listed in Table 3.

Based on these results a satisfactory method for the nondestructive inspection of Type 1 end fittings appears to be feasible through neutron radiography. If the imaging problems associated with radiation scattering and geometric distortion (problems similar to those encountered with x-ray methods) could be minimized, neutron radiography would probably be the best method for solving this complex inspection problem. Portable neutron sources, which would be needed for in-service inspection procedures, have already been effectively demonstrated in field tests (Ref. 5). The prognosis for Type 2 end fittings is not nearly as promising.

Figure 11 - Print of a thermal neutron radiograph of a Type 1 end fitting showing the cruciform wedge and the fractured rod end.

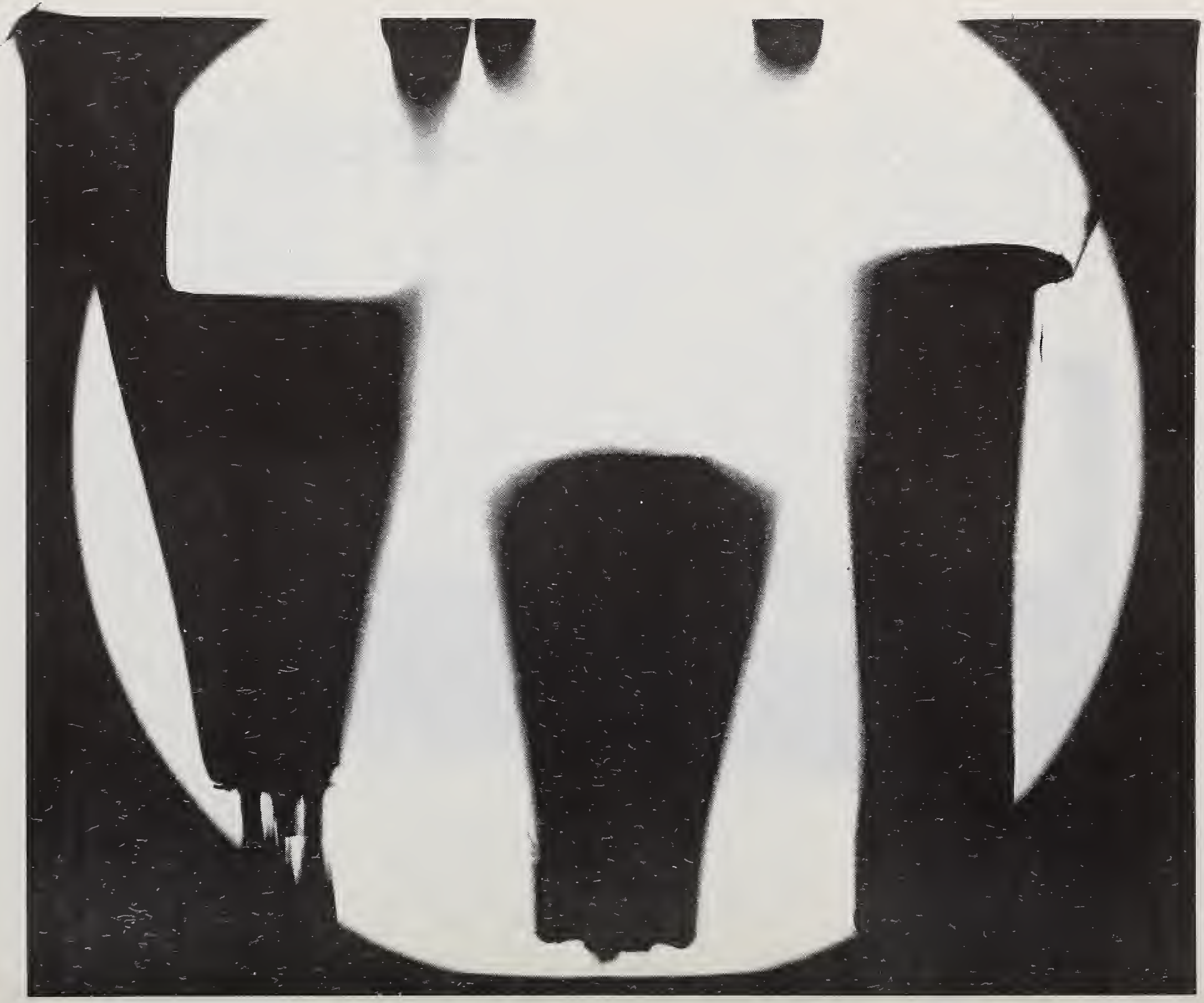

Figure 12 - Print of a thermal neutron radiograph of Type 2 end fittings (left and center) and a Type 1 end fitting (right).

Table 2 - Test Conditions Used to Produce Thermal Neutron Radiographs[a]

End fitting	Exposure time s	Film type[b]	Film screen	Figure No.
Type 1	600	AA	vapor-deposited gadolinium	11
Type 2	900	AA	0.025-mm (0.001-in) thick gadolinium conversion screen	12
Type 1	30	TLX	gadolinium oxy-sulfide fluorescent screen	-
Type 2	40	TLX	gadolinium oxy-sulfide fluorescent screen	-

[a] All radiographs listed were made with 25-mm (1-in) aperture diameter and a source-to-film distance of approximately 2 m (80 in).

[b] Commercial film types are identified in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the films are necessarily the best available for the purpose.

Figure 13 - Print of a fast neutron radiograph of one half of the Type 2 end fitting. The gross defect at the tip of the wedge is faintly visible.

Figure 14 - Print of a fast neutron radiograph of a Type 2 end fitting showing poor definition.

Table 3 - Test Conditions Used to Produce Fast Neutron Radiographs[a,b]

End Fitting	Film type	Figure No.
Half of Type 2	Blue Brand	13
Complete Type 2	RP/R	14

[a] A TL-2 film screen, a source-to-film distance of approximately 380 mm (5 in), and an exposure of 10^8 neutrons/cm^2 (16 x 10^6 neutrons/in^2) were used.

[b] A commercial film screen and film types are identified in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the products identified are necessarily the best available for the purpose.

5. CONCLUSIONS

An exploratory study was performed to investigate the feasibility of detecting voids and defects in potted compression end fittings mounted on GRP rods. Four techniques were tried: conventional pulse-echo ultrasonics, ultrasonic holography, x-radiography, and neutron radiography. Ultrasonic methods proved unsatisfactory due to geometric and material considerations. X-ray methods yielded promising results with thin-walled aluminum end fittings and it is suspected that improved x-ray techniques could provide satisfactory results with a thin-walled steel end fitting (Type 1). This end fitting was successfully penetrated by thermal neutron radiation, thereby demonstrating a potentially good nondestructive inspection technique for steel end fittings of this general size (less than 5 mm (3/16 in) thick). None of the techniques as tried was capable of detecting voids inside a thick-walled steel end fitting (Type 2).

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16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

An exploratory study was performed on the feasibility of using nondestructive examination techniques to detect voids in two types of potted compression end fittings. Four methods of nondestructive examination were tried: conventional pulse-echo ultrasonics, ultrasonic holography, x-radiography, and neutron radiography. The ultrasonic and x-ray methods that were tried proved unsatisfactory as a nondestructive examination tool for the two types of end fittings, and the neutron radiographic procedures successfully displayed the internal structure of only one of the specimen types. The procedures and results from the different methods of examination are summarized. Additional comments are given regarding the application of the methods to aluminum-jacketed specimens, and regarding improved methods for the inspection of steel-jacketed specimens.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)

End fitting; glass-reinforced-plastic rod end fitting; nondestructive examination; neutron radiography; ultrasonics; x-radiography.

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